KraftPal TECHNOLOGIES

EUR-sized Corrugated Cardboard and Wooden pallet Comparison

Life Cycle Assessment Study

KraftPal Technologies Ltd.

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Introduction

The fast growth of global trading calls for solutions underpinning the efficient transport and exchange of goods within and across continents. One such standardized and universally accepted solution is the pallet. Coming in many sizes and forms (corrugated cardboard, wood, compressed wood, plastic, and metal) they serve to quickly handle palletized goods at any stage of the logistics chain.

Globally, the market for pallets has expanded to 9,9 billion units in use, whereas further growth is expected due to increasing demand from a larger global economy requiring more pallets to accommodate greater shipping requirements, as well as increased utilization of pallets in developing markets (Freedonia Group, 2020). According to the European Pallet Association (EPAL) around 450 - 500 million EPAL pallets are in circulation mostly in Europe and around the globe (EPAL - The European Pallet Association, 2020).

With more and more manufacturers producing at remote locations and requiring long-distance deliveries of palletized goods the demand for one-way pallets is increasing as there's no effective system that would enable their re-use through pooling. For example, goods sent from China to the EU are palletized, however, pallets, once they finish their trips, cannot be effectively and efficiently transported back to their origin or collected by a pooling system for re-use. Need to produce new pallets for every delivery is a challenge especially for large net export countries. Therefore, single-use, lightweight, affordable, and easy to recycle pallets are gaining their relevance on the market.

Goal

Various studies compare different pallet types in terms of their environmental impact, but there is none to directly compare corrugated cardboard and wooden pallets' life cycles.

The methodology of this study follows the approach of relevant life cycle assessment (LCA) studies on pallets and other similar products performed by researchers and institutes. As quantitative data inputs the results and conclusions (secondary data) of previously published literature and reports assessing environmental impacts of manufacturing, operating, and disposing of wooden and corrugated cardboard pallets were used. In addition, information provided by KraftPal suppliers was used.

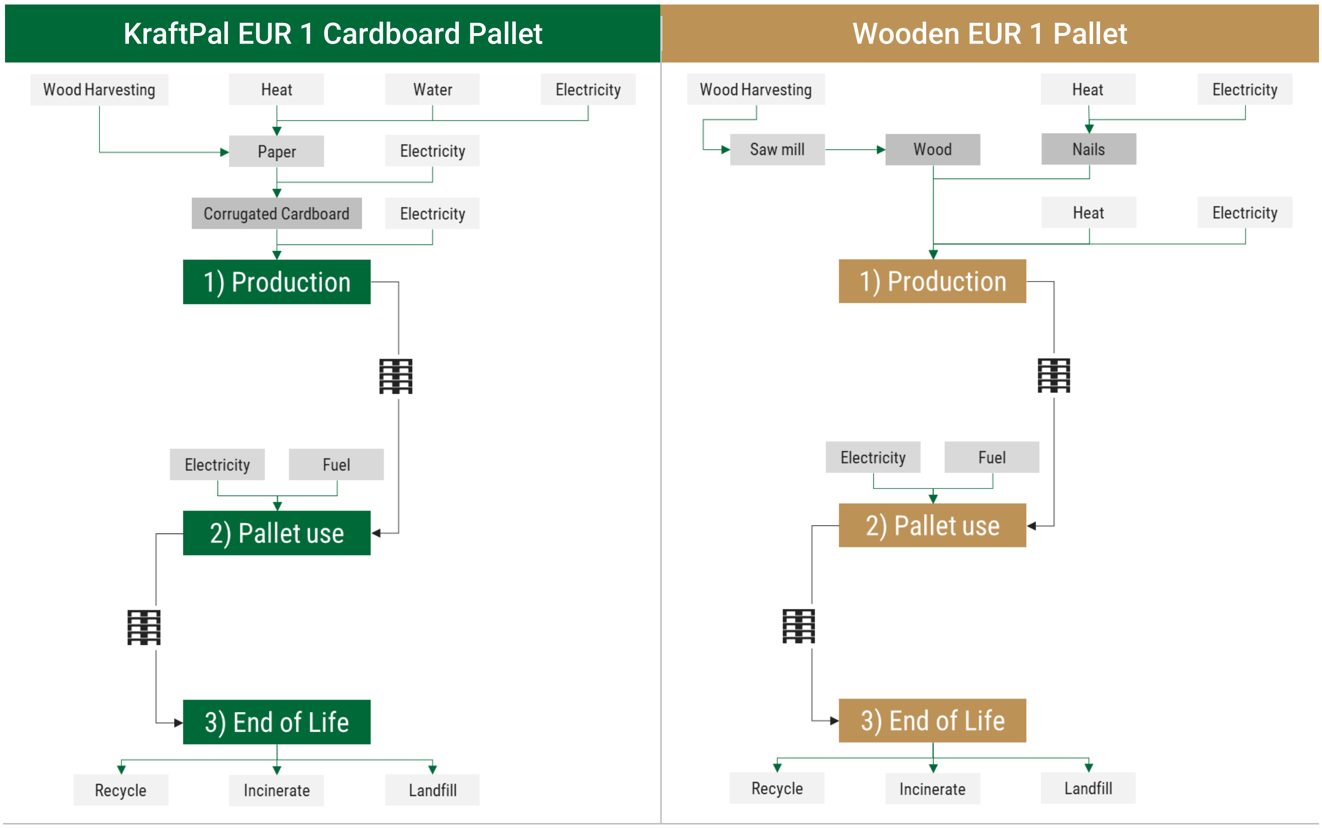
This study evaluates the carbon footprint of typical standard pallets (1.200 x 800mm) used in Europe.

The study focuses on the impacts on climate change.

KraftPal EUR 1 Pallet vs EPAL EUR 1 Pallet

	KraftPal EUR 1 Cardboard Pallet	Wooden EUR 1 Pallet
Dimensions (mm)	1.200 x 800 x 150 mm	1.200 x 800 x 144 mm
Weight	4,5 kg	25 kg
Design structure	Interlocking	Block
Safe working load (Dynamic)	600 - 1.500 kg	1.500 kg
Open Pallet Bottom Deck	Yes	Yes
Open Rack use	Yes	Yes
Forklift handling	4-way	4-way
Base Material	Corrugated cardboard	Wood (14 certified types) Iron nails
Export ready	ISPM 15 Compliant	ISPM 15 Compliant if heat treated
Use type	Single-trip	Single or Multi-trip

Pallet Life Cycle



1. Production

Wood consumption (impact on deforestation)

KraftPal EUR 1 Cardboard Pallet		Wooden EUR 1 Pallet	
Wood in kg per tree[1]	300 kg	300 kg	Wood in kg per tree
82% of extractable wood[2]	246 kg	246 kg	82% of extractable wood
100% of the extracted wood for pulping	246 kg		
55% a pulp yield for Kraftliner[3]	135,30 kg	125,46 kg	51% of the extracted wood is used[4]
Pallets per tree 5 kg of pulp per pallet	**27,06**	**5,75**	**Pallets per tree** 21,81 kg of dry wood per pallet

27,06x

5,75x

▲ 4,7x more KP pallets from a single tree

CO^2e emissions from pallet production

KraftPal EUR 1 Cardboard Pallet		Wooden EUR 1 Pallet	
CO^2e per ton of corrugated cardboard[5,6]	531 kg CO^2e	Acquisition of wood contributed 71% of the impact, provision of nails another 27%, and electricity and heat remaining 2% (Deviatkin & Horttanainen, 2020).	
Pallets per ton of corrugated cardboard	222,2		
CO^2e per pallet[7] [from corrugated cardboard]	2,39 kg CO^2e		
CO^2e per pallet[8] [from pallet production]	<0,002 kg CO^2e		
CO^2e per pallet [total]	**2,39 kg CO^2e**	**5,00 kg CO^2e**	**CO^2e per pallet[9]**

2,39

5,00

▼ 52% lower CO^2e emissions per KraftPal pallet during production

[1] Above ground biomass = 300.000 kg / ha; average nr. of trees / ha = 1.000; => 300 kg/tree
[2] 82% of the wood in a tree is extractable (An, Schryver, Guignard, Rossi, & Humber, 2013)
[3] The pulp yield is normally around 55% (FEFCO, n.a.)
[4] 51% of the extracted wood can be used (An, Schryver, Guignard, Rossi, & Humber, 2013)
[5] Sustainability fact sheet (DS Smith, 2020)
[6] For additional information on CO^2e emissions see FEFCO LCA report (link) and chart (link)
[7] KraftPal pallets from ton of corrugated cardboard = 1.000 kg / 5 kg per pallet = 212 pallets; CO^2e = 531 kg/1.000 kg / 212 pallets/1.000 kg = 2,66 kg CO^2e
[8] Energy consumption on KraftPal Austria site: 26.611,80 kWh; Pallets Produced: 33.256; Energy source mix (Hydro: 62,55%; Wind: 22,81%; Biomass: 9,08%; Solar; 2,93%; Biogas: 2,56%; Other eco: 0,07%); Energy consumption per Pallet: 0,79 kWh
[9] The production of a single EUR wooden pallets has a GWP of 5.0 kg CO2-eq (Deviatkin & Horttanainen, 2020)

DS Smith's sustainability policies and practices

Pallet production by KraftPal presents a part of value chain with negligible impact on the environment. However, a significant portion of the environmental impact during the production stage comes from the process leading up to point when pallets are delivered to KraftPal production site by the supplier of corrugated cardboard. For better overall understanding of this process and its environmental impact we outline the DS Smith's sustainability policies and practices below.

Forestry

DS Smith is committed to ensuring that all DS Smith-owned forests are sustainably managed, and all forest-derived products used in their manufacturing processes come from sustainable sources (DS Smith, 2019)

Sustainable Forest Management and Fibre Sourcing Policy 2019 (link)

Paper Mill Certification

DS Smith's paper mills are regularly audited by independent assessors, who inspect all aspects of their management systems before approving their accreditations, which include (DS Smith, 2020):

▪ Quality Management: ISO 9001	14/14 sites
▪ Environmental Management: ISO 14001	13/14 sites
▪ Safety Management: OHSAS 18001	9/14 sites
▪ Energy Management: ISO 50001	10/14 sites
▪ Chain of Custody: Forest Stewardship Council® (FSC®)	14/14 sites
▪ Chain of Custody: Programme for the Endorsement of Forest Certification (PEFC)	4/14 sites

DS Smith's Paper Mill Certifications (link)

DS Smith Group Carbon and Energy Efficiency

DS Smith group plans to cut their emissions by 30% per ton of production by rolling out energy efficiency initiatives to cut emissions by 15% and to switch away from fossil fuels to green energy meeting the remaining 15% commitment. They have already started their energy efficiency work by installing energy-efficient LED lighting at some of their facilities and are continuing this rollout to cover our other sites. In addition, they are planning on other energy efficiency investments such as replacing old boilers and compressors, installing building management systems, and improving the air balance in their factories. Regarding fuel switching, they're utilizing the gas generated from their effluent water treatment plants in their boilers and partnering with a local district heating company to install a biomass boiler at their Varnamo plant in Sweden. They are also investigating the economically viable deployment of small-scale CHP plants (Combined heat and power plants) for their packaging sites and the use of on-site renewable energy generation from solar panels (DS Smith, 2019).

DS Smith Group Carbon and Energy Efficiency Policy (link)

DS Smith Water Stewardship

Water is used as a transport medium for the key raw material (wood and paper fibers) and also as a means to transfer energy (in the form of steam) within the paper production process, therefore freshwater is vital to papermaking operations. DS Smith uses over 25 million m^3 of water across all sites every year and returns 21 million m^3 to the environment after treatment via their own or municipal effluent treatment.

DS Smith has established a monitoring system to monitor the number of non-conformances with their consents to discharge on a monthly basis. Any site which reports a value greater than zero investigates the incident and explains their action plan to prevent a recurrence.

DS Smith Group Water Stewardship Policy (link)

Black liquor treatment

For fluting production, the wood chips are cooked to pulp by the semi-chemical cooking process. It is a slightly alkaline cooking process most commonly using sodium sulfite and sodium carbonate as active cooking chemicals. The spent cooking liquor is drained off and washed out from the pulp. It contains the wood substance dissolved during the cooking together with the spent cooking chemicals. The **spent liquor is concentrated and burnt for steam production** and recovery of cooking chemicals (FEFCO, n.a.).

According to DS Smith's Sustainability Databook (DS Smith, 2019) the black liquor is used on site and consumed as a fuel for self-cogeneration or trigeneration (2018: 205.023 mWh).

Closed loop Recycling

DS Smith's closed-loop model means that they can recycle a lot of production waste internally, and seek to do this in the first instance to maximize the use of waste as a resource. Almost all their packaging facilities are equipped with underfloor conveyor belts or waste handling systems, which transport offcuts and trim to balers in readiness for transport back to their paper mills. For those waste streams that they cannot recycle internally, they actively seek partnerships to develop products that can be used as inputs to other processes thus developing the circular economy and avoiding landfill where possible (DS Smith, 2019).

DS Smith Group Zero Waste to Landfill Policy (link)

2. Product Use

Road Transport C0^{2}e emissions

66 pallets from Sankt Margarethen an der Raab (AT) to Leuven (BE)

Distance 1.110,59 km
Cargo 66x EUR1 Pallet with 350 kg Payload (FTL, 2 levels)

KraftPal EUR 1 Cardboard Pallet		Wooden EUR 1 Pallet	
Total weight pallets	297 kg	1.650 kg	Total weight pallets
Total weight payload	21.780 kg	21.780 kg	Total weight payload
Total weight	22.077 kg	23.430 kg	Total weight
Total CO^{2}e per trip[10]	1.800 kg	1.910 kg	Total CO^{2}e per trip[10]
CO^{2}e per pallet per trip	27,3 kg	28,9 kg	**CO^{2}e per pallet per trip**


27,3 28,9

▾ 5,8 % lower CO^{2}e emissions per pallet per trip with KraftPal Pallet

Air Freight C0^{2}e emissions

1 pallet from Vienna airport (AT) to JFK airport (USA)

Distance 6.898,86 km
Cargo 1x EUR1 Pallet with 350 kg Payload

KraftPal EUR 1 Cardboard Pallet		Wooden EUR 1 Pallet	
Total weight pallets	4,5 kg	25 kg	Total weight pallets
Total weight payload	330 kg	330 kg	Total weight payload
Total weight	334,5 kg	355 kg	Total weight
Total CO^{2}e per trip[11]	1.990 kg	2.120 kg	Total CO^{2}e per trip[12]
CO^{2}e per pallet per trip	**1.990 kg**	**2.120 kg**	**CO^{2}e per pallet per trip**


1.990 2.120

▾ 6,1 % lower CO^{2}e emissions per pallet per trip with KraftPal Pallet

[10,10,11,12] Emissions Calculator (DB Schenker, 2020)

Full B747-400 freighter from Vienna airport (AT) to JFK airport (USA)

Distance	6.898,86 km
Cargo	235 AF-1 Pallet with 350 kg payload or 168x EUR1 Pallet with 350 kg Payload

In airfreight, pallets are placed on Unit Load Devices (ULD) on which the outer frame rises above the usable loading area. This is why the Standard pallets (e.g. EUR 1) cannot use the whole available space on a ULD while the EUR 1 alternative from KraftPal, the AF-1 pallet, can. The loading area in a Boeing B747-400 Freighter can fit up to 5x 10 ft ULDs + 13x 20ft ULDs. A 10ft ULD (PMC/P6P) can fit 5 EUR 1 or 8 KraftPal's AF-1 and a 20ft ULD can fit 11 EUR 1 or 15 KraftPal's AF-1. This results in a significant difference in the number of pallets that can fit into one aircraft: 168 EUR 1 pallets vs. 235 AF-1 pallets.

KraftPal EUR 1 Cardboard Pallet		Wooden EUR 1 Pallet	
Pallet Quantity	245	168	
Total weight pallets	1057,5 kg	4.200 kg	Total weight pallets
Total weight payload	77.550 kg	55.440 kg	Total weight payload
Total weight	78.607,5 kg	59.640 kg	Total weight
Total CO^2e per trip[11]	468.950 kg	354.6020 kg	Total CO^2e per trip[11]
CO^2e per pallet per trip	**1.995,5 kg**	**2.117,8 kg**	**CO^2e per pallet per trip**
	1.996	2.118	

▼ 5,8 % lower CO^2e emissions per pallet per trip with KraftPal Pallet

While the CO^2e emissions per pallet are reduced by employing the lighter KraftPal pallet, such trip can also, in case of using the KraftPal AF-1 pallet instead of EUR 1 pallet, add greater savings per pallet (for more details see Kraftpal AF Case Study, 2020).

[11, 11] DB Schenker Emission Calculator (2020)

Sea Freight $C0^2$e emissions

1 container (50 pallets) from Antwerp, BEANT (BE) to New York, USNYC (USA)

Distance	6.097,62 km
Cargo	50x EUR1 Pallet with 350 kg Payload (1x 40 ft. container, 2 levels)

KraftPal EUR 1 Cardboard Pallet		Wooden EUR 1 Pallet	
Total weight pallets	225,0 kg	1.250,0 kg	Total weight pallets
Total weight payload	16.500,0 kg	16.500,0 kg	Total weight payload
Total weight	16.750,0 kg	17.750,0 kg	Total weight
Total CO^2e per trip[12]	920,0 kg	970,0 kg	Total CO^2e per trip
CO^2e per pallet per trip	**18,4 kg**	**19,5 kg**	**CO^2e per pallet per trip**
	18,4	19,5	

▾ 5,8 % lower CO^2e emissions per pallet per trip with KraftPal Pallet

[12, 12] DB Schenker Emission Calculator (2020)

3. End of Life

The end of life global warming potential (GWP) of a pallet depends on the availability and type of treatment, i.e. recycling, incineration, or landfill, while it also depends on the obstacles and economic consequences the end user faces when choosing one. In some cases, the final GWP of a pallet at the end of life depends on the subtype of a treatment, for example, landfill without gas collection, landfill with gas collection and flaring, landfill gas collection with energy recovery.

Recycling

Recycling KraftPal pallet is easy. Once the pallet has completed its trip it can be disposed into regular collecting containers placed behind the retailer's warehouse or a shop. From there it follows the established path of cardboard recycling: from collecting containers to the recycling company where the cardboard is graded, balled, and processed before being **turned into new cardboard products/or eventually into new KraftPal pallets.**

On the contrary, the recycling of a wooden pallet once it completes its trip cycles is complex and is rarely exercised. Firstly, wooden pallets are heavy and cannot be compressed at the retailer's warehouse or shop to save space. Secondly, before the wood can be cut the pallets have to be split up and all the 78 nails have to be removed which makes the pre-recycling process very time-consuming. Finally, parts of used wooden pallets can be used to repair damaged pallets or, in most cases, mulched into chips or processed into pulps for making paper. While the chips can be compressed into wooden blocks to make parts of a new pallet, the industrial **EUR 1 pallet can never be recycled into a new one in full**.

The Eurostat (2017) reports 67,5% of all corrugated cardboard packaging is recycled. However, the KraftPal pallets are recycled in 99% of cases. Firstly, they're mostly used in B2B logistics where all companies involved are forced to recycle waste by government regulations and therefore have established protocols of waste treatment already in place. Secondly, they have an economic incentive to recycle the cardboard (approx. 90€ / ton which equals 0,40 € / pallet). According to Eurostat (2017), 41% of wooden packaging is recycled. However, due to the complex nature of wooden pallet recycling, we argue that they are rarely recycled and more often than not end up in landfills.

Net GHG reductions **from using recycled inputs instead of virgin inputs** (raw material) per kg:

Corrugated Cardboard		**Wood**	
Emission Factor for corrugated containers[13]	- 0,00625 kg CO^2e / kg	- 0,00271 kg CO^2e / kg	Emission Factor for dimensional lumber[14]
CO^2e per kg	**- 0,00625 kg CO^2e**	**- 0,00271 kg CO^2e**	**CO^2e per kg**
	- 0,00625	- 0,00271	

[13] The net GWP for recycling 100% virgin inputs is -0,0089 kg CO2e per kg of corrugated cardboard (U.S. Environmental Protection Agency Office of Resource Conservation and Recovery, 2015), but with only 70% of virgin fibers used in the KP Pallets, the emissions factor is accordingly adjusted: -0,0089 kg CO^2e / kg * 70% = - 0,0063 kg CO^2e.

[14] U.S. Environmental Protection Agency Office of Resource Conservation and Recovery, 2015

Landfilling

Landfilling has been **identified as the fourth-largest source sector of emissions**, accounting for 3% of total GHG emissions among the EU-28 in 2017. The reduction of 13,6% in emissions from solid waste disposal for the EU-28 members follows the reduction in the amount of landfilling and increase in recovery of landfill gas (EUROSTAT, 2020). The EU legislation through various Directives, such as Landfill Directive 1999/31/EC, steers the national legislations to take measures to reduce the production of methane gas from landfills by reducing the landfill of biodegradable waste (European Council, 1999).

As described in the Recycling section above **the cardboard pallets are unlikely to end up in landfills while the wooden pallets commonly do**.

Net GHG emissions **from disposing raw material per kg** after a single (one trip) use includes: CH^4 emissions, Carbon storage, GHG Emissions Avoided from recovering the landfill gas and combusting it as an alternative to fossil fuels.

Corrugated Cardboard		**Wood**	
Emission Factor for corrugated containers[15]	0,00049 kg CO^2e / kg	- 0,00108 kg CO^2e / kg	Emission Factor for dimensional lumber[16]
CO^2e per kg	**0,00049 kg CO^2e**	**- 0,00108 kg CO^2e**	**CO^2e per kg**
	0,00049	- 0,00108	

The emission factor for landfilling the cardboard is an average emission factor value for all cardboard collected, including different types of cardboard with different levels of fibers. Due to the higher ratio of virgin fibers in KraftPal pallets which have greater (biogenic) carbon storage and emit less CH^4 emissions, we conclude that the **net emission factor should be adjusted and slightly lower**.

Incineration

When pallets end up in the incineration facility, they are combusted to produce heat and electricity.

The net GWP impact of **incinerating the material** at the end of life of a pallet after a single (one trip) use:

Corrugated Cardboard		**Wood**	
Emission Factor for corrugated containers[17]	- 0,00053 kg CO^2e / kg	- 0,00064 kg CO^2e / kg	Emission Factor for dimensional lumber[18]
CO^2e per kg	**- 0,00053 kg CO^2e**	**- 0,00064 kg CO^2e**	**CO^2e per kg**
	- 0,00053	- 0,00064	

The emission factor for combustion of corrugated cardboard is an average emission factor value for all cardboard collected with different levels of virgin fibers. Considering that the KraftPal pallets have a high ratio of virgin fibers and carbon content, it leads to greater amount of GHG avoided when combusted. Therefore, we consider that **the emission factor should be adjusted to reflect greater GHG reduction**.

[15,15] Both emission factors present a weighted average of net emissions for three types of landfill (without gas recovery – 18%, with gas recovery and flaring – 38%, with gas recovery and energy recovery – 44%) (U.S. Environmental Protection Agency Office of Resource Conservation and Recovery, 2015).

[17,17] U.S. Environmental Protection Agency Office of Resource Conservation and Recovery, 2015

End of Life Weighted Average

The end-of-life scenarios above should be put in a perspective where they are weighted according to the actual rates of end-of-life treatment of material.

KraftPal Pallet

- 99% recycled
- 0,5% landfilled
- 0,5% incinerated

Wooden Pallet (EPA, 2017)

- 67,48 % landfilled
- 16,68 % recycled
- 15,84% incinerated

In recent years EU made progress by increasing the recovery and recycling rate and reducing volume of packaging waste in landfills, but the wooden pallets remain just above the minimal recycling target rate of 15% as set by the Packaging Waste Directive since they're **more commonly disposed at landfills which is the least preferable option and should be limited to the necessary minimum**. KraftPal Pallets, on the other hand, are well ahead of the set recycling target of 60% and almost never end up in landfills (EUROSTAT, 2020; European Commission, 2019).

The end of life weighted average **GWP per kg of material**:

Corrugated Cardboard		Wood	
Cardboard	1,0 kg	1,0 kg	Wood
Recycling (99%)	-0,0062451	-0,000452	Recycling (16,68%)
Landfilling (0,5%)	0,0000002	-0,000728	Landfilling (67,48%)
Incineration (0,5%)	-0,0000003	-0,000101	Incineration (15,48%)
CO^{2}e per kg	**-0,00625 kg CO^{2}e**	**-0,00128 kg CO^{2}e**	**CO^{2}e per kg**
	- 0,00625	- 0,00128	

▲ 387% greater CO^{2}e reductions per kg of material in KraftPal Pallet at the End of Life

▼ *conversion into pallets* ▼

The end of life weighted average **GWP per pallet**:

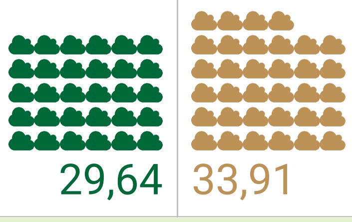
KraftPal EUR 1 Cardboard Pallet		Wooden EUR 1 Pallet	
Corrugated Cardboard	4,5 kg	21,82 kg	Wood
CO2e per kg	-0,00625 kg	-0,00128 kg	CO2e per kg
CO^{2}e per Pallet	**-0,02810 CO^{2}e**	**-0,02796 kg CO^{2}e**	**CO^{2}e per Pallet**
	-0,02810	-0,02796	

▲ 0,5% greater CO^{2}e reductions per pallet with KraftPal Pallet at the End of Life with 4,8x less material

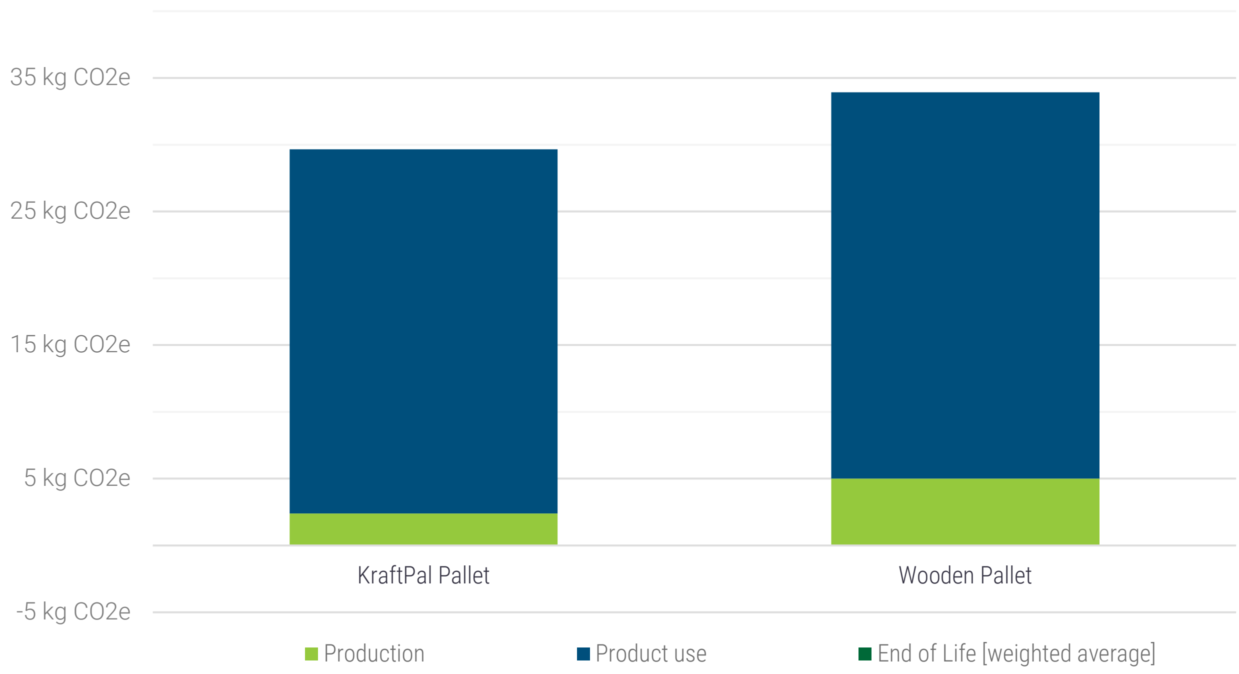
Results

Cumulative carbon footprint

KraftPal EUR 1 Cardboard Pallet		Wooden EUR 1 Pallet	
Production	2,39	5,00	Production
Product use[19]	27,27	28,94	Product use
End of Life [weighted average]	- 0,03	- 0,03	End of Life [weighted average]
CO^2e per pallet	**29,64 kg CO^2e**	**33,91 kg CO^2e**	**CO^2e per pallet**



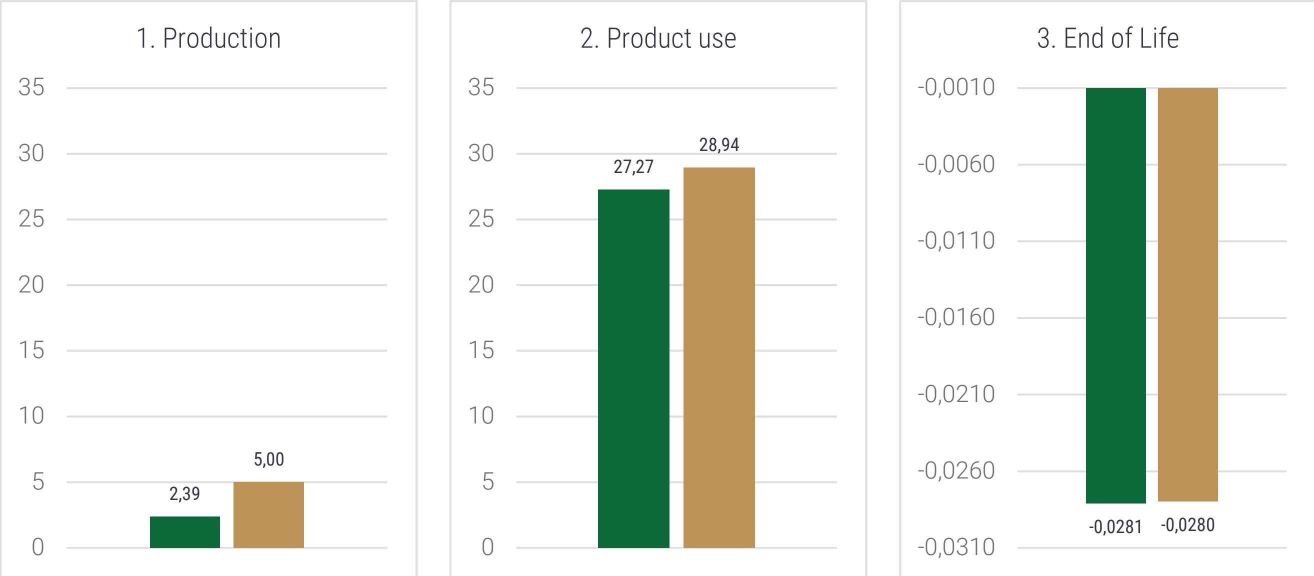
▼ 12,6% lower CO^2e emmissions per pallet with KraftPal Pallet



The cumulative results of the carbon footprint calculations are shown in the table and chart above. The carbon footprint of a product system (production – single-use – disposal) for 1 KraftPal Pallet has a carbon footprint of 29,64 kg CO^2e considering that 99% of the pallets are recycled. The carbon footprint of 1 wooden EPAL EUR 1 pallet is 33,91 kg CO^2e considering that the majority of wooden pallets are landfilled.

[19]For the calculation we used the carbon footprint of a single trip from: KraftPal Austria, Sankt Margarethen an der Raab, AT to Leuven, BE (1.110,59 km distance) with 66x EUR 1 pallets with 350 kg of payload each.

Emissions by stage in kg CO^{2}e



Comparing the two pallets by life-cycle's stages we can observe the significant difference in CO^{2}e emissions during the production stage (KraftPal pallet 2,39 vs. Wooden pallet 5,00) and greater impact of wooden pallet production (KraftPal pallet: 27 pallets per tree, Wooden pallet: 6 pallets per tree) on the deforestation.

The KraftPal pallet performed better during the Product use stage regardless of the mean of transport used. It's more than 80% lighter in weight which in comparison to the wooden pallet results in lower fuel consumption and associated CO^{2}e emissions.

At the end of life, both pallets perform almost identically. While they both reduce the CO^{2}e, their own end-of-life methods are different. The **KraftPal pallets are recycled and can, therefore, be used as an input material to make other paper and cardboard products, even new cardboard pallets, in numerous cycles**. Recycling them offsets the need for new raw material inputs (wood, paper) and therefore lowers the emissions associated with the production of new paper to make cardboard products. On the other hand, **wooden pallets are often landfilled due to being too complex to recycle**.

However, landfilling wooden pallets does not add to Global Warming Potential (GWP) because of wood's high permanent landfill carbon storage and low emittance of CH^4 (biogenic emissions) that does not contribute to human-generated GHG emissions. However, they **take up valuable space in nature and add up to the accumulation of landfills** across the world even though the process of a wooden pallet degradation in a landfill is very similar to the process that a (naturally) fallen tree undergoes in the forest.

Limitations

The study focuses on a single one-way trip, i.e. cradle to grave approach, and does not include the cyclical nature of pallets' life cycle. In practice, corrugated cardboard pallets go through multiple cycles from raw material input (paper pulp) to recycling. On the other hand, wooden pallets are often pooled and reused in multiple cycles during the product use stage (2-5 times) before reaching the end of life. The 'circular' use of wooden pallets is also associated with additional emissions related to transporting empty pallets to the pool and to the sender as well as acquisition of additional provisions to keep them in usable form (nails, lumber) which was not considered in the study.

To counterbalance the lack of primary data and use of secondary data the authors used only recognized and credible databases and sources.

Calculation of emission factors required conversion of units due to original data being available in units not common in Europe.

Conclusion

The extensive LCA study concludes that in comparison to their plastic or metal counterparts the KraftPal and wooden pallets both offer the most 'nature-friendly' standardized loading platform to be used in logistics.

During the Production stage the KraftPal pallet performs significantly better than the wooden pallet as it requires **less input of raw materials (trees) by a factor of 4,7**. The production process of KraftPal pallet **produces 52% less CO^2e than production of a wooden pallet**. The difference comes mostly from the fact that acquisition of inputs and the production itself is more eco-friendly when it comes to the KraftPal pallet.

The Product use stage contributes to more than 85% of all emissions in a whole life cycle of a pallet. Due to being more than 80% lighter than the wooden pallet the KraftPal pallet **produces less CO^2e emissions regardless of the transportation method used: 5,8% less in road freight, 5,9% - 6,1% less in air freight, and 5,2% less in sea freight**.

In the end of life stage, the clear advantage of the KraftPal pallet lays down in the multiple recyclability factor as opposed to landfilling for the wooden pallet, meanwhile, the CO2e emissions emitted during this stage **don't contribute to cumulative GHG emissions** (negative emissions) in case of both pallet types. **The two pallets preformed almost identically** by reducing the CO^2e emissions per pallet at comparable weighted average levels **even though the weight of disposed material is different (4,5 kg of cardboard vs. 21,82 kg of wood)**.

Cumulatively the **CO^2e emissions of the KraftPal pallet in life-cycle are 12,6% lower than of a wooden pallet** (29,64 kg CO^2e vs. 33,91 kg CO^2e).

The final conclusion shows that the KraftPal pallet is a better alternative to wooden pallets for any companies sending large quantities of palletized goods on mid-to-long distance trips, focusing on increasing the sustainability and minimizing the negative environmental impact of their products and business.

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