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TNO 2026 R10869 – 21 July 2026

Life Cycle Assessment (LCA) of different packaging solutions for white and brown goods

Executive Summary

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Classification report	TNO Public
Title	TNO Public
Report text	TNO Public
Number of pages	10
Number of appendices	0
Project name	Life Cycle Assessment of EPS
Project number	060.57709

Contents

1 Introduction

This executive summary presents the main findings of the comparative Life Cycle Assessment (LCA) conducted by TNO on packaging solutions for the delivery of **televisions** and **washing machines**. EUMEPS approached TNO to conduct this study to assist decision makers in understanding the implications of transitioning from EPS protective packaging to alternative materials.

Goal & Scope
The study evaluates the **cradle-to-grave environmental performance** of four packaging solutions: **Expanded Polystyrene (EPS), Expanded Polypropylene (EPP), honeycomb paperboard,** and **moulded pulp.** Each option includes the environmental burdens of **product loss due to transport damage**, which has a prevalent impact for high-value goods.

Functional Unit & System Boundaries
The functional units, which constitute the basis for the assessments, are defined as follows:

- **For TV:** Providing protective packaging for the delivery of one 50-inch flat-screen TV from the manufacturer to the client by truck in Europe.
- **For washing machine:** Providing protective packaging for the delivery of one 80kg washing machine from the manufacturer to the client by truck in Europe.

The system boundaries for all solutions assessed include:

- Packaging production
- Transport of packaging
- Transport of packaged products
- End-of-life (recycling, energy recovery, landfill)
- Climate and environmental impacts caused by damage-induced product replacement
- Multi-cycle reuse dynamics (6 life cycles)

Damage and recycling rate scenarios
In the scenarios modelled, different rates were assumed for product damage, packaging return and packaging recycling.TNO did not have access to sufficient data/evidence to support the assumed rates, thus opted for a break even analysis which highlighted that the conclusions can be very sensitive to small changes in these rates.

There is also no basis to determine whether the assumed rates in each scenario are conservative or optimistic considering current and future practices. Thus the results can only be interpreted as exploratory scenarios highlithing potential impacts under specific conditions and consumer behaviours that must be met.

Critical Review Findings (Conducted by CE Delft)
An external reviewer (CE Delft) concluded that:

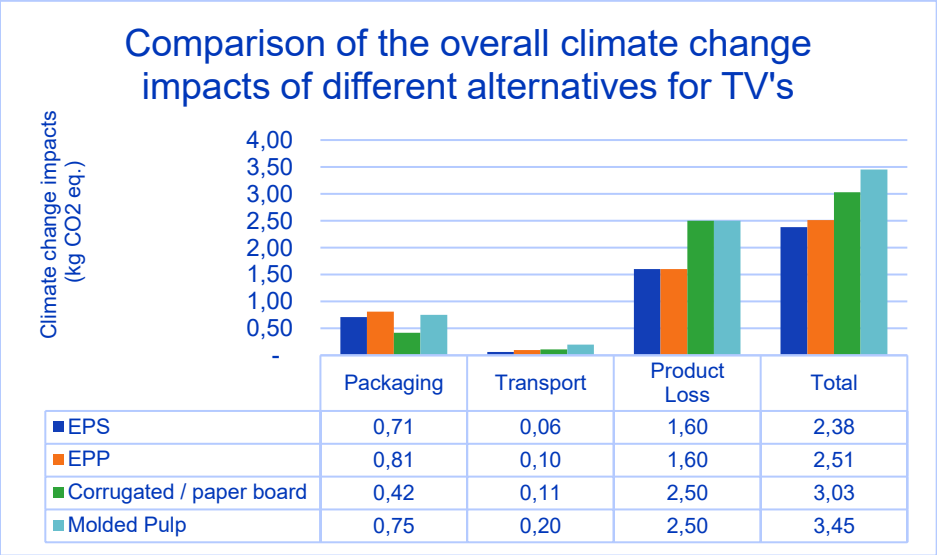
- The LCA is compliant with ISO 14040/44;
- Modelling choices, data quality, and scenario assumptions introduce **high uncertainty**, and conclusions should therefore be interpreted *with caution*;
- Damage rates, package mass, and modelling choices are **key drivers** of the results;
- Sensitivity analyses demonstrate that small parameter shifts can reverse comparative outcomes.

2 Results & Interpretation

The interpretation of results across both product scenarios shows consistent patterns in the comparative environmental performance of the packaging alternatives. For televisions and washing machines, EPS generally yields the lowest overall climate-change impacts, followed by EPP, while moulded pulp and paperboard show the highest impacts, largely due to higher damage-related contributions and heavier packaging. Sensitivity analyses for both products highlight that even small variations in reuse return and recycling collection rates can significantly shift results and, in some cases, alter ranking between EPS and EPP, underscoring the influence of modelling assumptions and damage rates. Together, these findings stress that packaging mass, protection performance, and end-of-life assumptions all critically shape environmental outcomes and must be interpreted with caution.

2.1 Results Television Scenario

The overall climate change impacts of the delivered packaged TV product, show that the delivery of TV with the EPS package shows the best performance (2.38 kg CO2 eq), followed by the delivery with the EPP package (2.51 kg CO2 eq), delivery with the paperboard package (3.03 kg CO2 eq), and then delivery with the moulded pulp package (3.45 kg CO2 eq).



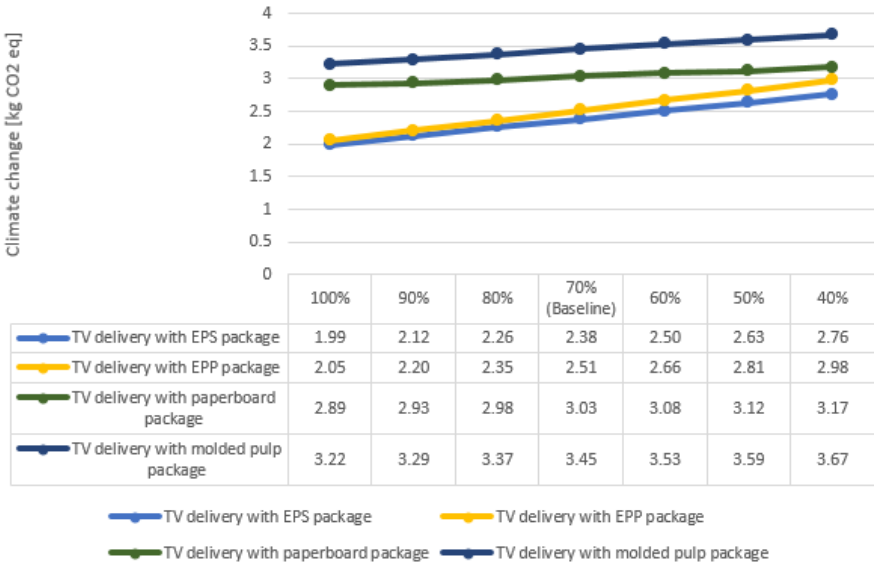
	Packaging	Transport	Product Loss	Total
EPS	0,71	0,06	1,60	2,38
EPP	0,81	0,10	1,60	2,51
Corrugated / paper board	0,42	0,11	2,50	3,03
Molded Pulp	0,75	0,20	2,50	3,45

Figure 2.1 Comparison of the overall climate change impacts of different alternatives for TVs[1]

The sensitivity analysis indicates that, the reuse, return and recycling collection rates inversely affect the climate change impact: higher rates reduce the climate change impact, while lower rates increase it. For TVs, a ±30% variation in the reuse return and recycling

[1] Based on Figure 4.1 in full report TNO. Environmental Comparison of Protective Packaging Materials. Delft: Netherlands Organisation for Applied Scientific Research (TNO), 2026. P. 19. Totals do not match due to rounding. (Figure 4.1 covers TV and Washing Machines, for ease of reading the data has been split).

collection rates leads to an average ±17% change in the climate change impact for deliveries using the EPS package and an average ±22% change for those using the EPP package. These results depend strongly on damage rate, package mass, modelling choices. Small shifts showed reverse rankings in sensitivity analysis. Additionally, it should be noted that the reuse return rate and recycling collection rate were assumed to be equal, variations in these rates could significantly affect the results of these alternatives.

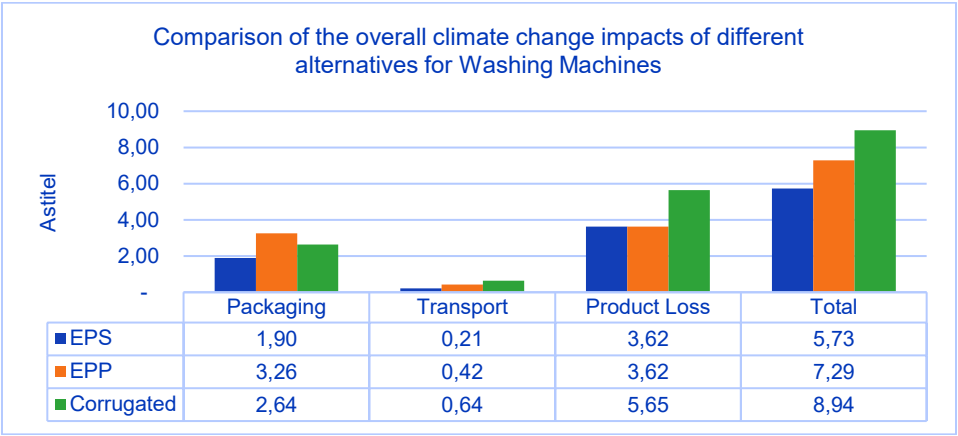


	100%	90%	80%	70% (Baseline)	60%	50%	40%
TV delivery with EPS package	1.99	2.12	2.26	2.38	2.50	2.63	2.76
TV delivery with EPP package	2.05	2.20	2.35	2.51	2.66	2.81	2.98
TV delivery with paperboard package	2.89	2.93	2.98	3.03	3.08	3.12	3.17
TV delivery with molded pulp package	3.22	3.29	3.37	3.45	3.53	3.59	3.67

Figure 2.2 The influence of the recycling and reuse return rates on the overall climate change impact of different alternatives for TVs

2.2 Results Washing Machines Scenario

The overall climate change impacts of the delivered washing machine show that the delivery with the EPS package has the lowest climate change impacts (5.73 kg CO2 eq), followed by delivery with the EPP package (7.29 kg CO2 eq), and delivery with the paperboard package (8.94 kg CO2 eq).

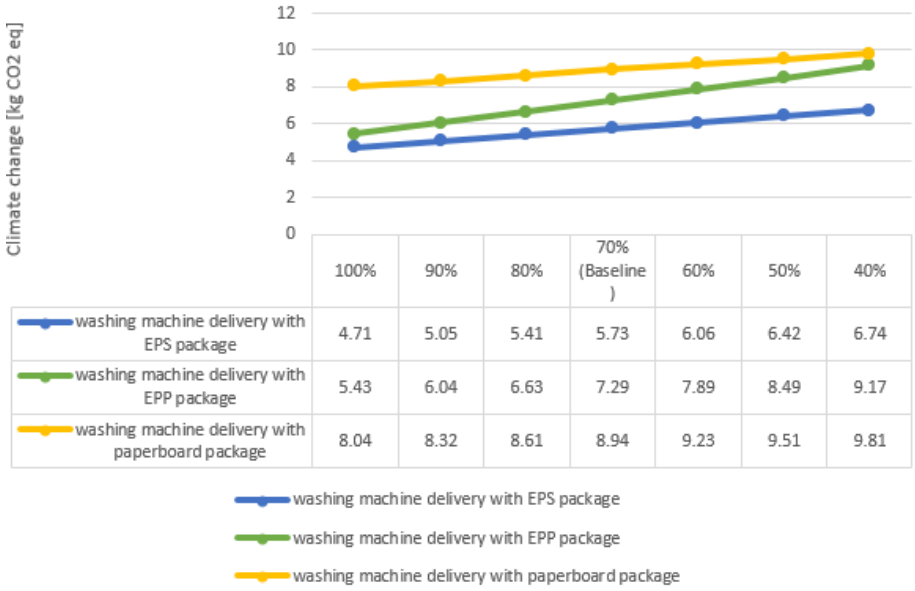


	Packaging	Transport	Product Loss	Total
EPS	1,90	0,21	3,62	5,73
EPP	3,26	0,42	3,62	7,29
Corrugated	2,64	0,64	5,65	8,94

Figure 2.3 Comparison of the overall climate change impacts of different alternatives for Washing Machines[2]

[2] Based on Figure 4.1 in full report TNO. Environmental Comparison of Protective Packaging Materials. Delft: Netherlands Organisation for Applied Scientific Research (TNO), 2026. P. 19. Totals do not match due to rounding. (Figure 4.1 covers TV and Washing Machines, for ease of reading the data has been split).

Similarly to the TVs, the sensitivity analysis for the washing machines shows a ±30% variation in the reuse return and recycling collection rates leads to an average ±18% change in the climate-change impact for deliveries using the EPS package, and an average ±26% change for deliveries using the EPP package.



	100%	90%	80%	70% (Baseline)	60%	50%	40%
washing machine delivery with EPS package	4.71	5.05	5.41	5.73	6.06	6.42	6.74
washing machine delivery with EPP package	5.43	6.04	6.63	7.29	7.89	8.49	9.17
washing machine delivery with paperboard package	8.04	8.32	8.61	8.94	9.23	9.51	9.81

Figure 2.4 The influence of the recycling and reuse return rates on the overall climate change impact of different alternatives for washing machine

Figure 2.4 illustrates that the return-rate can impact the environmental performance of EPP (with higher than 70% return rates) compared to EPS if this has low recycling rates (below 40%). Regardless of recycling rates paperboard packaging had a substantially higher climate impact than EPS, while a high recycling rate for paperboard (100%) outperformed EPP when the return rate was lower than 60%.

A key driver in the difference is the assumed damage rate. Our results therefore underscore that choosing packaging materials without a robust assessment of the various materials' ability to safely deliver the transported materials may lead to sub-optimal environmental performance, even if one material has lower recycling rate than another.

2.3 Broader Environmental Indicators

Across all environmental impact categories for TV and washing machines moulded pulp and then paperboard packages show the highest impacts. It can also be observed that delivery with the EPP package shows a higher impact than delivery with the EPS package in all impact categories, except for water use. It should be noted that these comparisons reflect full life cycle impacts, including packaging production, damaged products, and transportation.

3 Conclusions, Limitations & Publication Note

3.1 Key Conclusions

The comparison of the four packaging alternatives shows that results are highly sensitive to a few key factors particularly damage rates, the mass of the package, and modelling choices on whether damaged products during transportation are taking into account. EPS generally scores well under specific scenarios, but results are not robust enough to be extrapolated to all systems or real world conditions. Because damage product loss dominates total impacts, small variations in these parameters can quickly shift or even reverse the relative ranking of materials. Packaging mass and assumed return or recycling rates further influence outcomes, affecting reusable and single-use systems differently. Overall, the performance of EPS, EPP, paperboard and moulded pulp is therefore context dependent, and the results underline the need for robust empirical data, especially on real-world, industry wide, harmonized damage rates, mass requirements, and return behaviours in order to support confident and generalizable conclusions.

3.2 Key Limitations

- **Return Rates:** The study models a high return-rate scenario (70% reuse or recycling return rate) during the first five cycles. This modelling choice is not representative of current EU practices and should be interpreted as an exploratory outlook in which recycle and reuse targets for the future PPWR for 2040 are met.
- **Damage Rates:** Damage rates (0.8% vs. 1.25%) were derived from European white-goods manufacturer inputs, not from EPS industry data. Even small changes strongly influence outcomes in both product systems. The damage rates used in this study are based on manufacturer inputs provided via a trade association, derived from internal testing and are not drawn from publicly available or harmonised industry-wide datasets. As a result their applicability across different products, supply chains, and logistics configurations is subject to uncertainty. Given the strong influence of damage-related product replacement on the results impacts, these rates were treated as uncertain primary inputs and tested through sensitivity analyses. Accordingly, results related to damage rates should be interpreted with caution and are intended to illustrate their potential influence rather than to provide definitive or generalisable benchmarks.
- **Equal Recycling Rates and Return Rates**: Real-world evidence does not support equal 40% overall EPS recycling rate with a 40% return rate within a controlled multi-cycle take-back system. These are fundamentally different parameters with different behavioural and infrastructure requirements. Using aligned rates ensures a fair scenario comparison but introduces substantial uncertainty, results should therefore be interpreted with caution. It is therefore important to always have clear verified data for return rates for comparative assessments rather than assume certain levels of return can actually be achieved.
- **Data Quality:** The external reviewer emphasises that based on data uncertainty and modelling assumptions definitive, generalised claims across all contexts cannot be made.

3.3 Publication Note

In order to ensure correct interpretation and transparency, this executive summary must be published only together with:

- TNO full report[3] including CE Delft critical review statement.

[3] TNO. Environmental Comparison of Protective Packaging Materials. Delft: Netherlands Organisation for Applied Scientific Research (TNO), 2026. https://publications.tno.nl/publication/34645850/GTMQC9Kq/TNO-2026-R10863.pdf

Signature

TNO Energy & Materials Transition Utrecht, 21 July 2026

ValidSigned by Mateo Gongora Torres
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