NEGATIVE CARBON FOOTPRINT OF PACKAGING PAPER PRODUCTS, IS IT POSSIBLE?

Erwin M. Schau[1], Anna Sandak[1], Jakub Sandak[1], Lone Ross Gobakken[2]

[1]InnoRenew CoE, Izola, Slovenia
[2]NIBIO, Ås, Norway

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erwin.schau@innorenew.eu

Abstract: *Humanity has only 12 years to start a deep decline in emissions of Greenhouse gases in order to prevent dangerous, non-reversible climate change. Cascading use of wood might be a way to mitigate climate change. In this contribution, we investigate how the cascading use of wood from demolished buildings as a raw material for paper production could influence climate change impact) of packaging paper. We apply a well-defined allocation process from life cycle assessment (LCA) methods (i.e., cut-off based from EN 15804:2013) and also the circular footprint formula as established by the EU Environmental Footprint pilot phase (2013 – 2018). Three different scenarios are tested: 1) paper from pulp made of demolished wood, 2) paper made from paper and 3) paper from virgin pulp. This contribution demonstrates how the carbon footprint of packaging paper can be influenced by circular economy principles and, especially, how the cascading use of wood compares to other typical raw materials for packaging paper production.*

Key words: packaging paper, wood, carbon footprint, Product Environmental Footprint (PEF), life cycle assessment (LCA), cascading use, circular economy

1 INTRODUCTION

Climate change is on the international agenda. According to the Intergovernmental Panel on Climate Change (IPCC), humanity has less than 12 years to start a deep decline in emissions of carbon dioxide and other greenhouse gases to the atmosphere to prevent dangerous non-reversible climate change (IPCC, 2018). Humanity has a long tradition for using wood as a building material. Trees capture carbon dioxide in the atmosphere and store the carbon in the wood as they grow. When forest harvesting is performed in a sustainable way, and the production/manufacturing phase has a low carbon footprint, using wood products (instead of fossil-based) on a greater scale can be a way to mitigate climate change.

Cascade use is the sequential use of certain resources, originally biomass-based (Haberl et al., 2000; Kalverkamp et al., 2017), for different purposes that "enables using the same material unit in multiple high-grade material applications occurring consecutively from the most complex to the simplest. The ultimate stage of the cascade use is usually energy conversion" (Sandak et al, 2019. p. 60). Similar to recycling, cascade use is, therefore, at the core of the circular economy (European Commission, 2018). Construction and Demolition (C&D) wood waste is already recycled in many European countries according to circular economy principles. Wood waste can be recycled using several strategies: reused in its original form, direct recycle (into new timber products, such as particleboards, finger jointing and lamination, MDF, wood plastic composites) and indirect recycle (into non-timber products, such as animal bedding, landscape mulch, surface products, composting, cement boards) before energy recovery.

Höglmeier et al (2013) demonstrated great potential for cascading of wood recovered from building deconstruction. In German Bavaria's building stock, 25% of the wood components could be re-used and 44% recycled. Of these, 21% could even be cascaded into high-value secondary applications (Höglmeier et al., 2013). The particleboard manufacturing industry is a large consumer of recovered wood. According to the European Panel Federation, 34% of the wood used to make particleboard was recovered wood (EPF, 2018); this represents about 6.7 million dry tonnes of wood. Manufacturers in Italy produce particleboards that are made of 90% recovered wood (EPF, 2016). Clean solid wood can be used for several applications, including mulch, animal bedding, particleboards, pulp and paper (Vis et al, 2016). In many real-world cases, recovered wood is currently considered as not usable for cascade use and is simply burned or landfilled (Sandak et al, 2019). Ahmed et al (1998) performed an experiment producing pulp, the precursor of paper and its derived products, from four different fibre sources: 1) a truckload of industrial wood (a mix of wood from demolished buildings and other manufacturing and construction waste in addition to used wood pallets) and 2) conventional 19-mm wood chips from 2a) loblolly pine (Pinus taeda L.), 2b) aspen (Populus tremuloides Michx.) and 2c) small-diameter Douglas fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco). The industrial wood had a moisture content of 10-12%, which is a competitive and environmental advantage compered to fresh wood and chips. The authors concluded that the "unique blend of hardwood and softwood in the industrial wood waste gave a unique kraft pulp, which was similar to or better than the loblolly pine kraft pulp" (Ahmed et al, 1998. p. 996). Glue and additives in wood construction products can be a problem when pulping demolished building wood. However, Balbercak et al. (2018) reported on a lab experiment where production of fluting liners from pulp obtained from waste wood particle boards (PB) and oriented strand boards (OSB) was studied. They found an optimal solution for PB and OSB pulping and concluded that the strength of the fluting liners from the waste PB matched that of traditionally produced Semi Chemical Fluting 2 and Brown Testliner 2. Paper and cardboard producers are one of the main users of wood in Europe. In this contribution, we focus our study on the investigation of cascading use of wood from demolished buildings. This wood material is often incinerated, which means that the material is transformed into mainly water and CO_2 emissions. While this energy can be used, the material as such is lost for human use. However, if the wood is used as a material, it remains in the technosphere and can, for example, be used as a raw material for paper and cardboard production (Hendriks and Pietersen, 2000). We assess the carbon footprint of a packaging paper product and compare it to a paper and cardboard product made of 100% recycled paper and one made of 100% virgin paper from green/fresh wood directly from the forest. These are extreme cases as packaging paper is often a mix of recycled paper fibres and new fibres from virgin pulp directly from wood; however, they should serve well as illustrative alternatives to our case study on paper made from cascaded wood from demolished buildings.

2 METHOD AND DATA

For the LCA analysis, we use open accessible data like those given in Environmental Product Declarations according to ISO 14025 and EN 15804. These data sets indicate the life cycle impact assessment indicators for the different life cycle of building materials as modules A to D, where A1 is raw materials production, A2 is transport (of the raw materials), A3 is manufacturing, B1-B7 is the different modules of the use phase and C1-C4 is the end of life (EoL) phase. A1-A3 is often combined into one result per indicator. We assume sustainable forestry with balanced growth and harvesting and zero growth or reduction in carbon content in soil over time. The latter is important, but outside the scope of this paper. Figure 1 shows the path of the three different scenarios between forestry and incineration at the end of life of the packaging paper. The black circles indicate processes included in the system boundary of the packaging product, while the grey colour indicates that these processes belongs to other products in the cradle to grave.

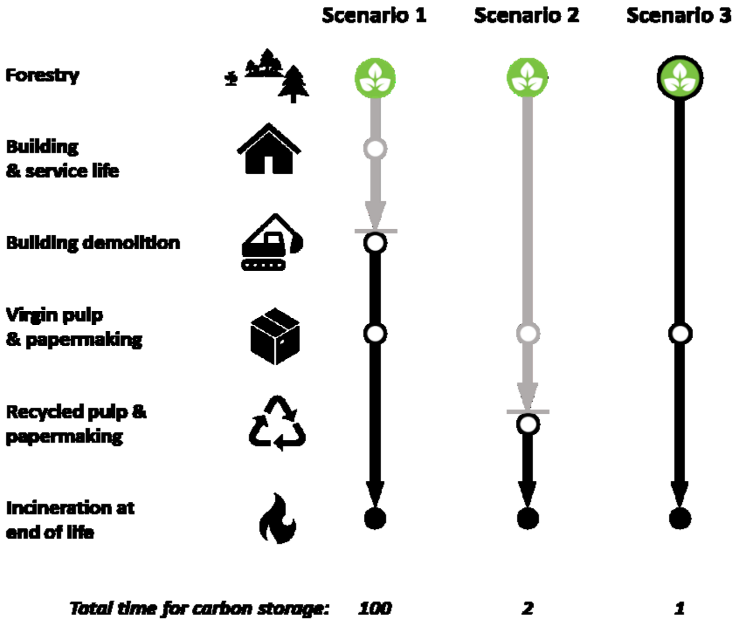

Figure 1: The packaging paper life cycle from cradle to grave and different scenarios studies.

Table 1 shows the starting scenarios for our analysis. The data are meant to be realistic for a European situation, do not represent a real production or a specific paper producer, but are still assumed to be within the natural variability. The variability, which is large, is caused using natural raw materials and many different paper qualities (so-called paper grades).

The use and distribution of the packaging paper is omitted from this analysis as it would be the same for all scenarios.

Table 2 shows the different scenarios and type and quantity of the emissions of CO_2equivalent (CO_2e). Biogenic emissions or uptake is from biological-based materials other than fossil fuels. In Table 2, the sum of CO_2e emissions are slightly higher than uptake of CO_2 in forestry. This is partly due to the small amount of not fully reacted carbon (like CO and CH_4) emissions and partly due to biogenic carbon in the additives (e.g. starch).

Table 1: Input of materials and energy sources for the three investigated scenarios.

		Scenario 1	Scenario 2	Scenario 3	
'Raw' material	**Unit**	**Wood waste**	**Paper**	**Virgin wood**	**Comment**
Wood from forest	kg			3600	1800 kg dry weight, 50 % water, 50 % pulp yield*
Demolition wood	kg	2000			1800 kg dry weight, 10 % water, 50 % pulp yield*
Recovered paper	kg		1095		10 % water, 90 % pulp yield*
Transport of raw materials	tkm	400	219	720	diesel truck, assumed 200 km
Pulping:					
Water (gross)	m^3	82	6	80	All water in integrated mills assumed to be for pulping
Natural gas	GJ	0.5		0.5	
Bioenergy	GJ	10		10	Assumed to come 100 % from the wood source*
Electricity (net bought)	GJ	0.5	0.5	0.5	
Additives and chemicals	kg	50		50	NaOH, etc.
Wastes	Kg	50	50	50	
Papermaking:					
Natural gas	GJ	2	7.5	2	
Bioenergy	GJ	4		4	Assumed to come 100 % from the wood source (same as pulp)*
Electricity (net bought)	GJ	1	-0.5	1	Natural gas co-combustion plants often produce excess electricity
Additives and chemicals	kg	150	100	150	e.g., CaO, starch; For recovered paper, it is assumed that 50 % of additives, etc. are recycled
Packaging paper	**kg**	**1000**	**1000**	**1000**	5 % water
End Of Life:					
Waste handling and incineration of paper	kg	1000	1000	1000	

** Recovered (packaging) paper mainly consist of paper fibres, while the other components of wood, lignin and hemicellulose (and some fibres) have been removed in the kraft pulping process. Therefore, a large amount of bio-based materials can be used as an energy source in the scenarios 1 and 3.*

Table 2: Carbon biogenic and fossil uptakes and emissions in the three investigated scenarios [kg CO_2equivalent per tonn of paper].

	Scenario 1		Scenario 2		Scenario 3			
'Raw' material	**Wood waste**		**Paper**		**irgin wood**			
	biogenic	fossil	biogenic	fossil	biogenic	fossil	**Comment**	**Source**
Forestry	3277)	64)			3277	64	Wood for buildings and pulp assumed to have same emissions	Based on (Billerud Korsnaes, 2018) and (Tellnes, LGF 2015)
Building demolition		1					Based on average of two EPDs	(Wurm & Boogman, 2017) and (Tellnes, 2015)
Recovered paper			1703)				Biogenic CO2e emissions (i.e., uptake)	(Ringman, 2018)
Transport		39		21		69	Conversion factor: 0.0964	(UK Government, 2019)
Water (gross)		27		2		27	Conversion factor: 0.334	(U Government, 2019)
Natural gas		34				34	Conversion factor: 67.59	(EC, DG ENERGY, 2015)
Bioenergy	206				206		Only direct emissions, upstream accounted for in wood supply	
Electricity (net)		64		64		64	Conversion factor: 127.65 for Electricity EU mi medium v tage	(EC, DG ENERGY, 2015)
Additives and chemicals		38				38	Conversion factor: 75	Based on (BillerudKorsnäs, 2018)
Waste	61	9	61	9	61	9	e.g., sludge for incineration	Based on (Hoenthal et al, 2019)
SUM Pulping	**267**	**172**	**61**	**75**	**267**	**172**		
Natural gas		135		507		135	Conversion factor: 67.59	(EC, DG ENERGY, 2015)
Bioenergy	482				482		Only direct emissions as upstream accounted for in wood supply	
Electricity (net)		128		64		128	Conversion factor: 127.65	(EC, D ENERGY, 2015)
Additives and chemicals		113		75		113		Based on (BillerudKorsnäs, 2018)
Sum papermaking	**482**	**376**		**518**	**482**	**376**		
End of life	1642	244	1642	244	1642	244	Assumed including transport from user to incineration plant	Based on Hoenthal et a 2019
SUM life cycle	**3391**	**831**	**1703**	**858**	**114**	**925**		

3 ALLOCATION

As can be seen from Figure 1, packaging paper can be produced from different production routes (demolished wood from buildings scenario, recycled paper scenario and virgin wood scenario). The life cycle from tree seedling production to forest harvesting to final incineration of the packaging paper might involve several useful products. For the recycled paper scenario, this involves, in our study (at least), two packaging products (virgin packaging products and one recycled packaging paper product). For the packaging paper made from demolished wood, the previous life of the wood was as products in the building (e.g., panels, windows, wall and structural elements). However, in the cradle to grave life cycle, these products have the cradle and grave in common. With the use of allocation, we aim here to distribute the environmental burden and benefits of the cradle and grave to different products. The term allocation is defined in ISO 14040 as “partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems” (ISO 14040:2006, clause 3.17). In our case, the product system studied is the packaging paper production, including incineration of paper at the end of life (see Figure 1). For example, the other product system in scenario 2 (paper made from recovered paper for recycling) is that the paper before was regarded as waste and recycled. It had another “life” as paper before it was recycled. Important when dealing with allocation is the principle of no double counting of credits (like uptake of CO_2) or debits (like emissions).

3. 1 Allocation based on the EU Circular Footprint Formula (EU CFF)

Between 2013 and 2018, the European Commission arranged broad in scope development of Product Environmental Footprint (PEF) Category Rules and Organisation EF Sector Rules (European Commission – Environment, 2018). During this period, three workshops and extended discussions in the different pilots for the EF 50-50 End of life formula (European Commission, 2013) ended in a proposal for a circular footprint formula (Zampori and Pant, 2019).

The intermediate paper pilot took part in the development of the EU CFF and defined in detail how to set the boundaries between the recovered paper for recycling (belonging to the previous paper life) and the production of the subsequent recycled paper. The reduced formula to use for modelling the recycling content in the EU CFF for packaging paper (for intermediate products not including the end of life) is given as (adopted from Ringman, 2018):

$$(1 - R_1) \times E_V + R_1 \times \left(0.2\, E_{recycled} + 0.8\, E_V\right) \quad (1)$$

In which:

E_v = specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin paper (e.g., relevant upstream silvicultural, transport or wood processing activities, pulping without intermediate paper production (see figure in Ringman, 2018; Schau, 2019).

$E_{recycled}$ = specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (or reused) paper, e.g., collection, sorting, transportation, deinking, pulping without intermediate paper production (see figure in Ringman, 2018; Schau, 2019).

R_1 [dimensionless] = "recycled (or reused) content of the intermediate paper product" is the proportion of material (dry weight) in the intermediate product that has been recycled from a previous system (0=<R1<=1) (see Table 3).

Table 3 indicates the parameters E_v, $E_{recycled}$ and R_1 as used in this study.

Table 3: Parameters for the EU circular footprint formula.

	Scenario 1		***Scenario 2***		***Scenario 3***	
Parameter	***Biogenic***	***Fossil***	***Biogenic***	***Fossil***	***Biogenic***	***Fossil***
E_v	*-3277*	*64*	*-3277*	*64*	*-3277*	*64*
$E_{recycled}$	*1267*	*211*	*61*	*96*	*n.a.*	*n.a.*
R_1	*100%*		*100%*		*0*	

3. 2 No allocation, but cut-off according to EN15804

In EN 15804 (2013), for building products, allocation between different products is connected to the end of waste stage definition. Until the recovered material, product or construction element (here wood materials in the building) is commonly used for "a material serving as input to the production process of another product or of energy" (6.3.4.5. Note 1), it belongs to module C. C1 is deconstruction, including dismantling and demolition and initial sorting. C2 includes transport. Collection and transport of waste is included in the building product system. "However, after having reached the 'end-of-waste' state further processing may also be necessary in order to replace primary material or fuel input in another product system. Such processes are considered to be beyond the system boundary." (Note 3, EN 15804). The pulping process is, therefore, considered as part of the paper product system and not to the building product. The limitation between the building system and the paper system according to EN15804 is, therefore, after the transport of the recovered wood at the gate to the pulping facility.

4 RESULTS

Figure 2 shows the results with the EU Circular Footprint Formula allocation. Waste handling at end of life has a high contribution to biogenic CO_2 emissions, but also some for fossil climate impact, and is the same for all scenarios. This means that the materials (wood and fibres) should be kept in the loop as long as possible to reduce the carbon footprint. Papermaking contributes about equally to the Global Warming Potential (GWP) in the biogenic as well as fossil indicator for both scenario 1 (waste wood as raw materials) and scenario 3 (virgin wood as raw materials). However, for scenario 2 (recycling of recovered paper), only the fossil impact category for papermaking shows a positive impact (negative for the environment). This can be explained by the much larger amount of bio-based materials used as an energy source in the wood scenarios (1 and 3), while in scenario 2, most recovered paper is used for new paper production and not for energy production in the papermaking process, where natural gas is the main source.

Recycled content contributes to a large negative (positive for the environment) biogenic GWP impact both in scenario 1 and even larger in scenario 2. This is because pulp from recovered materials replaces virgin pulp. However, in scenario 1, pulping of used wood requires much more energy (here from the demolished building materials) with associated biogenic CO_2e emissions. In scenario 2, re-pulping of recovered paper for recycling is much less energy and material intense. The virgin material content (pulp) in scenario 3 has a large negative (positive for the environment) contribution to the biogenic GWP potential but also some positive (negative for the environment) impact on the fossil GWP potential. The papermaking process contributes about the same for all scenarios, but for scenarios 1 and 3, the emissions are roughly equally divided between the biogenic and fossil GWP potential, while for scenario 2, the emissions are only of fossil characters. Scenario 1 has, in total, the largest CO_2e emissions. Scenario 3 is slightly better than scenario 2 when applying the EU CF formula.

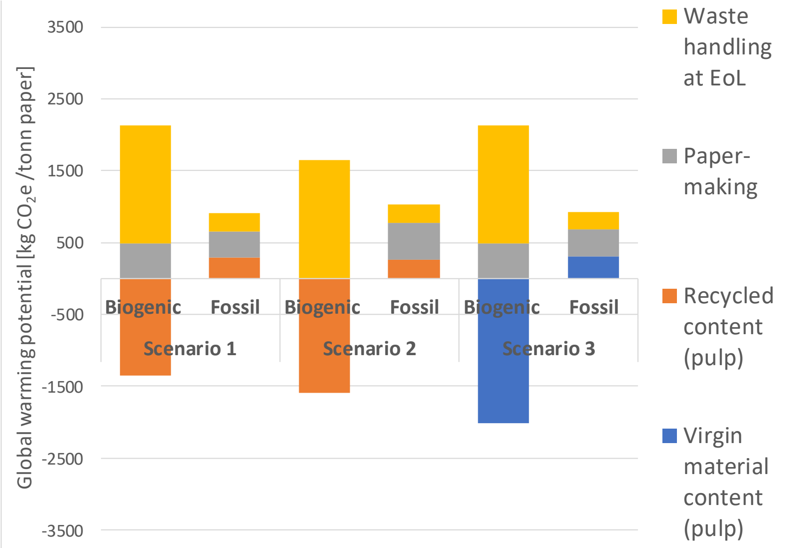

Figure 2: Results of the EU Circular Footprint Formula allocation on scenarios 1 – 3

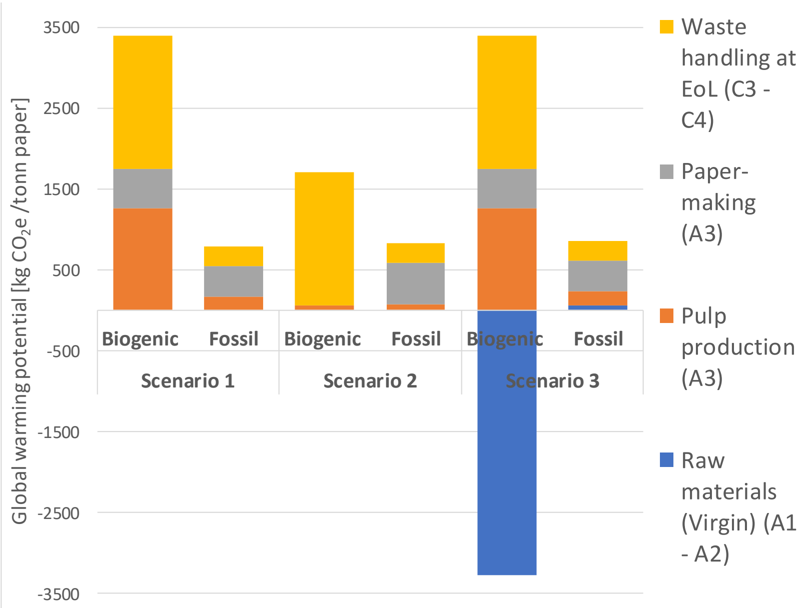

Figure 3: Results of the EN 15804 Cut-off allocation

Figure 3 shows that, also here, waste handling at end of life is a major contributor to biogenic and (to lesser degree) fossil GWP for all scenarios. Scenario 1 and 2 do not have any negative results (below 0 – positive for the environment) from using recycled material (replacing virgin material). However, for scenario 3, the biogenic emissions in the waste handling, papermaking and pulp production are almost balanced with the uptake of CO_2 for the raw materials production (tree growth). Therefore, in Figure 3, scenario 3 looks to be the better option. By comparing Figure 2 with Figure 3, some interesting observations are possible. The EU CFF average out results of the different scenarios. This is not the case for EN 15804, where using recovered materials (waste wood or paper) for recycling into a new product does not seem to be very beneficial.

5 DISCUSSION AND CONCLUSION

In reality, transport distances depend on the location of the raw materials and the pulp and paper mill (see Schau et al, 2015 for a map of pulp and paper mills in Europe). In this study, we assumed equal transport distances for all scenarios of 200 km resulting from 220 tkm for recovered paper for recycling to 720 tkm for virgin (green/fresh) wood from the forest. The distribution to the consumer and the use phase were not included as this is assumed quite equal for the different scenarios. However, it might be that recovered wood is located nearer to pulp and paper mills and consumers of packaging paper than virgin wood from the forest. In addition, variation in moisture content of virgin wood, waste wood and recovered paper influences the transport impact. Recovered paper and waste wood is considerably drier than fresh wood. The contribution of transport of the main raw material to the carbon footprint was moderate in our study. For specific cases, real transport distance and real moisture content should be considered. For EN 15804 cut-off allocation, and also (to a certain degree) EU CFF allocation, recycling is beneficial in terms of climate change (biogenic emissions) as the products involved share the emissions for the recycling process (here defined as transport of recovered material and energy consumption in the pulping process). Taking a step back and looking at what the results of the paper production scenarios could mean from a building materials point of view, EN15084 cut-off allocation in scenario 1 for recycled wood does not allocate any uptake of CO_2 in forestry to the paper product as there is no credit (no bar below 0 for scenario 1). This implies that when wooden building material are recycled at the end of life, the complete uptake of CO_2 in forestry remains for the building materials. The (final) end of life with incineration and emissions of biogenic CO_2 is allocated to the subsequent product, paper made of used wood. Following the principle of no double counting and a balanced input and output from cradle to grave, we can conclude that wood products that are cascaded or recycled, and not incinerated at the end of life, might have a negative carbon footprint. Wood is used in conjunction with other materials like paints, varnishes, metal fixings, laminates, foils and so on. Recovered wood is, therefore, heterogeneous, and so its suitability for a particular end-use must be verified. Contamination control and sorting technologies can be costly and include energy-intensive operations that will have an impact on the total carbon footprint of the product. Nevertheless, by utilizing recovered wood from buildings, the time span of carbon storage in the products increases and, consequently, delays contribution to the greenhouse effect (Höglmeier et al, 2013). This shows that the time parameter is important when assessing the environmental impact of wood products but is left for future studies.

Our results indicate that waste handling at end of life (here incineration without energy recovery) is the main driver of biogenic CO_2 emissions. Recycling or cascading use at end of life, or at least an effective use of the energy in the wasted product, is a premise for considerably reducing the carbon footprint of packaging products. From the scenarios investigated here, it looks like packaging paper still has some way to go to reach a negative carbon footprint. But this is left for future research.

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