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Comparative carbon footprint study: Paper sacks versus woven PP sacks in markets outside Europe

Report prepared by Michael Sturges on behalf CEPI Eurokraft

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1 Introduction

1.1 Background

Paper sacks are an effective, cost-efficient and sustainable packaging solution for packaging of powdered product such as cement, flour, milk powder, etc. They are made from renewable resources, have a low carbon footprint, and are recyclable.

In many markets woven polypropylene (WPP) sacks are also used for these products. In particular, cement producers in some regions outside Europe are increasingly considering WPP sacks, but without having the relevant arguments behind their decisions.

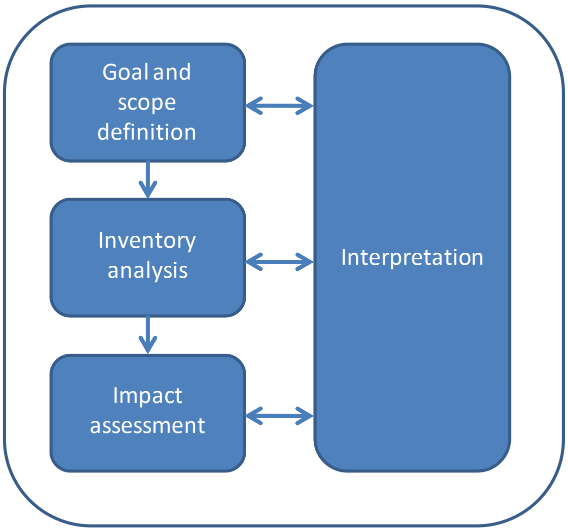
Subsequently, CEPI Eurokraft is pursuing a series of initiatives with the aim of identifying pros and cons for paper sacks in comparison to cross bottom construction sacks with valve/ pasted valve sacks made from WPP intended for the cement industry. The following regions / countries are the focus of the initiative: Africa, Middle East, Southeast Asia, Mexico and Central America.

With this in mind, CEPI Eurokraft contracted RISE (Research Institutes of Sweden) to conduct a comparative carbon footprint study benchmarking paper sacks against cross bottom construction sacks with valve/ pasted valve sacks made from WPP.

The objective of the work was to conduct a detailed cradle-to-gate assessment of the carbon footprint associated with each packaging solution. This report details the methods applied, results achieved and conclusions that can be drawn from the study.

1.2 About life cycle assessment and carbon footprinting

Life cycle assessment (LCA) is a technique to quantify the environmental impacts of a product or system, typically from the cradle to the grave i.e. from the winning and conversion of raw materials (including mining, forestry and agriculture), through manufacturing of products, distribution, use, and finally management of wastes (e.g. disposal to landfill, incineration, recycling, reuse). The methodological approach is summarised in Figure 1 below.



Source: ISO 14040/ISO14044

Figure 1 LCA methodology

ISO international standards define LCA methodology, but by necessity these standards are non-prescriptive. They set out a framework to be followed that ensures that LCA practitioners identify all the parameters and decisions that need to be made in order to complete a justifiable and transparent study.

The methodology consists of four stages: goal and scope definition; inventory analysis; impact assessment and interpretation. The whole process is iterative, and it is possible and sometimes necessary to adjust the goal and scope as a result of findings during the inventory analysis, impact assessment and interpretation stages.

A carbon footprint is effectively an LCA study but with a focus on the Global Warming Potential impact category only. It measures the total greenhouse gas (GHG) emissions caused directly and indirectly by a person, organisation, event or product. There are many different emissions which can contribute to climate change, although the Kyoto protocol encompasses the six most important GHG emissions: Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6).

The footprint is measured in carbon dioxide equivalents (CO_2e). This unit takes account of the fact that some of these gases are more potent than others in terms of their potential to contribute to climate change. For example, over the 100-year time frame from its release into the atmosphere, 1kg of methane is potentially 28 times more powerful as a GHG than 1 kg of CO_2, and it is therefore recorded as 28kgCO_2e. Adopting the unit of CO_2e allows all emissions to be summed together and a single carbon footprint score to be calculated.

This life cycle study focuses on the fossil global warming potential for the studied systems and follows the requirements of ISO14040/14044.

2 Goal and scope

2.1 Goal of the study

The study presented in this report was commissioned by CEPI Eurokraft, the trade association representing sack kraft paper producers in Europe. The work was performed by RISE. A steering group provided input and direction to ensure that the systems studied and data applied were as reflective of the real world experience as possible. The steering committee comprised of technical representatives from:

- CEPI Eurokraft
- Billerud
- Canadian Kraft Paper Limited
- Canfor
- Gascogne Papier
- Mondi Group
- Nordic Paper
- Smurfit Westrock

The goal of the study is to calculate the potential cradle-to-gate contribution to global warming of paper sacks (manufactured from virgin sack kraft paper) and woven polypropylene (WPP) sacks (manufactured from virgin polypropylene) for packaging 50kg of cement in markets outside of Europe, in particular markets in Africa, the Middle East, South/Central America and South East Asia. The results are then applied to compare the two solutions in each market, with a view to understanding the differences in the carbon footprint of paper sacks and WPP sacks for cement and identifying the factors that have most influence over relative standing of the two solutions. This information will provide CEPI Eurokraft and its members with quantitative insights into the carbon implications of the alternative solutions.

Study goal:

- To quantify the life cycle global warming potential for paper sacks for 50kg of cement in the selected markets
- To quantify the life cycle global warming potential for WPP sacks for 50kg of cement in the selected markets
- To understand the key drivers influencing the results for each solution
- To compare and contrast the global warming potential for each solution

Initially, the study is intended to be used internally by CEPI Eurokraft and its members. The findings may also be shared with selected customers.

2.2 Scope of the study

2.2.1 Product systems to be studied

The study investigates paper sacks and WPP sacks for cement in four specific markets:

- Africa – represented by a case study considering Ivory Coast
- Middle East - represented by a case study considering Saudi Arabia
- South/Central America – represented by a case study considering Mexico
- South East Asia – represented by a case study considering Indonesia.

The packaging specifications considered in the baseline scenarios are presented in Table 1 and Table 2. These specifications are based on the experience of CEPI Eurokraft members.

The overall assumptions for each market are summarised in Table 3.

The specifications and assumptions have been the subject of sensitivity analysis.

Table 1 Specifications considered for paper sack for 50kg of cement

Component	Weight (g per sack)
Outer ply (85 gsm)	68.0
Inner ply (85 gsm)	68.0
Starch glue	2.5
Ink	3.0
Total paper sack weight	141.5

Table 2 Specifications considered for WPP sack for 50kg of cement

Component		Weight (g per sack)
Polypropylene, virgin PP	**(~62gsm)**	47.1
Calcium Carbonate, CaCO3 (filler)		1.5
Ink		2.0
Polypropylene, virgin PP for coating/laminating (~22 gsm)		16.5
Total WPP sack weight		67.0

Table 3 Summary of studied systems

Sack type	Market	Production of raw material	Converting location	Assumed transport to convertor	Sack waste during converting and filling	Filling location	Assumed transport to filling
Paper	Africa - Ivory Coast	Sack kraft paper produced in Europe	Abidjan region	European mill to European port = 500km European port to Port of Abidjan = 8,947km Port of Abidjan to converting site = 250km	Converting waste 2% Filling waste 0.3%	Abidjan region	Converting site to fillers = 250km
	Middle East - Saudi Arabia		Jeddah region	European mill to European port = 500km European port to Port of Jeddah = 9,441km Port of Abidjan to converting site = 250km		Jeddah region	
	South/Central America - Mexico		Tampico region	European mill to European port = 500km European port to Tampico = 11,032km Port of Abidjan to converting site = 250km		Tampico region	
	South East Asia - Indonesia		Jakarta region	European mill to European port = 500km European port to Jakarta = 17,870km Port of Abidjan to converting site = 250km		Jakarta region	
WPP	Africa - Ivory Coast	Virgin PP granules produced in South Africa	Abidjan region	Plastics facility to South African port = 150km South African port to Port of Abidjan = 5,863km Port of Abidjan to converting site = 250km	Converting waste 7% Filling waste 0.15%	Abidjan region	Converting site to fillers = 250km
	Middle East - Saudi Arabia	Virgin PP granules produced in Jeddah region	Jeddah region	Plastics facility to converting site = 50km		Jeddah region	
	South/Central America - Mexico	Virgin PP granules produced in Tempico region	Tampico region	Plastics facility to converting site = 125km		Tampico region	
	South East Asia - Indonesia	Virgin PP granules produced in Jakarta region	Jakarta region	Plastics facility to converting site = 250km		Jakarta region	

Both the paper sack and the WPP sack systems are representative of the situation in 2023. The following systems were considered:

Paper sack – the sack kraft paper is manufactured in Europe. Average European sack kraft production is considered. The sack kraft paper is then transported by road and ship for converting into paper sacks in the case study market. At the convertors, paper sacks are produced using an entirely automatic process. It is divided into two main parts: tube forming and bottom folding. The outer ply is either printed separately or on its way to the tube forming. The production process is monitored by electronic inspection systems and machine operators.

The main inputs to the sack converting process are sack kraft paper, non-fibre inputs (glues, inks), and electricity to power the machinery. Production losses during the paper sack converting process are estimated at 2%. Based on the experience of the steering group for the study, this is a high estimate. Operational experience suggests that in reality the production losses could be as low as 0.5% or less. It is assumed that process waste from the sack converting process are sent for recycling into corrugated case materials.

The converted paper sacks are then palletised and transported to the filler.

Filling is a fully automated process. A major advantage of paper sacks is that they are naturally porous: air can escape through their pores allowing an optimal filling behaviour. Subsequently, very high filling speeds can be achieved. Current technology allows filling speeds for cement of up to 6,000 packs per hour (Eurosac and CEPI Eurokraft, 2016). It is assumed that there is a 0.3% loss of paper sacks at the filling operation and it is assumed that the waste paper is sent for recycling into corrugated case materials.

The filled sacks are then palletised ready for distribution.

WPP sack – the virgin polypropylene is manufactured as granules or pellets. For the case study considering Ivory Coast as the market for sacks, no local supplier of PP granules could be identified. Anecdotal evidence suggests that the virgin PP used in Ivory Coast is produced in South Africa and the PP granules are then transported by road and ship for converting into WPP sacks in Ivory Coast[1].

For the case studies considering Saudi Arabia and Indonesia as the markets for sacks, local suppliers of PP granules were identified through an Internet search, and therefore a nominal road transport distance has been assumed for the delivery of PP granules to the converting operation.

For the case study considering Mexico as the market for sacks, local suppliers of PP granules were identified through an Internet search. However, information published suggests that almost 50% of plastic resins currently used by Mexico's manufacturing sector is imported (UK Department for International Trade, 2017). Further research suggests that manufacturers from India are a key supplier of PP granules to the Mexican market, but a conservative assumption has been applied and it is assumed that all granules for WPP sacks are sourced nationally and a nominal road transport distance has been assumed for the delivery of PP granules to the converting operation.

[1] Private communications with industry experts

At the convertors, the PP is converted into a tape which is then weaved into a substrate, coated/laminated, printed and formed into WPP sacks in an integrated process.

The main inputs to the sack converting process are PP pellets, calcium carbonate (as a filler), and energy (electricity to power the machinery).

Production waste at the converting site is estimated at 7%. This figure is based on anecdotal evidence.[2] This waste may be recycled at the converting site in a closed loop process and therefore in the modelling 0% waste has been considered as a conservative estimate. However, the process waste may also be sold for recycling by external third parties, and therefore the influence of this assumption is investigated further in the sensitivity analysis.

Filling is an automated process, although loading of the bags onto the filling spouts is usually a manual process. Filling speeds are much slower compared to filling speeds for paper sacks. It is assumed that there is a 0.15% loss of WPP sacks at the filling operation, and it is assumed that the waste WPP is sent for recycling by a third party into rPP pellets.

The filled sacks are palletised ready for distribution.

2.2.2 Functions of the product systems

The function of the product is the containment of 50kg of cement.

2.2.3 Functional unit

The functional unit considered is the primary packaging for one thousand filled sacks ready for distribution.

2.2.4 System boundaries

The system boundaries considered are cradle-to-filler out-gate. The overall systems are described in Figure 2 and Figure 3.

[2] Private communications with industry experts

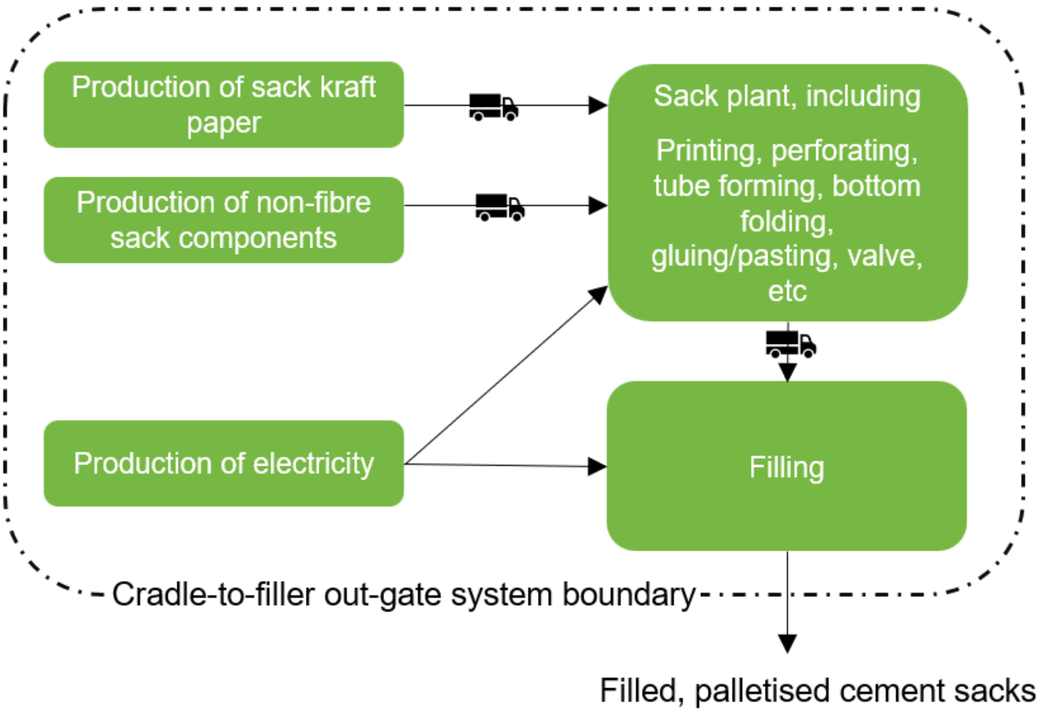


Figure 2 Paper sack system

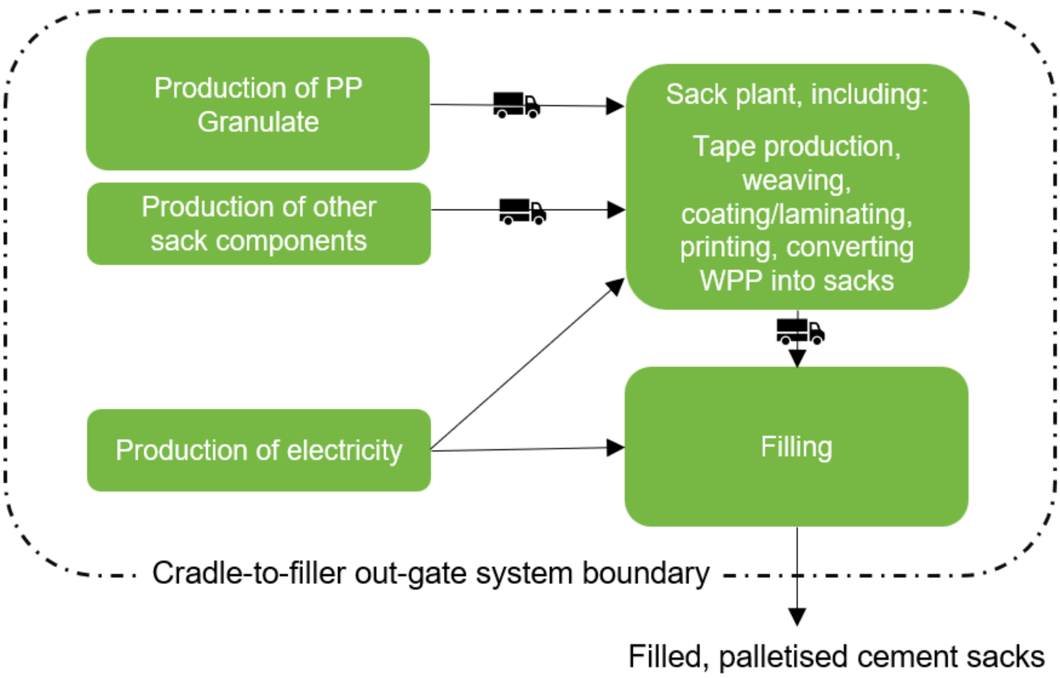


Figure 3 WPP sack system

Cradle-to-filler out-gate system boundaries have been chosen as these represent the life cycle stages where the sack supplier and filler have control over the potential impacts. Downstream life cycle stages, in particular end-of-life, cannot be easily influenced by the sack supplier or convertor. In the markets considered in this study, waste management policy and infrastructure is immature and it is not possible to get credible information relating to the fate of cement sacks at end-of-life. Therefore, a cradle-to-grave analysis is not possible.

The study focuses on the primary packaging only. Excluded from the system boundaries is the production of the cement itself. However, this approach assumed equivalent performance between the two solutions. Lab tests indicate that losses of cement are higher during the filling operation and in the downstream value chain for WPP sacks compared to paper cement sacks. To investigate the potential influence of these additional losses, an additional scenario has also been considered which includes the impact of the production of the cement losses from the two solutions.

Also excluded from the system boundaries is the production and end-of-life management of transport packaging (palletisation wrap and pallets). Past experience shows that transit packaging is likely to make only a small contribution to the overall impact and as the transit packaging will be equivalent for both the paper sack system and the WPP sack system its exclusion will not affect the comparative standing of the two solutions.

2.2.5 Allocation procedures

No allocation was required in the foreground systems.

A review of the background meta data shows that allocation was applied in the upstream processes for production of sack kraft paper and production of PP granulate.

For PP granulate, the background data used is sourced from the Ecoinvent 3.10 cut-off database. The dataset represents the production mix of commercial PP production technologies. Activity starts with monomers and comonomers entering the polymerisation plant. Energy supply is included in terms of heat production inside the battery limits of the plant. Steam and electricity supply is outside the activity. From cradle, i.e. including all upstream activities. Activity ends with polymer granulate leaving the factory. The polyolefin production itself is regarded as a single-output process since only one polymer type is produced by one installation. All other products of this installation, e.g. monomers being recycled to the cracker or distillation, or hydrocarbons being used thermally, are treated as internal flows replacing the respective input materials (i.e. monomers or energy carriers). Hence, no allocation is needed for the polyolefin production process.

For sack kraft paper, the background data is sourced from CEPI Eurokraft's life cycle inventory (RISE, 2023a). Paper mills producing sack kraft papers may also produce other paper grades and may also produce excess electricity and/or heat/steam which can be sold to the grid or to other third party users. In addition, by-products such as turpentine may also be produced. In the life cycle inventory for sack kraft paper, the following allocation rules have been applied:

- Allocation of burdens between physical product (e.g., pulp, paper) and energy products has been made on the basis of causation – i.e., the proportion of fuel inputs and emissions to air allocated to the energy products have been determined according to the quantities required to deliver those energy products

- Allocation of burdens between paper grades has been made on the basis of causation where possible or if this is not possible then on the basis of mass – i.e., the proportion of flows allocated to each paper grade have been determined according to the specific quantities required to manufacture those specific grades wherever possible
- No allocation of burdens has been made to byproducts. All burdens have been allocated to the paper products and sold energy products.

Processing wastes occur during sack converting and sack filling processes. For paper sacks, sack kraft paper waste arising during converting and filling is assumed to be recycled into corrugated case materials by a third party. A cut-off methodology is applied, meaning that all burdens associated with the recycling process are allocated to the product using the recycled fibre. Only the impact of process waste collection are allocated to the paper sack system. For WPP sacks, process waste arising at the sack convertor is assumed to be recycled internally in a closed loop process, and therefore no allocation is required. For process waste arising from the sack filling process, this is assumed to be recycled into rPP pellets by a third party. A cut-off methodology is applied, meaning that all burdens associated with the recycling process are allocated to the product using the rPP. Only the impact of process waste collection are allocated to the WPP sack system.

2.2.6 Impact categories

Many impact categories are available for life cycle assessment, but this study focuses on the fossil global warming potential impact category. This impact category has been chosen as it has been the focus of claims of environmental superiority from providers of WPP sacks. Also, according to the Product Environmental Footprint (PEF) methodology, the climate change impact category has the highest weighting for the calculation of the PEF single score.

Biogenic emissions and removals are not considered. Paper is a bio-based product. Growth of forests for the production of fibres used in paper production leads to GHG removals. However, as paper sacks are a relatively short-lived product, and carbon storage will be short-lived. It is assumed that the biogenic carbon emissions are in balance with the biogenic carbon removals, and therefore these biogenic carbon removals and emissions are not accounted for. This is known as the 0/0 approach. Removals and emissions associated with direct land use change are also excluded from the analysis. Experience from previous studies shows that direct land use change makes only a limited contribution to the global warming potential of paper products when the paper is sourced from sustainably managed forests.

2.2.7 Limitations

The following limitations should be highlighted when considering this study:

- Asymmetry of the data – the model for the paper sacks system is largely based on primary data relating to the actual situation. Primary data previously collected by CEPI Eurokraft and Eurosac is the basis for the sack kraft paper production and paper sack converting processes (RISE, 2023a), (RISE, 2023b). The models for this study have been described in liaison with a steering group of industry experts (drawn from members of CEPI Eurokraft), and there is therefore a high degree of confidence in the models produced. For the WPP sack systems, these have been described based on literature review.

Although the WPP systems are based on best available information from the literature, there is a lower degree of confidence in the validity of the data used, assumptions applied and models generated. However, the results achieved and conclusions drawn can be considered as indicative of the magnitude of the carbon impact of WPP sacks. The results can certainly be used to draw conclusions as to the drivers and influencers behind the footprint of WPP sacks and demonstrate the factors that influence the relative performance compared to paper sacks.

- Specific systems studied – the results are applicable only to the specific paper sack and WPP sack systems studied. For the paper sacks, the results may be considerably different considering sack kraft papers manufactured at specific papermills – efficiency and energy strategies vary considerably between different paper manufacturers and therefore the carbon impact of paper produced at specific mills can vary considerably compared to the industry average applied in the baseline analysis. Similarly, industry average data has been applied for the production of polypropylene granules. The emissions profile of specific suppliers may vary considerably from this average. Furthermore, the transportation distances considered are indicative of the probably transport between the production of the raw materials and the sack converting process. Distances for specific suppliers may vary. Readers should be aware of the potential influence of these factors when considering the results presented and conclusions drawn.
- Geography – the results are applicable only to the specific geographies considered in the case studies (i.e., sack kraft paper production in Europe, PP production in different regions, distribution to the case study markets for conversion, and conversion and filling in the case study markets).
- Impact categories considered – the study considers only fossil global warming potential impact category. Other environmental impact categories may show different trends and results when the systems are compared.
- System boundaries – the study considers cradle-to-filler out-gate system boundaries. These boundaries are justified on the basis that these represent the life cycle stages where the stakeholders (substrate producers, sack convertors, fillers) can make decisions that influence the impacts. These stakeholders do not have influence over the downstream activities, in particular end-of-life management. Furthermore, data relating to end-of-life fate of paper and WPP cement sacks in the case study markets is not available. Readers should be aware that there may be additional impacts associated with both paper sack and WPP sacks during end-of-life management which are not captured by the current system boundaries.

2.2.8 Critical review requirements

This study makes comparative assertions. As it is intended that this study will be published and made available to stakeholders, in line with the requirements of ISO14040/14044, an independent critical review will be commissioned.

3 Life cycle inventory

3.1 Data and data quality requirements

Whilst no quantitative data quality goals were set for this study, the data quality principles outlined in Table 4 below were applied. The subsequent data sourced and described in Table 5 and Table 6 are evaluated against these principles to highlight any data points of lower quality which have then been prioritised in the sensitivity and uncertainty analysis.

Table 4 Data quality principles applied in this study

Data quality principle	Description	Comments on approach
Relevance	Data should be representative of the current (2015 or later) technology and market situation. Data should cover the main sources of inventory inputs/outputs across the life cycle Data should be representative of the relevant geography	To achieve these objectives primary data was collected wherever possible for foreground unit processes and the aim was to use secondary data from widely used publicly available databases, dating from 2015 onwards, for background unit processes.
Completeness	Data should cover all major unit processes in the life cycle for each system considered Inventory data should include all major inventory burdens relevant to the fossil GWP impact category for each stage of the life cycle	
Consistency	Data provided should be consistent in order to enable aggregation of data from different suppliers	For primary data, efforts were made to ensure that all sites providing data did so considering consistent system boundaries, allocation principles, etc. For secondary data, wherever possible data was sourced from the Ecoinvent3.10 Cut-off database only. This ensures consistency of boundaries, allocations, etc for secondary datasets. Where alternative datasets are required for selected inputs this is highlighted and any potential limitations are discussed.
Accuracy	Uncertainties in the data should be minimised	
Transparency	Within bounds of confidentiality, data used should be transparent and/or referenced	All secondary data used in the analysis is clearly referenced.

Table 5 Data and assumptions for paper sack systems

Life cycle stage/ unit process	Data points	Data sources and assumptions	View on LCI Data quality
Sack kraft paper production	Cradle to gate GHG emissions for sack kraft production	*The carbon footprint of sack kraft paper and paper sacks 2021* (RISE, 2023c) The calculations make use of the gate-to-gate life cycle inventory data covering sack kraft paper production compiled by CEPI Eurokraft (RISE, 2023a). This life cycle inventory data covers the resources, energy, emissions and wastes per tonne of average sack kraft paper in Europe during the calendar year 2021. The data was collected from 11 mills producing sack kraft paper covering 75% of sack kraft paper production in Europe. A weighted average grid electricity mix is considered based on actual consumption at each mill and the relative share of production for each mill. Fossil GHG emission factors for electricity consider specific product mixes where possible. Where this information is not available, national grid electricity mixes are considered. Emission factors for electricity purchased from the national grid are sourced from IEA Emission Factors 2021	Data quality is deemed high. The dataset meets all data quality principles.
Inbound logistics: Transport of sack kraft paper from papermill to sack converting site	Transport modes and transport distances	Representative transport modes and distances are based on assumptions made by the LCA practitioners, considering main production locations for European sack kraft paper, likely shipping routes and assumed location of converting operations for each market case study	Data quality is deemed fair. Accuracy could be compromised as actual distances will be highly variable depending on locations of mills and convertors.
	LCI data for transport operations	Truck transport within Europe: market for transport, freight, lorry 16-32 metric ton, EURO6 | transport, freight, lorry 16-32 metric ton, EURO6, RER, Ecoinvent 3.10	Data quality is deemed high. The dataset meets all data quality principles.

		Truck transport in other regions: market for transport, freight, lorry 16-32 metric ton, EURO6 | transport, freight, lorry 16-32 metric ton, EURO6, ROW, Ecoinvent 3.10 Ship transport: market for transport, freight, sea, container ship | transport, freight, sea, container ship, GLO, Ecoinvent 3.10	
Paper sack converting	Life cycle inventory data for paper sack converting	The gate-to-gate life cycle inventory for paper sacks was sourced from *Gate-to-gate life cycle inventory data for average European paper sack converting 2021* (RISE, 2023b). This was used to quantify consumption of purchased electricity, starch glue, priting inks and process waste	Data quality is deemed high. The dataset meets all data quality principles.
	GHG emissions for purchased electricity	Sourced from IEA (IEA, 2022)	Data quality is deemed high. The dataset meets all data quality principles.
	GHG emissions for Starch glue	Average of market for potato starch | potato starch | GLO and market for maize starch | maize starch, GLO, Ecoinvent 3.10.	Data quality is deemed high. The dataset meets all data quality principles.
	GHG emissions for Inks	market for printing ink, offset, without solvent, in 47.5% solution state | printing ink, offset, without solvent, in 47.5% solution state | Cutoff, ROW, Ecoinvent 3.10.	Data quality is deemed high. The dataset meets all data quality principles.
Outbound logistics: Transport of paper sacks from convertor to filler	Transport modes and transport distances	Representative transport modes and distances are based on assumptions made by the LCA practitioners	Data quality is deemed low. Accuracy could be compromised as actual distances will be highly variable depending on locations of convertors and fillers. However, as this life cycle stage makes only a minor contribution to the overall impact this lower quality data point is deemed acceptable

	LCI data for transport operations	Truck transport in non-European markets: market for transport, freight, lorry 16-32 metric ton, EURO6 | transport, freight, lorry 16-32 metric ton, EURO6, ROW, Ecoinvent 3.10	Data quality is deemed high. The dataset meets all data quality principles.
Filling	Electricity consumption for sack filling	Carbon Emissions of China's Cement Packaging: Life Cycle Assessment (Ma, Li, & Li, 2019)	Although the dataset is geographically representative of filling in China, filling machines are similar globally and the energy consumption value matches the expectations of the steering group members. Therefore, data quality is deemed high. The dataset meets all data quality principles.

Table 6 Data and assumptions for WPP sack systems

Life cycle stage / unit process	Data points	Data sources and assumptions	View on LCI Data quality
Polypropylene granules production	Cradle to gate GHG emissions for PP production	polypropylene production, granulate | polypropylene, granulate, ROW, Ecoinvent 3.10	
Inbound logistics: Transport of PP granules to WPP sack plant	Transport modes and transport distances	Representative transport modes and distances are based on assumptions made by the LCA practitioners, considering potential production locations for PP granules, likely shipping routes and assumed location of converting operations for each market case study	Data quality is deemed fair. Accuracy could be compromised as actual distances will be highly variable depending on locations of PP production facilities and convertors.
	LCI data for transport operations	Truck transport within Europe: market for transport, freight, lorry 16-32 metric ton, EURO6 | transport, freight, lorry 16-32 metric ton, EURO6, RER, Ecoinvent 3.10 Truck transport in other regions: market for transport, freight, lorry 16-32 metric ton, EURO6 | transport, freight, lorry 16-32 metric ton, EURO6, ROW, Ecoinvent 3.10 Ship transport: market for transport, freight, sea, container ship | transport, freight, sea, container ship, GLO, Ecoinvent 3.10	Data quality is deemed high. The dataset meets all data quality principles.
WPP sack converting	Electricity required for WPP sack converting	Carbon Emissions of China's Cement Packaging: Life Cycle Assessment (Ma, Li, & Li, 2019)	Although the dataset is geographically representative of conversion in China, equipment is similar globally and the energy consumption value matches the expectations of the steering group members.

			Therefore, data quality is deemed high. The dataset meets all data quality principles.
	GHG emissions for purchased electricity	Sourced from IEA (IEA, 2022)	Data quality is deemed high. The dataset meets all data quality principles.
	GHG emissions for Calcium carbonate $CaCO_3$ (filler)	Average of market for calcium carbonate, precipitated | calcium carbonate, precipitated, ROW and lime production, milled, loose | lime, ROW, Ecoinvent 3.10.	Data quality is deemed high. The dataset meets all data quality principles.
	GHG emissions for Inks	market for printing ink, offset, without solvent, in 47.5% solution state | printing ink, offset, without solvent, in 47.5% solution state | Cutoff, ROW, Ecoinvent 3.10.	Data quality is deemed high. The dataset meets all data quality principles.
Outbound logistics: Transport of WPP sacks from convertor to filler	Transport modes and transport distances	Representative transport modes and distances are based on assumptions made by the LCA practitioners	Data quality is deemed low. Accuracy could be compromised as actual distances will be highly variable depending on locations of convertors and fillers. However, as this life cycle stage makes only a minor contribution to the overall impact this lower quality data point is deemed acceptable
	LCI data for transport operations	Truck transport in non-European markets: market for transport, freight, lorry 16-32 metric ton, EURO6 | transport, freight, lorry 16-32 metric ton, EURO6, ROW, Ecoinvent 3.10	Data quality is deemed high. The dataset meets all data quality principles.
Filling	Electricity consumption for sack filling	Expert opinion from the project steering group – there is consensus amongst the steering group that filling WPP sack takes typically takes approximately 15% more electricity compared to filling paper sack	Data quality is deemed fair.

For the additional scenario where cement losses from the two solutions are considered, data for cement production has been sourced from Ecoinvent 3.10 (cement production, CEM II/A | cement, CEM II/A | Cutoff, S, ROW).

3.2 Modelling

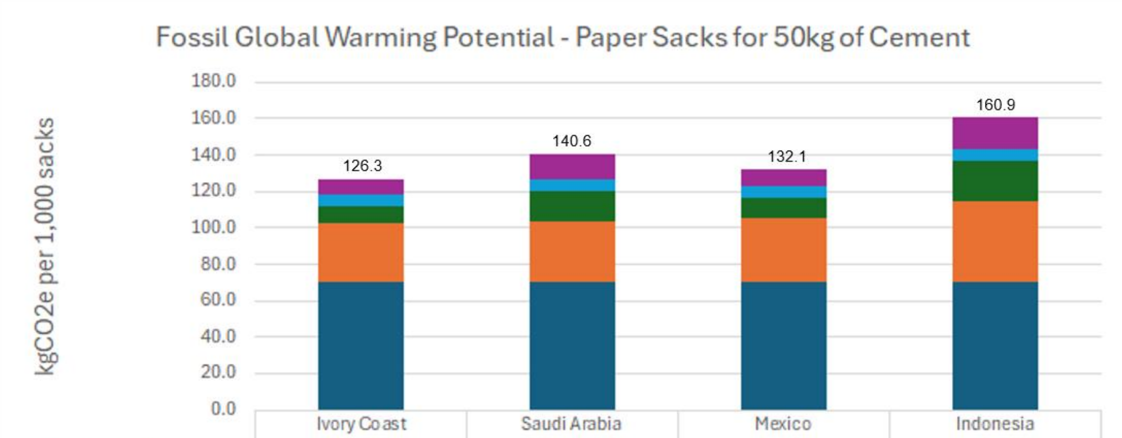
The models for each system were constructed in MS Excel. The models are available to CEPI Eurokraft and its members as a confidential annex to this report.

4 Impact assessment

Fossil global warming potential has been determined considering IPPC 2021. The results of the impact assessment for each of the baseline systems are presented in Figures 4 – 9 below.

4.1 Paper sacks for 50kg of cement

Figure 4 presents the global warming potential for the baseline paper sack scenarios, i.e., 1,000 paper sacks for 50 kg of cement, as produced and filled in the case study markets of Africa (represented by Ivory Coast), the Middle East (represented by Saudi Arabia), Central and South America (represented by Mexico) and South East Asia (represented by Indonesia).



	Ivory Coast	Saudi Arabia	Mexico	Indonesia
SACK FILLING	7.6	13.7	8.9	17.4
OUTBOUND LOGISTICS	6.7	6.7	6.7	6.7
SACK CONVERSION	9.5	17.1	11.1	21.7
INBOUND LOGISTICS	32.0	32.7	35.0	44.6
RAW MATERIALS	70.4	70.4	70.4	70.4

Figure 4 Global warming potential – paper sacks for cement

The results show that the production of raw materials (in this case sack kraft paper) contributes the largest share of the fossil GHG emissions, accounting for 70.4kgCO2e per 1,000 sacks (between 44% and 56% of the total fossil global warming potential, depending on the market case study). The absolute value for raw materials remains constant for all market case studies, as the same paper sack specifications are considered in each market.

Figure 5 provides a breakdown of the different components to the raw materials life cycle stage. It can be seen sack kraft paper is the most significant raw material, accounting for 83% of the raw materials impact.

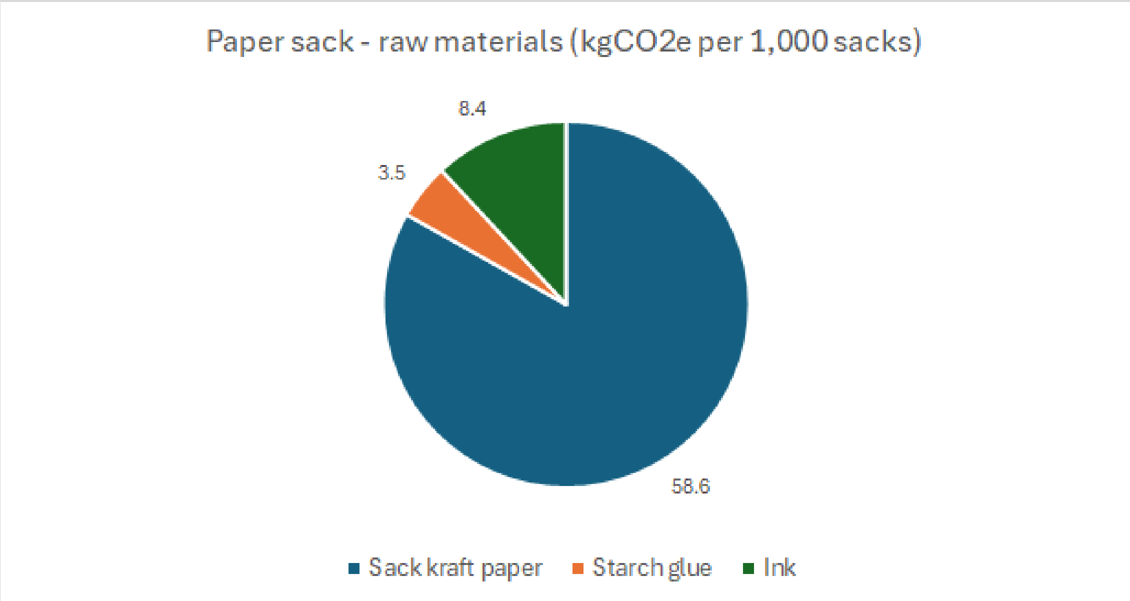


Figure 5 Relative contribution of different components to raw materials impact

The second most important life cycle stage is inbound logistics (i.e., delivery of the sack kraft paper from the European mill to the converting site in each market). This step contributes between 32.0kgCO2e and 44.6kgCO2e per 1,000 sacks depending on the market and represents between 23% and 28% of the total impact. Figure 6 breaks down the inbound logistics according to the different transport stages. The absolute value for inbound logistics varies between market case studies due to the different shipping distances considered between Europe and the location of the market case studies.

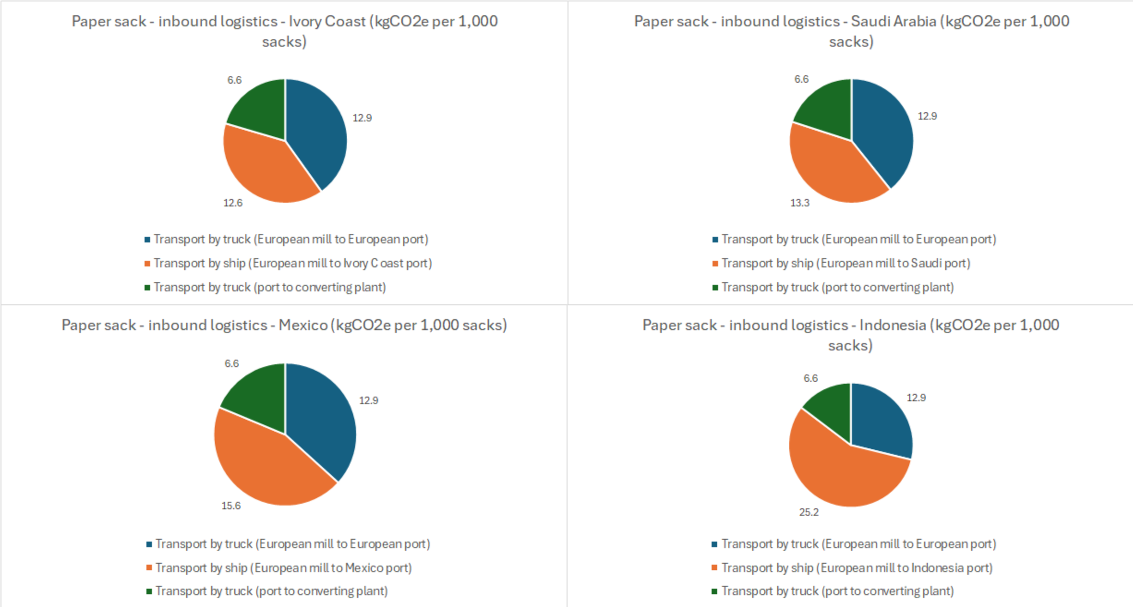


Figure 6 Relative contribution of transport steps to the inbound logistics impact

Sack conversion is the third most important life cycle stage, contributing between 9.5 and 21.7kgCO2e per 1,000 sacks. This represents between 8% and 14% of the total fossil global warming potential, depending on the case study. The only input into the sack converting process is electrical energy to power the machinery. The variation in the absolute value for filling between market case studies reflects differences in purchased grid electricity mix in each country considered.

Outbound logistics (the delivery of converted sacks to the fillers) contributes 6.7kgCO2e per 1,000 sacks, representing between 4% and 5% of the total fossil global warming potential depending on the market case study considered. The absolute value for outbound logistics remains constant for all market case studies, as the same distance between paper sack conversion and sack filling is assumed in all case studies.

Filling contributes between 7.6kgCO2e and 17.4kgCO2e per 1,000 sacks, representing between 6% and 11% of the total fossil global warming potential depending on the market case study considered. The only input into the sack filling process is electrical energy to power the machinery. The variation in the absolute value for filling between market case studies reflects differences in purchased grid electricity mix in each country considered.

4.2 WPP sacks for 50kg of cement

Figure 7 presents the global warming potential for the baseline WPP sack scenarios, i.e., 1,000 paper sacks for 50 kg of cement, as produced and filled in the case study markets of Africa (represented by Ivory Coast), the Middle East (represented by Saudi Arabia), Central and South America (represented by Mexico) and South East Asia (represented by Indonesia).

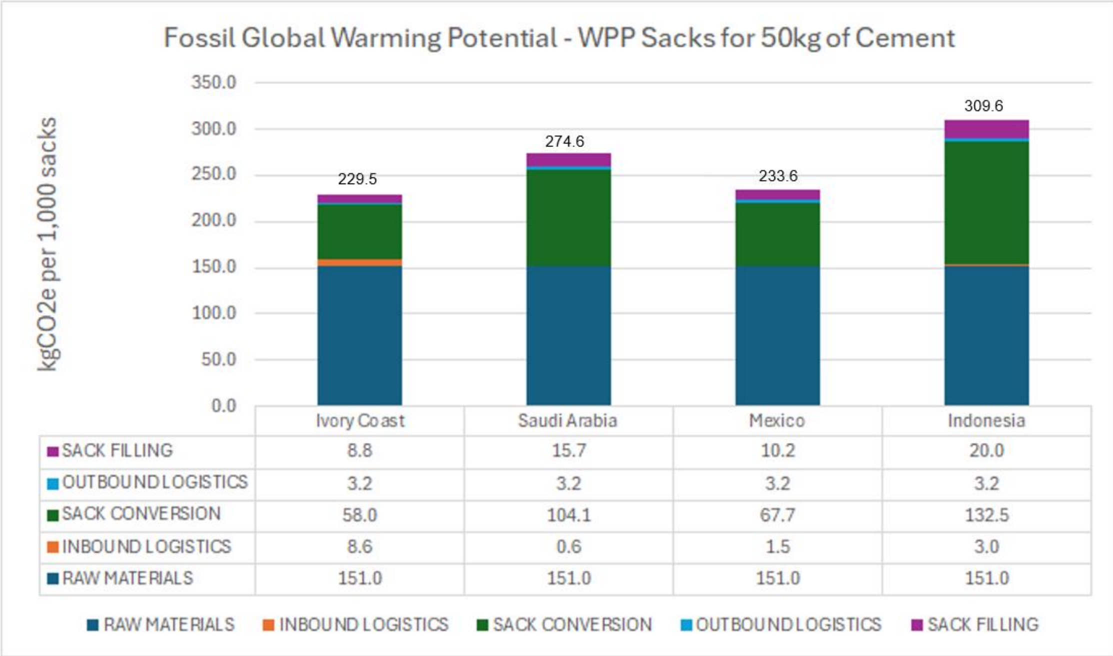


Figure 7 Global warming potential – WPP sacks for cement

The results show that the production of raw materials (in this case polypropylene granules) contributes the largest share of the fossil GHG emissions, accounting for 151.0kgCO2e per 1,000 sacks (between 49% and 66% of the total fossil global warming potential, depending on the market case study). The absolute value for raw materials remains constant for all market case studies, as the same WPP sack specifications are considered in each market.

Figure 8 provides a breakdown of the different components to the raw materials life cycle stage. It can be seen that the PP (for the woven substrate and the laminate) is the most significant raw material, accounting for 96% of the raw materials impact.

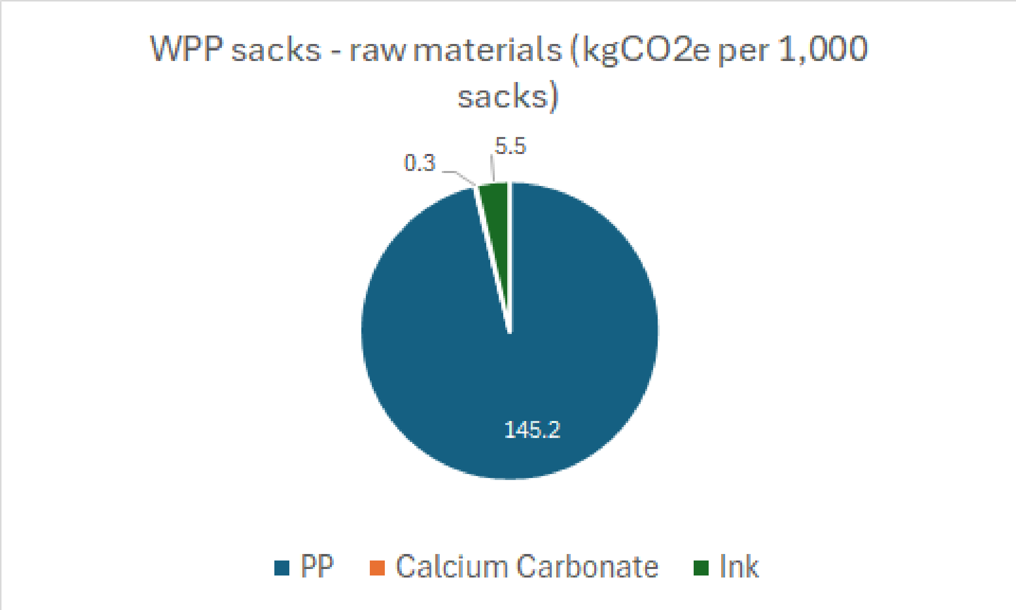


Figure 8 Relative contribution of different components to raw materials impact

Inbound logistics (i.e., delivery of the PP granules from the producer to the converting site in each market) contributes between 0.6kgCO2e and 8.6kgCO2e per 1,000 sacks depending on the market and represents between 0.2% and 3.7% of the total impact. For Saudi Arabia, Mexico and Indonesia, local producers of PP granules were identified, and this is reflected in relatively short transport distances, and therefor relatively low fossil GHG emissions associated with inbound logistics. In contrast, no local supplier of PP granules was identified for the Ivory Coast market case study. Anecdotal evidence suggests that PP consumed in Ivory Coast is produced in South Africa and shipped to the Ivory Coast.

Figure 9 breaks down the inbound logistics for the Ivory Coast case study. For all other case studies, there is only one transport step for the deliver of the PP granules from the producer to the WPP sack converter. This transport is by truck,

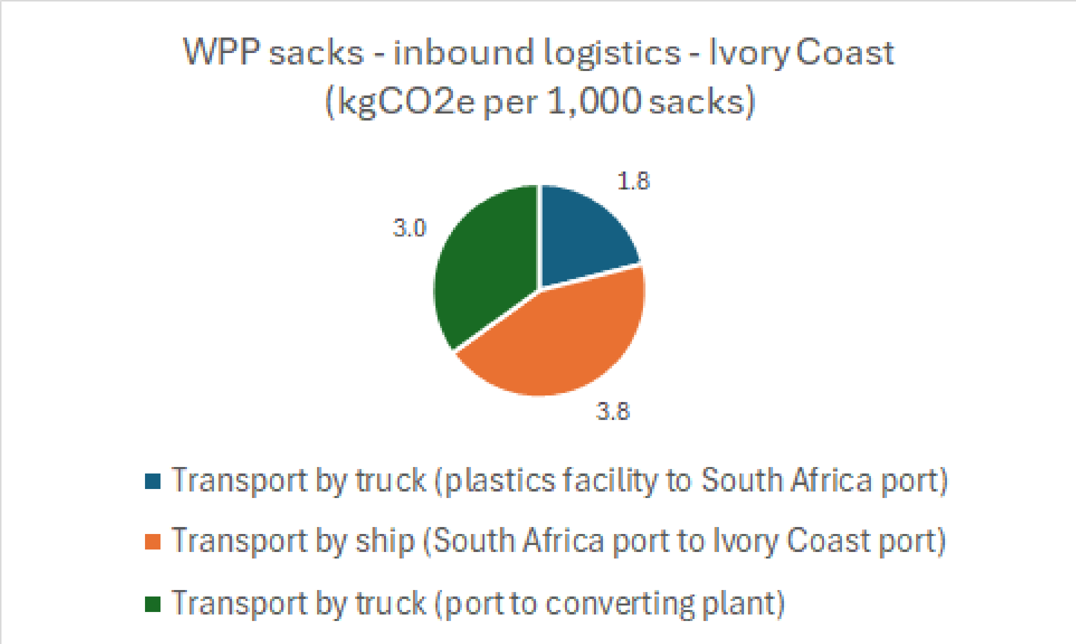


Figure 9 Relative contribution of transport steps for the Ivory Coast case study to the inbound logistics impact

Sack conversion is the second most important life cycle stage, contributing between 58.0kgCO2e and 132.5kgCO2e per 1,000 sacks. This represents between 25% and 43% of the total fossil global warming potential, depending on the case study. The only input into the WPP sack converting process is electrical energy to power the machinery. Although the same production process and WPP sack specification is considered for all market case studies, the absolute value for conversion varies between market case studies due to different purchased grid electricity mixes in each country.

Outbound logistics (the delivery of converted WPP sacks to the fillers) contributes 3.2kgCO2e per 1,000 sacks, representing between 1.0% and 1.4% of the total fossil global warming potential depending on the market case study considered. The absolute value for outbound logistics remains constant for all market case studies, as the same distance between WPP sack conversion and WPP sack filling is assumed in all case studies.

Filling contributes between 8.8kgCO2e and 20.0kgCO2e per 1,000 sacks, representing between 4% and 6% of the total fossil global warming potential depending on the market case study considered. The only input into the WPP sack filling process is electrical energy to power the machinery. The variation in the absolute value for filling between market case studies reflects differences in purchased grid electricity mix in each country considered.

5 Interpretation

5.1 Comparison of paper sacks and WPP sacks

Figure 10 compares the results for each of the baseline scenarios modelled. Due to the inherent uncertainty in some of the data and assumptions relating to LCA modelling, a difference between two scenarios is only considered to be significant if the difference is greater than +/-10%.

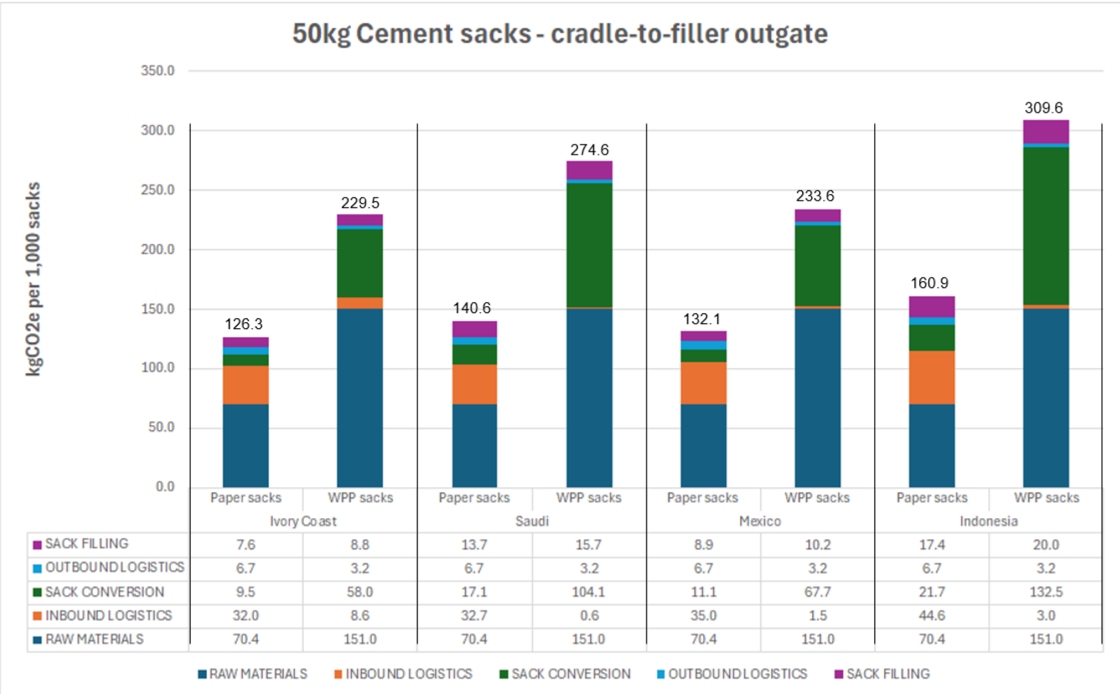


Figure 10 Comparison of paper sacks and WPP sacks – baseline systems

Key takeaways from the analysis are:

- For both solutions, production of the raw materials makes the highest contribution to the fossil global warming potential. In the case of paper sacks, the majority of this impact is due to the production of sack kraft paper ready for conversion into paper sacks. In the case of WPP sacks, the majority of this impact is due to the production of polypropylene granules ready for conversion into WPP sacks.
- Sack conversion has a higher impact for WPP sacks compared to paper sacks, due to the higher electricity demand for converting PP granules into sacks in an integrated process compared to converting sack kraft paper into sacks.
- Inbound logistics has a higher impact for paper sacks compared to WPP sacks. This is due to the fact that the sack kraft paper is produced in Europe and must be transported long distances to the convertor, whereas PP granules are produced more locally.

Furthermore, the paper sacks are heavier compared to the WPP sacks and therefore more weight of raw materials has to be delivered to the converting site.

- Outbound logistics has a higher impact for paper sacks compared to WPP sacks. This is due to the fact that the paper sacks are heavier compared to the WPP sacks and therefore more weight of packaging has to be distributed.
- Overall, according to the baseline scenarios considered, for all market case studies the total cradle-to-filler out-gate fossil global warming potential impact of WPP sacks for 50kg of cement is approximately twice as high as the fossil global warming potential impact of paper sacks for 50kg of cement.

5.2 Sensitivity and uncertainty analysis

As in any LCA study, there are a number of data points, assumptions and methodological choices which have the potential to significantly influence the results. The following uncertainties and sensitivities have been investigated, using the Ivory Coast market study to indicate the likely influence of the various parameters on the results achieved and conclusions drawn:

- Alternative LCI data for sack kraft paper – in the base case, LCI data has been derived from CEPI Eurokraft's own study compiling an average life cycle inventory for sack kraft paper in Europe (RISE, 2023a). This source was chosen as it is well known to the industry and is trusted as being representative of the average European production. However, the data considered for WPP is sourced from Ecoinvent 3.10. The CEPI Eurokraft LCI data has also been implemented in Ecoinvent 3.10, and as different methodological choices by different LCA practitioners (e.g., allocation rules, etc) can generate different results a sensitivity scenario is investigated applying the Ecoinvent 3.10 dataset for sack kraft paper.
- Alternative LCI data for converting of paper sacks – in the base case, LCI data has been derived from Eurosac's own study compiling an average life cycle inventory for paper conversion in Europe (RISE, 2023b). This source was chosen as it is well known to the industry and is trusted as being representative of the average European production. It quantifies the electricity required for paper sack converting at 0.020kWh per sack. This value has been fairly consistent over six iterations of the study since 2007, and is therefore deemed to be highly representative of practical experience. However, the reference in the literature used as the source of data for the electricity required for producing WPP sacks lists the electricity required for paper sack converting at 0.12kWh per sack (Ma, Li, & Li, 2019). This value does not reflect the experience of the project steering group, but has nonetheless been applied in a sensitivity analysis to investigate the potential influence of this value.
- Alternative LCI data for sack kraft paper and alternative LCI data for converting paper sacks – in this scenario, both the Ecoinvent data for sack kraft paper and the alternative data for paper sack converting described above is applied.
- Lower and higher base weight sack kraft paper – in the base case, a two ply paper sack is considered with each ply consisting of 85gsm sack kraft paper. Paper sacks can be produced using a variety of base weight papers. In these sensitivity scenarios, a low base weight solution (two plies consisting of 80gsm sack kraft paper) and a high base weight solution (two plies consisting of 95gsm sack kraft paper) are considered.

- WPP sacks incorporating 30% recycled content – in the base case, a 100% virgin WPP sack has been considered. However, sacks are available on the market which contain a proportion of recycled content. In this sensitivity scenario, a 30% recycled content WPP sack is investigated. It is known that WPP sacks incorporating recycled content require more material in order to achieve the same physical properties as 100% virgin WPP sacks. However, in order to be conservative in the modelling the recycled content WPP sack weight has been assumed as the same as a virgin WPP sack. Anecdotal evidence from the study steering group suggests that most of the recycled PP granules used for recycled content in Ivory Coast are imported from India.
- Low weight (best-in-class) WPP sacks – in the base case, a WPP sack weight of 67g is considered. In the experience of the project steering group, this is a representative weight for WPP cement sacks for 50kg of cement. However, the steering group is also aware of lower weight sacks in the market. Best-in-class has been identified as 64g, which is investigated in this sensitivity scenario.
- PE laminated WPP sacks – in the base case, the WPP sacks are considered to be manufactured solely from PP, but the project steering group is aware of PE laminated WPP sacks in the market. In this sensitivity analysis, a PE laminated WPP sack is considered, assuming the following specifications: 32g PP, 32g PE, 0.96g calcium carbonate, 2g ink.
- Recycling of process waste rate for WPP sack production – in the base case, it is assumed that all process waste during the WPP sack production process is reused within the sack plant, displacing an input of virgin PP granules (a closed loop recycling process). This is certainly the case in some WPP sack plants, but in some cases process waste may be sold to third parties for recycling offsite (an open loop recycling processes) or sent for disposal in cases where there is no market. In this scenario, it has been assumed that the process waste is sent for recycling by a third party, and therefore it no longer displaces an input of virgin PP. The quantity of virgin PP used to manufacture the sacks is therefore increased. A process waste rate from WPP sack manufacturing of 7% is considered, based on anecdotal evidence from the project steering group.

Figure 11 summarises the results of the sensitivity and uncertainty analysis.

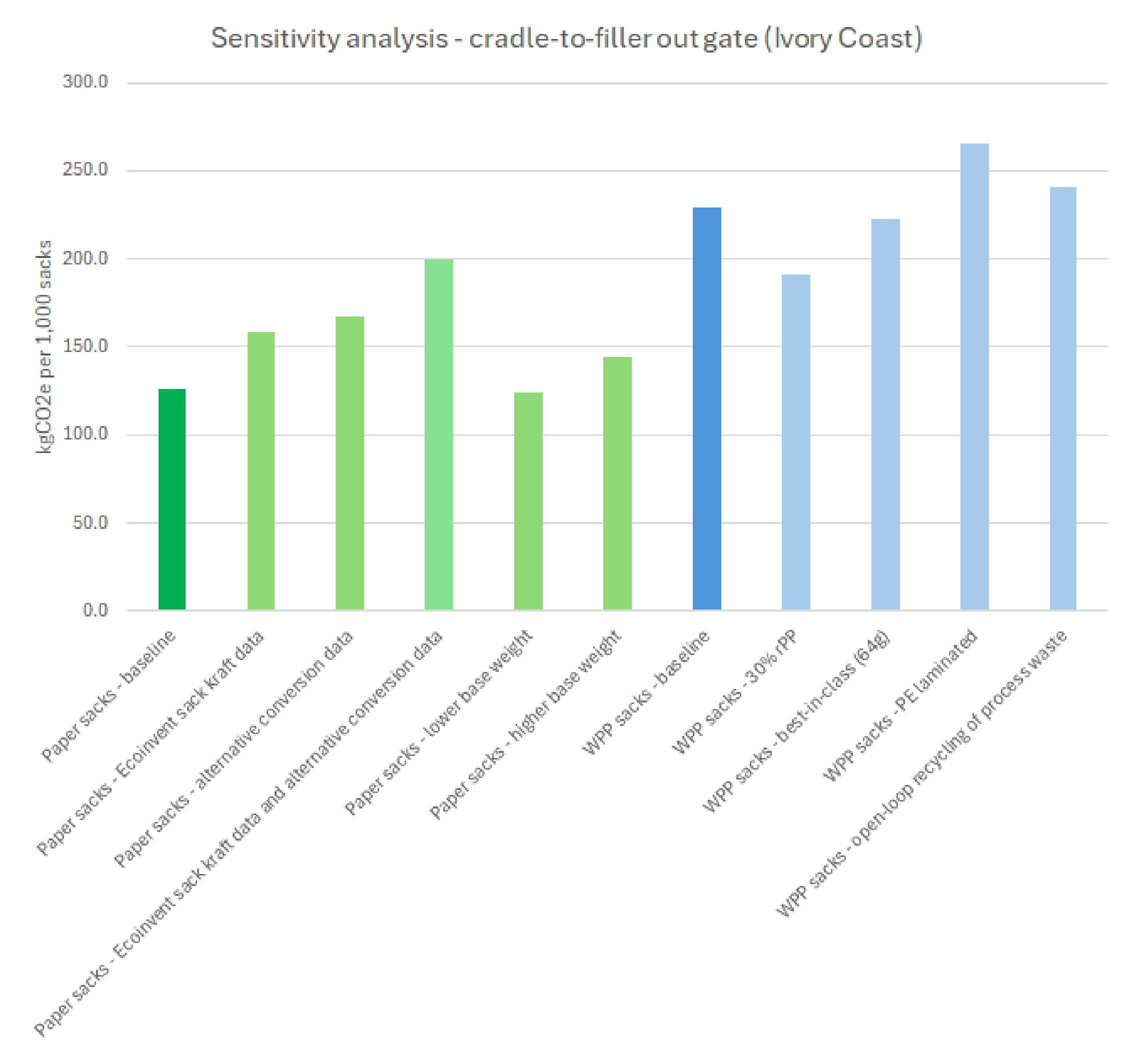


Figure 11 Results of the sensitivity and uncertainty analysis

Overall, the sensitivity and uncertainty analysis suggests that the results achieved and conclusions drawn for the baseline studies are very robust. For almost every scenario considered, the fossil GHG emissions from paper sacks are nearly 20% lower than the fossil GHG emissions from the best case WPP sacks scenario (WPP sacks incorporating 30% recycled content. If the very worst case scenario for paper sacks is considered (considering the Ecoinvent LCI data for sack kraft paper production and the unrealistically high alternative conversion data for sack converting) then there is no significant difference between paper sacks and WPP sacks (differential <5%, which is not considered significant given the inherent uncertainties in LCA modelling).

5.3 Additional scenario – considering product waste

Laboratory testing organised by CEPI Eurokraft indicates that losses during the filling operation and handling afterwards are considerably higher from WPP sacks compared to paper sacks for cement. The losses are summarised in Table 7 below.

Table 7 Cement losses during filling and handling[3]

	50kg paper cement sack	50kg WPP cement sack
Cement losses from sack filling (grams of cement per sack)	0.24	0.95
Cement losses from sack handling (grams of cement per sack)	2.20	8.60
Cement losses – total (grams of cement per sack)	2.24	9.55
Cement losses – total (%)	0.005%	0.019%

The effect of including the impact of the production of these cement losses within the system boundaries is presented in Figure 12.

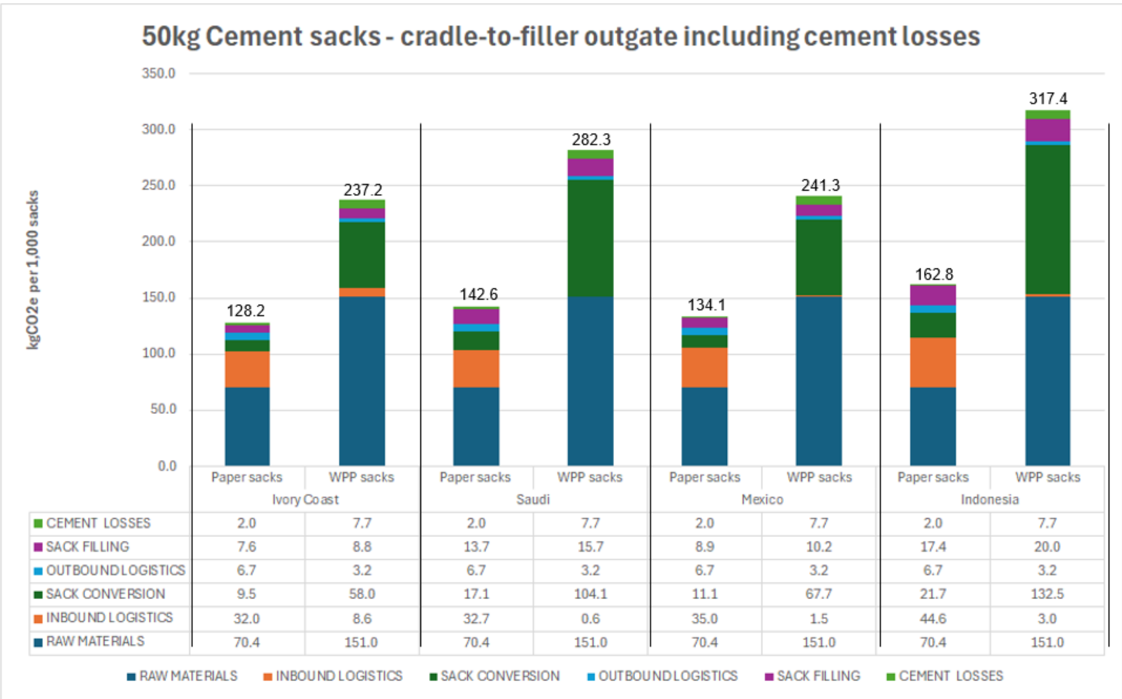


Figure 12 Results including the production of cement losses within the system boundaries

For the paper cement sacks, including the cement losses in the system boundaries increases the global warming potential for each case study by 2.0kgCO2e per 1,000 sacks. For the WPP cement sacks, the higher filling and handling losses contribute to an increase of 7.7kgCO2e per 1,000 sacks. The effect of including the impact of the

[3] Private communication with CEPI Eurokraft. The full test details will be published during 2025 at www.cepi-eurokraft.org

production of cement lost during filling and handling in the system boundaries is to further increase the differential between paper sacks and WPP sacks.

5.4 Study limitations

As with all life cycle studies, there are limitations that should be appreciated by the reader when considering the results. For this study in particular, two limitations are highlighted:

- Cradle-to-gate system boundaries – the study considers the fossil GHG emissions associated with each packaging solution from the cradle to the filler out-gate. A more complete comparison would include end-of-life management of the sacks after use. However, data could not be secured as to the end-of-life fate of paper sacks or WPP sacks for the markets case studies considered. In any case, waste management policy and infrastructure is currently immature in most of the case study markets considered and is likely to be subject to significant change in the future.
- Focus on fossil GHG emissions – the study focuses on the climate change impact category, considering only fossil GHG emissions across the life cycle. Other impacts also occur across the life cycle which are not considered in this analysis, such as acidification, eutrophication, resource consumption, etc. The comparative standing of the solutions may be different for other impact categories, and trade-offs in life cycle impacts would be required.
- Some environmental impacts do not currently lend themselves to quantification and analysis through life cycle assessment. For example, littering and microplastics generation are impacts that are not currently quantified through life cycle assessment. These are impacts that could be very relevant to the comparison of the studied systems, but they have not been addressed in this study.

5.5 Conclusions

This study calculates and compares the cradle-to-filler out-gate fossil carbon footprint of paper sacks against cross bottom construction sacks with valve/ pasted valve sacks made from WPP for 50kg of cement. Representative case studies are considered for four specific markets:

- Africa – represented by a case study considering Ivory Coast
- Middle East - represented by a case study considering Saudi Arabia
- South/Central America – represented by a case study considering Mexico
- South East Asia – represented by a case study considering Indonesia.

The study is based on best available information relating to each packaging solution, and realistic scenarios for the value chains for paper sacks and WPP sacks in each market case study.

The results show that the fossil GHG emissions associated with WPP sacks are approximately double those associated with the equivalent paper sack in each market. Sensitivity and uncertainty analysis shows that the results achieved and conclusions drawn are robust.

Including the impact of the production of cement lost during filling and handling in the system boundaries further increases the differential between paper sacks and WPP sacks.

The comparison could be improved if information and data were available that facilitated the extension of the system boundaries to cover the end-of-life of the used sacks. Inclusion of other impact categories in the analysis would also provide insights into the environmental trade-offs to consider when choosing between paper sacks and WPP sacks for 50kg of cement.

Nonetheless, it can be stated with confidence that choosing paper sacks over WPP sacks for 50kg cement significantly reduces the cradle-to-gate climate change impact of cement packaging.

6 References

Eurosac and CEPI Eurokraft. (2016). Paper Sacks Meet High Demands. *World Cement*.

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Annex: Critical Review Statement

CRITICAL REVIEW STATEMENT

Comparative carbon footprint study:
Paper sacks versus woven PP sacks in markets outside Europe

Report prepared by Michael Sturges RISE on behalf CEPI Eurokraft

RISE Bioeconomy Report No: 2402-326

This is the critical review summary statement designed to be included in the LCA report:

Critical review statement

An independent critical review has been undertaken of this comparative carbon footprint study carried out by RISE (Research Institutes of Sweden), commissioned by CEPI Eurokraft. The carbon footprint study compares paper sacks versus polypropylene sacks for cement and other powdered products.

The report is believed to represent, on the basis of available data, a fair, reasonable and accurate identification of the potential impacts related to the products under study. The report has been prepared according to the principles of the LCA standards ISO 14040:2006/AMD 1:2020 and ISO 14044:2006/AMD 2:2020, taking into account the assumptions and limitations highlighted in the report.

Within the limits of the review, the reviewer agrees with the report's findings and conclusions. The reviewer finds that the work has been carried out with attention to detail, experience and expertise. The data used, quality and applicability are accurately described in the report. The system boundaries, processes that have been included and excluded, and overall methodology, are considered appropriate. As far as the reviewer can determine, impact calculations have been carried out accurately.

In conclusion, the study and its results are considered to be robust. The conclusions reached are judged to be sound and fair. The report is likely to provide useful evidence to support the selection of lower carbon intensity sacks for cement and similar powdered products.

Gary Parker
Director
Sustainability in Metrics
12 February 2025

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RISE Research Institutes of Sweden / RISE Innventia AB
Box 5604, 114 86 STOCKHOLM, Sweden
Telephone: + 46-8-676 70 00
E-mail: info.innventia@ri.se, Internet: www.ri.se

Bioeconomy and Health
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