Comparative Life Cycle Assessment of polypropylene and cardboard layer pads for transport

Report on updated calculation 2021 (based on extended LCA from 2014)

commissioned by Cartonplast Holding GmbH

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Management Summary

As the leading European provider of polypropylene (PP) layer pads used as divider sheets in the food, beverage, pharma, and cosmetic industries, the Cartonplast Group offers its customers reusable layer pads on a rental basis under strict hygiene standards. In 2014, the company conducted a comparative environmental life cycle assessment (LCA) of reusable layer pads made from polypropylene (PP) versus corrugated cardboard (CB). This report discusses the results based on updated data from 2020.

In this study, the functional unit used is 50.58 use cycles for a single PP layer pad. In contrast, CB layer pads can only be used once. Thus, the reference flows are as follows:

- PP: 50.58 uses per pad
- CB: 50.58 single-use pads

To investigate the two types of layer pads, the scope was defined to cover Western Europe (EU15) for the production, distribution, processing, and recycling/disposal of layer pads. Additionally, 2020 was used as the reference time period for the comparison. For both product systems, primary data was provided by Cartonplast.

Version 9.1.1.7 of SimaPro (PRé Sustainability, 2020) and version 3.6 of the Ecoinvent database (ecoinvent Centre, 2019) were used to model the product systems and calculate the results.

Overall, the life cycle assessment of the updated activity data using currently available state-of-the-art methodology and LCA databases reconfirms the main results from the extended LCA study from 2014, which was externally verified by TüV Nord. The updated results show that PP layer pads perform significantly better over their life cycle regarding greenhouse gas emissions, fossil fuel use, and water consumption. The main results are illustrated in Figure 1.

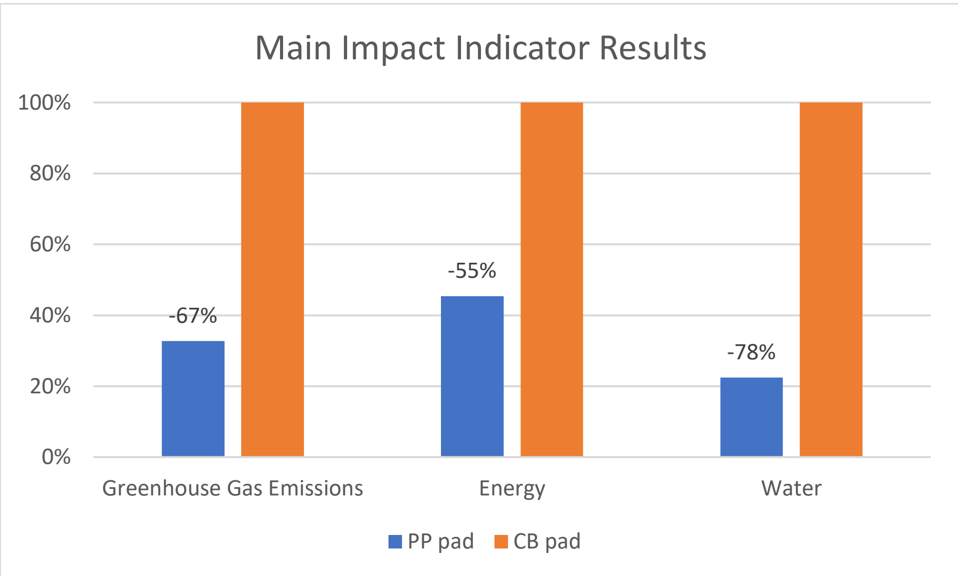

Figure 1. LCA results for the greenhouse gas emissions (global warming), energy (fossil resource scarcity), and water (water consumption) impact indicator categories.

- A PP layer pad emits 67% less kg CO_2-eq. than the CB pad variant over the span of a product life cycle. This represents a difference of more than 17 kg CO_2-eq. in emissions.
- In a product life cycle of a PP pad, 78% less water is required compared to the equivalent CB pad variant.
- A life cycle of a PP pad consumes 55% less fossil resources than the equivalent in CB pads.

It is noteworthy that all ReCiPe 2016 (Huijbregts *et al.,* 2017) environmental impact indicator categories show lower impacts for PP layer pads than for the CB pad variant (cf. Appendix F Results of Impact Indicators). PP pads outperform CB pads primarily due to the impacts inherent in the cardboard production process for every new CB layer pad that is produced.

Background

Cartonplast Group is the leading European provider of reusable plastic layer pads on a rental basis. In 2014, a comparative environmental life cycle assessment (LCA) of reusable corrugated layer pads made from polypropylene (PP) and corrugated cardboard (CB) which are used as divider sheets for the transport of glass containers was conducted. The LCA was commissioned by Cartonplast Holding GmbH (Dietzenbach, Germany) and carried out by Sustainserv GmbH (Zurich, Switzerland). Additionally, the original study complies with ISO 14040 standards and was thus certified by TÜV NORD CERT Umweltgutachter GmbH.

Compared to CB layer pads, the results in the report of 2014 show (Sustainserv GmbH, 2014), that PP layer pads are responsible for considerably lower impacts regarding carbon footprint, fossil fuel consumption, and water depletion. This mainly stems from the number of average use cycles for a single PP layer pad while CB pads are disposed of after one use cycle. Furthermore, another main lever for the environmental impact of PP pads is the content of recycled polypropylene used in the production of the pads (Sustainserv GmbH, 2014).

The original LCA study of 2014 (Sustainserv GmbH, 2014) forms the basis of the updated comparative life cycle assessment of PP and CB layer pads for transport at hand. The updated study is based on 2020 updates of activity data of the PP layer pad life cycle and uses most recent updates in LCA methodology and relevant databases.

Since the initial LCA report in 2014 has been issued the organizational structure of Cartonplast has changed and the current structure is as follows:

Cartonplast Group (CPL Group) - Cartonplast Holding GmbH and its subsidiaries
Cartonplast Holding GmbH – corporate parent company only
Cartonplast Group GmbH – German subsidiary only

Goal and Scope Definition

Goal of the Study, Target Audience, and Critical Review

As in the original report of 2014 (Sustainserv GmbH, 2014), this study aims to conduct a comparative LCA of layer pads for glass container transport in the food and beverage, pharmaceutical, and cosmetic industries. Hence, this study should investigate the environmental effects of the polypropylene (PP) layer pad under European market conditions and compare its environmental performance with that of a cardboard (CB) layer pad variant. Nevertheless, this study clearly aims to only update the calculations and interpret the emerging results. Thus, the report at hand does not formally comply with ISO 14040 standards and is not certified. However, the results of this updated calculation compare well with the results from the detailed 2014 LCA that was certified. Cartonplast will communicate the results of the study at hand internally and externally. Furthermore, Cartonplast will publish it on its website.

Scope of the Study and Functional Unit

The goal of this study is to update the results of the LCA of 2014. Thus, not all chapters of the original report from 2014 are included in this section.

In this study, two types of layer pads are investigated. The study comprises a comparison of Cartonplast's reusable corrugated PP layer pad (constituting approximately 80% of its layer pad pool) and an equivalent corrugated CB variant.

As in the original report, this study again focuses on Western Europe (EU15) for the production, distribution, processing, and recycling/disposal of layer pads. Additionally, 2020 is used as the reference time period for the comparison.

In this study, the functional unit used is 50.58 use cycles for a single PP layer pad. In contrast, CB layer pads can only be used once. Thus, the reference flows are as follows:

- PP: one pad is (re)used 50.58 times
- CB: 50.58 single-use pads

For further information on the product's specifications, please confer Chapter 3.2 and 3.3 of the original report (Sustainserv GmbH, 2014).

System Boundaries

For this study, a cradle-to-grave LCA was carried out. Thereby, the extraction and production of raw materials, conversion processes, all transports and the final disposal or recycling of the layer pads are considered. As shown in Figure 2, the life cycle of PP layer pads comprises production, transport, cleaning/washing, storage, as well as disposal and recycling.

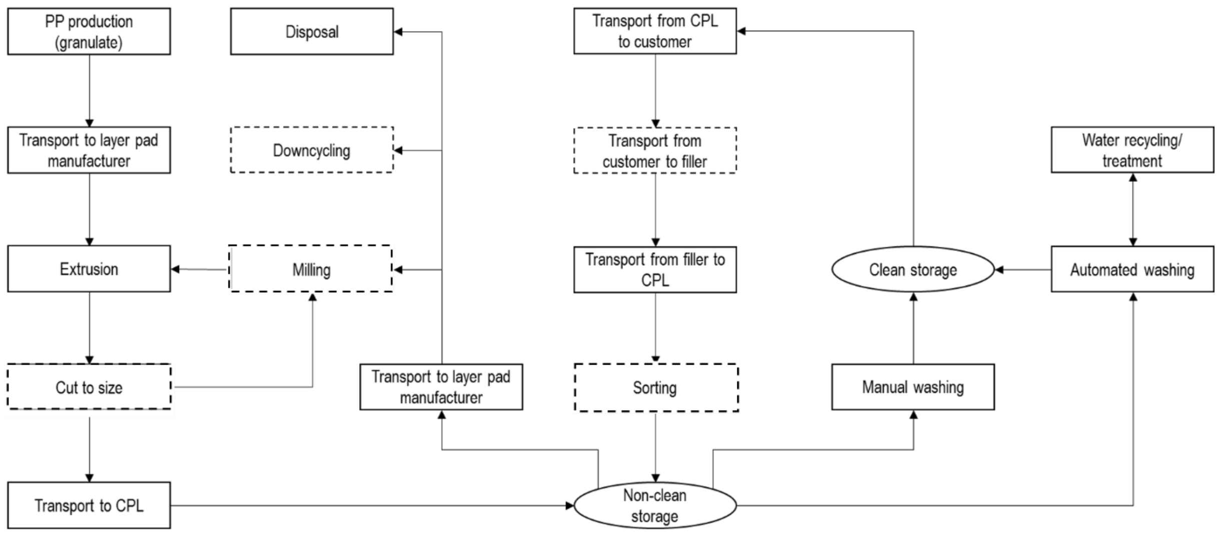

Figure 2. PP layer pad system flow chart[1].

On the other hand, the life cycle of CB layer pads comprises production, transport, and recycling and disposal (cf. Figure 3).

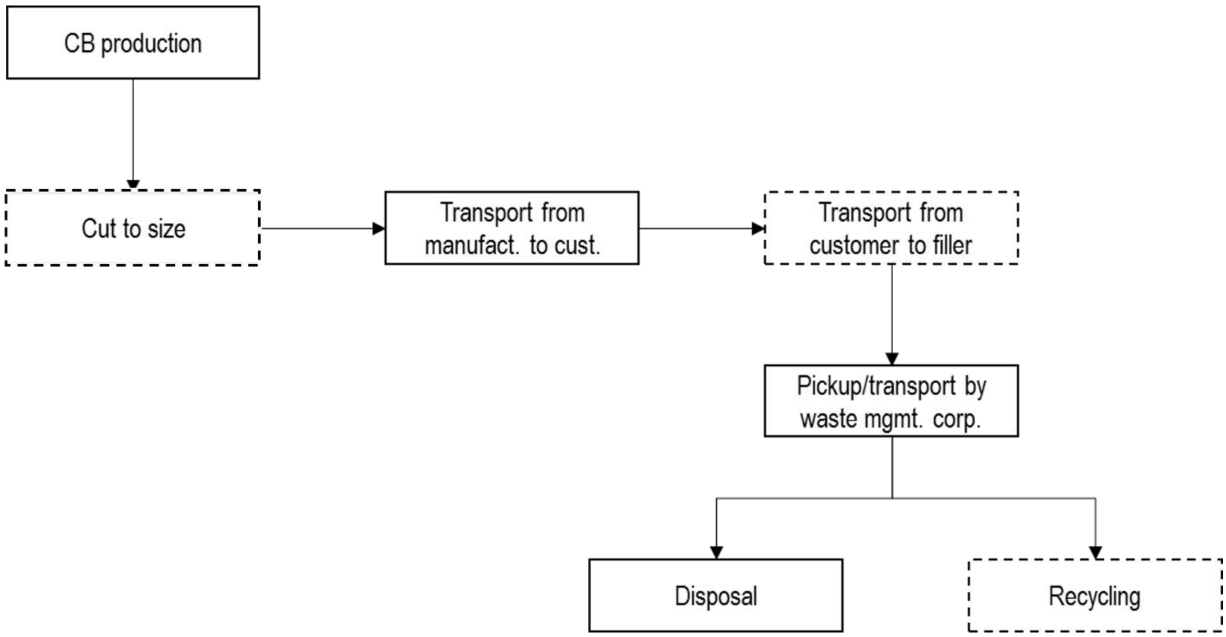

Figure 3. CB layer pad system flow chart[2].

More in-depth descriptions of the life cycles of both, the PP layer pads, as well as the CB layer pads, can be found in Chapter 4.2 and Chapter 4.3, respectively of the LCA study of 2014.

Environmental Impact Assessment

The environmental impact of the pads was determined using the updated ReCiPe 2016 (Huijbregts *et al.,* 2017) method, which considers 18 midpoint impact categories in three areas of protection: human health, ecosystem quality, and resource scarcity. The midpoint method, hierarchist version, which is

[1] Dashed lines indicate excluded unit processes.
[2] Dashed lines indicate excluded unit processes.

considered the default, was used. The following midpoint impact categories were investigated in detail:

- Climate change
- Human non-carcinogenic toxicity
- Freshwater ecotoxicity
- Land use
- Fossil resource scarcity
- Water consumption

Life Cycle Inventory

The following chapter shows data on energy, water, and chemical agent use for both, polypropylene (PP) and cardboard (CB) layer pads. Table 1 contains the life cycle inventory for both, PP and CB layer pads. All data of the life cycle inventory was provided by Cartonplast for the reference year 2020. In consultation with Cartonplast, data from CB pads are assumed to remain on 2014 levels, as it is assumed that the relevant product system has not changed.

Process step/ material	Life cycle inventory aspect	Value	Unit
Layer pads	CB/PP pad area	1.2	m^2
	PP pad grammage	1.15	kg/m^2
	PP pad use cycle (average)	50.58	no.
	PP pad pool rotation (based on the monthly average stock) Full Uses	2.81	no.
	PP pad pool size Group (DE)	15.7 M	no.
	CB pad grammage	0.415	kg/m^2
	CB pad recycling rate	80	%
	CB pad use cycles	1	no.
Transport	PP pad transport volume per truckload	14’040	no.
	Distance PP pad manufacturer to CPL	800	km
	Distance CPL to customer	173.09	km
	Distance filler to CPL	242.63	km
	Distance filler to CB pad recycler	50	km
	Distance CB pad manufacturer to customer	500	km
Storage/Washing	Electricity consumption	3’100’000	kWh/year
	Natural gas consumption	1’428’151	m^3/year
	Water consumption	8’250	m^3/year
	Sodium Hypochlorite (Divosan) consumption	3’120	kg/year
	Sodium Hydroxide (Tresolin) consumption	51’178	kg/year
	Citric acid consumption[3]	8’870	kg/year
	Liquid Petroleum Gas	93’469	kg/year
End of life	PP pad recycled content (average)	≤50	%
	PP pad disposal rate	0.01	%

Table 1. Activity data for both product systems for the reference year 2020.

For its four German sites located in Dietzenbach, Essen, Leese, and Schweitenkirchen, Cartonplast further provided the area size, energy source, total consumption, and consumption distribution for each site, shown in Table 2.

[3] Chemical agent consumption was extrapolated from procurement data.

		Distribution of Gas Consumption (%)			
	Energy Source	**Cleaning**	**Storage**	**Consumption (m^3)**	**Surface Area (m^2)**
Dietzenbach	Natural Gas	20	80	71’500	2700
Essen	Natural Gas	20	80	20’250	2150
Leese	Natural Gas	20	80	39’338	3600
Schweitenkirchen	Liquefied Petroleum Gas	50	50	46’510	4000

Table 2. Data for German sites for the reference year 2020.

The consumption values had to be aggregated through conversion values. The calculation of the total natural gas and liquefied petroleum gas consumption can be found in Appendix D Calculations of Natural Gas Consumption and Appendix E Calculations of Liquefied Petroleum Gas Consumption, respectively.

As the electricity consumption was allocated by 50% to both, cleaning and storage in the original study, it was assumed that this reflects the area of the buildings. Therefore, the building infrastructure was also allocated 50% to the cleaning and storage processes for the PP product system.

Background Datasets

For this study, the latest version of the ecoinvent database (v3.6) and the cut-off approach were used (ecoinvent Centre, 2019). The life cycle inventory modelling and the calculation of results were carried out using the LCA software SimaPro (v9.1.1.7). SimaPro is a leading standard tool to perform LCA (PRé Sustainability, 2020). The list of all concrete cut-off datasets used can be found in

Appendix C List of Processes Used.

Transport Processes

Similar to the original LCA of 2014, transport processes are adjusted for actual achievable payload utilizations. Thus, PP transport processes are adjusted to 19.4 t for PP pads and 7 t for CB pads. For further information on the calculation of the adjustment factors, please confer Chapter 4.1.1.2 of the original Report of 2014 (Sustianserv GmbH, 2014).

End-of-Life Allocation

As CB fibers are damaged through the recycling process, an open-loop recycling process is considered for CB pads. This results in 80% of the CB fibers being recycled while 20% are disposed of. On the other hand, PP material can be reused for producing PP pads. But as a pad of 100% recycled polypropylene does not satisfy the quality requirements, only up to 50% recycled PP material is used. Hence, both, closed- and open-loop recycling processes are considered. Thus, 99,99% of the material undergoes closed loop recycling, while 0.01% of the polypropylene is disposed of (Sustainserv GmbH, 2014). A detailed description of the end-of-life allocation can be found in Chapter 4.4 of the original report.

Life Cycle Impact Assessment and Discussion

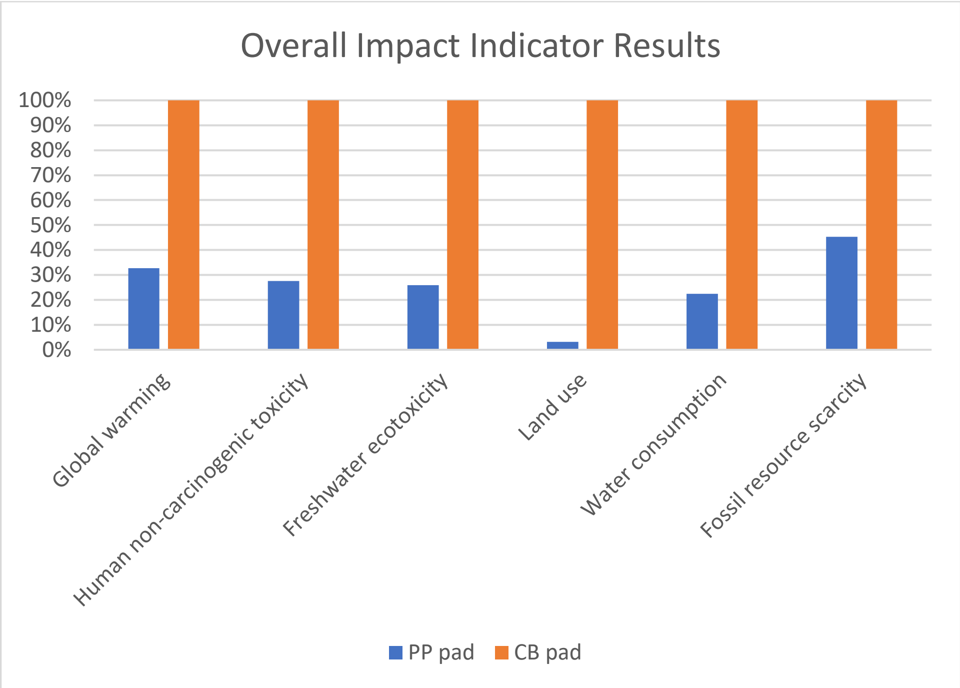

Figure 4. Overview of impact indicator results according to ReCiPe 2016 (Huijbregts et al., 2017), Midpoint (H).

Figure 4 provides an overview of the results for the selected environmental impacts according to ReCiPe 2016 (Huijbregts *et al.,* 2017). Please note that these results are to be understood in the context of a full life cycle of a single polypropylene (PP) layer pad, which is the equivalent of 50.58 single-use CB pads. For every indicator chosen, the environmental impact of PP layer pads is lower than the impact of cardboard (CB) pads.

The environmental impact for the fossil energy consumption is 55% lower for PP pads than for CB pads. The impacts in terms of water use, freshwater ecotoxicity, human toxicity, and global warming are between 67-78% lower for PP pads than for CB pads. Most significantly, land use impact of PP layer pads is just 3% of the land use impact of CB pads.

The overall results of all impact indicators can be found in Appendix F Results of Impact Indicators.

The following sections illustrate detailed results for the chosen impact categories. Again, one has to be aware that these results are to be understood in the context of a full life cycle of a single polypropylene (PP) layer pad. As a CB pad is used only once, there are no environmental impacts associated to storage and cleaning of said layer pads.

Global Warming

The reference substance for global warming is CO_2 emissions. Hence, the unit is kg CO_2-equivalents (Huijbregts *et al.,* 2017). As shown in Figure 5, the carbon footprint for the PP layer pad is 67% lower than for the CB pad variant. While about one third of the carbon footprint for a PP layer pad is generated in the production process, transport, storage, and cleaning contribute somewhat equally to the greenhouse gas emissions. For CB pads, the main contribution to the global warming potential also comes from production processes. Both layer pads have similar impacts for the transport life-cycle stage.

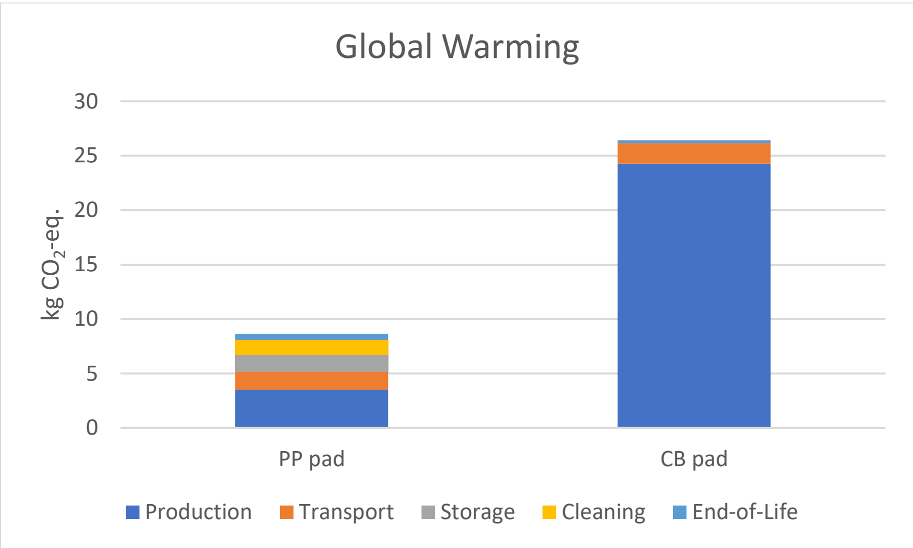

Figure 5. Global warming impact indicator category results according to ReCiPe 2016 (Huijbregts et al., 2017), Midpoint (H).

Global warming is mainly driven by the electricity and natural gas consumption during the cleaning and storage life cycle stages of PP pads. As both, the electricity mix and the gas consumption are based on non-renewables, they strongly contribute to the total of greenhouse gas emissions (Arvidsson & Svänström, 2016). Due to the high consumption during the cleaning and storage life cycle stages of the PP pad product system, the impact arises accordingly.

Water Consumption

The impact of water consumption is measured by the total amount of water used in m^3 (Huijbregts *et al.,* 2017). Figure 6 shows that water consumption is 78% lower for PP pads than for CB pads. While the impacts of the transport and storage process for PP pads are somewhat similar, the impact from cleaning is almost double. For PP pads, the end-of-life impact on water depletion is negligible. For CB pads, the main contribution to the water consumption impact stems almost entirely from production. The production process comprises 97%. While both layer pads again have similar impacts for the transport life-cycle stage, the end-of-life impact is approximately 2% of the total impact on water consumption of the CB pad which arises mainly from disposal of the cardboards.

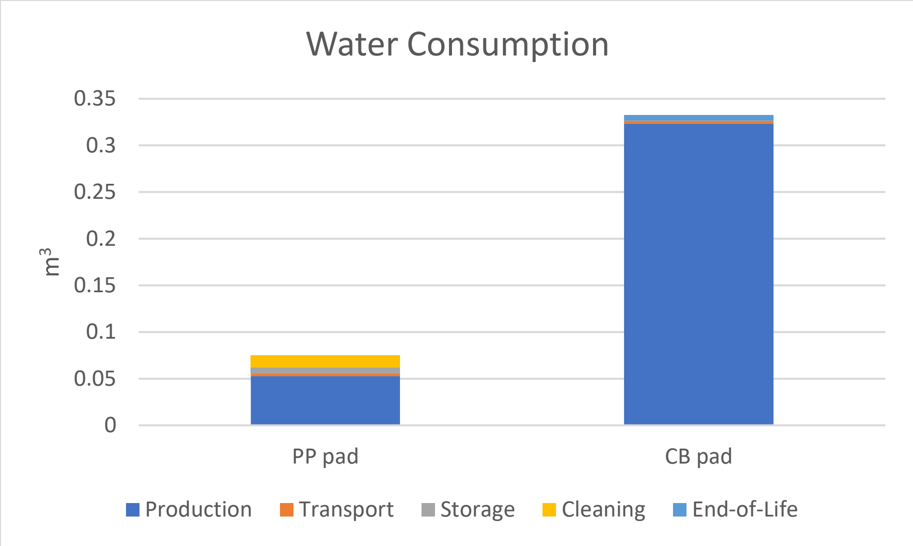

Figure 6. Water consumption impact indicator category results according to ReCiPe 2016 (Huijbregts et al., 2017), Midpoint (H).

For both, the PP and CB layer pad, electricity generation accounts for the largest water consumption impact. Again, Arvidsson & Svänström (2016) state that the impact on global warming of energy use indicators strongly depends on their composition.

Fossil Resource Scarcity

The impact on fossil resource scarcity is measured in terms of extracted fossil fuel (kg oil equivalent) (Huijbregts *et al.,* 2017). In line with common LCA practice, inherent fossil fuel content associated with polypropylene is reflected in the results (Sustainserv GmbH, 2014).

The results are summarized in Figure 7. Fossil resource consumption is 55% lower for PP pads than for CB pads. For PP pads, transport, storage, and cleaning processes show again similar impacts and comprise of about 15% of the total impact. Again, for CB pads, the main contribution to the fossile resource scarcity impact stems from production. Furthermore, both layer pads have similar impacts for the transport life-cycle stage which contributes approximately 16% to the total impact of PP boards and 9% to the total impact of CB boards, respectively.

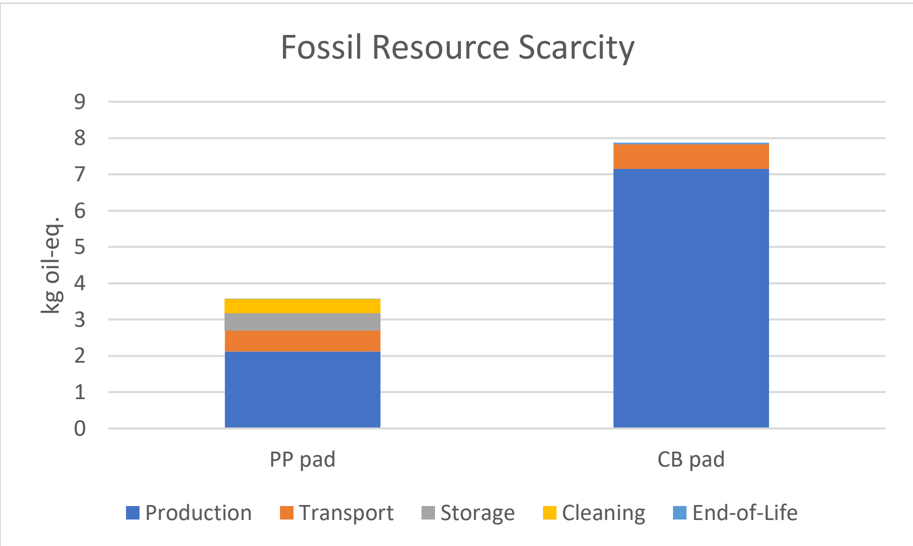

Figure 7. Fossil resource scarcity impact indicator category results according to ReCiPe 2016 (Huijbregts et al., 2017), Midpoint (H).

For both product systems the production process of polypropylene granulate (including inherent fossil energy content) and corrugated cardboard, respectively, has the single highest impact on fossil resource scarcity. This is due to associated energy supply processes.

Integration of Results

The results of the life cycle impact assessment are in line with the results of the original LCA conducted in 2014. Many elements of the analysis at hand, e.g. the investigated products, were used as stable artefacts from the original study. Furthermore, some elements, i.e. the life cycle inventory data, did change only slightly. Thus, it is evident that the results of the conducted LCA did not change substantially compared to 2014. Nevertheless, some systems underwent substantial alterations compared to 2014. First and foremost, the methodological decision was altered. According to the developers of the updated ReCiPe 2016 method "due to significant methodological differences, the results of ReCiPe 2008 and ReCiPe 2016 cannot and should not be compared" (Huijbregts *et al.,* 2017). Furthermore, as this LCA is built in an environment using an updated version of background data within ecoinvent and cut-off instead of APOS processes, the results of this study are not directly comparable with the results of the original study. Nonetheless, the life cycle impact assessment clearly shows the low environmental impact of PP pads compared to a CB pad variant. But, as shown in the sensitivity analysis of the original LCA[4] (Sustainserv GmbH, 2014), it can be expected that the difference of the degree of impact between the two product systems on the indicators is strongly influenced by the number of use cycles for PP pads. Furthermore, limitations, e.g. data accuracy, scope application, and others, have to be considered for future studies.

Conclusions

Using model assumptions, PP layer pads perform better over their life cycle regarding greenhouse gas emissions, fossil fuels use and water consumption. While all ReCiPe environmental impact indicator categories show lower impacts for PP layer pads, the main results are as follows:

- A PP layer pad emits 67% less kg CO_2-eq. than the CB pad variant over the span of a product life cycle. This represents more than 17 kg CO_2-eq. difference in emissions.
- The impact of PP pads on human non-carcinogenic toxicity and freshwater ecotoxicity is almost 75% lower than the impact of CB pads on these indicators.
- The impact on land use of PP pads is only 3% of the impact of CB pads.
- 78% of water is saved when using PP pads.
- During a life cycle of a PP pad, 55% less fossil resources are consumed.

[4] Please confer chapter 6.1 – Sensitivity Analysis for further information.

References

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Appendix A List of Figures

Appendix B List of Tables

Appendix C List of Processes Used

Process Step	Characterization of Datasets (Ecoinvent v3.6.)
CB pad EoL	Paper (waste treatment) {GLO}| recycling of paper | Cut-off, S
	Waste paperboard {DE}| market for waste paperboard | Cut-off, S
	Waste paperboard {DE}| market for waste paperboard | Cut-off, S
CB pad production	Corrugated board box {RER}| market for corrugated board box | Cut-off, S
	Heat, district or industrial, natural gas {CH}| market for heat, district or industrial, natural gas | Cut-off, S
	Heat, district or industrial, other than natural gas {Europe without Switzerland}| market for heat, district or industrial, other than natural gas | Cut-off, S
	Lubricating oil {GLO}| market for | Cut-off, S
CB pad transport	Transport, freight, lorry >32 metric ton, euro4 {RER}| market for transport, freight, lorry >32 metric ton, EURO4 | Cut-off, S
PP pad cleaning	Building, hall {GLO}| market for | Cut-off, S
	Citric acid {GLO}| market for | Cut-off, S
	Electricity, medium voltage {DE}| market for | Cut-off, S
	Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler atmospheric non-modulating <100kW | Cut-off, S
	Hydrochloric acid, without water, in 30% solution state {RER}| market for | Cut-off, S
	Liquefied petroleum gas {Europe without Switzerland}| market for liquefied petroleum gas | Cut-off, S
	Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, S
	Sodium hypochlorite, without water, in 15% solution state {RER}| market for sodium hypochlorite, without water, in 15% solution state | Cut-off, S
	Tap water {Europe without Switzerland}| tap water production, conventional treatment | Cut-off, S
	Wastewater, average {Europe without Switzerland}| market for wastewater, average | Cut-off, S
PP pad downcycling	DummyWasteTreatment
	Electricity, medium voltage {IT}| market for | Cut-off, S
	Polypropylene, granulate {GLO}| market for | Cut-off, S
	Waste polypropylene {DE}| market for waste polypropylene | Cut-off, S
PP pad EoL	PP (waste treatment) {GLO}| recycling of PP | Cut-off, S
	Waste polypropylene {DE}| market for waste polypropylene | Cut-off, S
	Waste polypropylene {DE}| market for waste polypropylene | Cut-off, S
PP pad production	Electricity, medium voltage {DE}| market for | Cut-off, S
	Extrusion, plastic film {GLO}| market for | Cut-off, S
	Polypropylene, granulate {GLO}| market for | Cut-off, S
PP pad storage	Building, hall {GLO}| market for | Cut-off, S
	Electricity, medium voltage {DE}| market for | Cut-off, S
	Heat, central or small-scale, natural gas {Europe without Switzerland}| heat production, natural gas, at boiler atmospheric non-modulating <100kW | Cut-off, S
	Liquefied petroleum gas {Europe without Switzerland}| market for liquefied petroleum gas | Cut-off, S
PP pad transport	Transport, freight, lorry >32 metric ton, euro4 {RER}| market for transport, freight, lorry >32 metric ton, EURO4 | Cut-off, S

Appendix D Calculations of Natural Gas Consumption

Reference Year	2020		
Site	Dietzenbach	Leese	Essen
Natural Gas Consumption (m3)	71’500	39’338	20’250
Heating Value (kWh/m3)	11.298	9.894	11.414
Natural Gas Consumption (kWh)	807’807	389’210	231’134
Sum			1’428’151

Appendix E Calculations of Liquefied Petroleum Gas Consumption

Reference Year	2020
Site	Schweitenkirchen
Liquefied Petroleum Gas Consumption (m3)	46’510
Heating value Propane (kWh/m3)	28.095
Liquefied Petroleum Gas Consumption (kWh)	1’306’698
Heating value Propane (kWh/kg)	13.98
Liquefied Petroleum Gas Consumption (kg)	93’469

Appendix F Results of Impact Indicators