Comparison of Morrisons' Reusable Paper Bags and Plastic Bags for Life

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-- Prepared for Morrisons --

Executive Summary and Recommendations

This report compares Morrisons' reusable paper bags and plastic bags for life, on a whole life cycle, cradle-to-grave, basis. The analysis was carried out in accordance with both ISO14040 and the Product Environmental Footprint (PEF).

Interpretation of Results

We recommend comparing the impacts of plastic bags with the impacts of paper bags plus recycling of back of store plastic. This ensures a fair comparison – in the paper bag case the back of store plastic is still produced and must still be collected, sorted and recycled. We also recommend using the avoided burden approach for analysis of results – this takes into account the global impacts and includes all stages of the process. The cut-off approach, which does not include production of secondary material, and cuts off after sorting and before recycling and any associated credits at end-of-life, is more representative of the impacts that Morrisons has direct control over and, whilst a valid assumption to make, is not as complete a comparison.

We do not recommend including biogenic carbon (carbon taken in by biomass as it grows) in the analysis – this is the default recommendation of the ReCiPe method for impact assessment. In addition, inclusion of biogenic carbon can give confusing results when using the avoided burden approach and if the trees were growing anyway then it is hard to justify that those that were chopped down for paper production sequestered more CO_2 than would have been sequestered anyway. Indeed, chopping down trees to make paper can reduce uptake of CO_2 in the long term as those trees are no longer there.

Key Results

In the majority of cases considered, the paper bag (taking into account the processing of back of store plastic) has lower impacts than the plastic bag, including for global warming potential (equivalent to carbon footprint) and water consumption. Ozone formation, ionizing radiation and land use are all higher for the paper scenario (due to the Swedish electricity mix and the growing of trees). If the proportion of plastic bags that are recycled increases, then the global warming potential drops and becomes very similar to the paper scenario. Using an unbleached bag (assuming the same weight of paper is used) decreases both the global warming potential and the water consumption.

Using renewable electricity (as opposed to grid average) has a very small impact (< 3%) at the paper bag making facility due to the small amount of electricity used, whereas at the plastic bag recycling facilities impacts are reduced by up to 12%.

Reuse and end-of-life

By far the biggest reduction in the carbon footprint, and other impacts, of the bags is achieved by reusing the bags, preferably at least 5 times. If Morrisons' are to do one thing to reduce the footprint of the bags-for-life then it should be to encourage reuse. Consideration should be given to signs and messaging, in store, in carparks and in adverts. Normalising reuse is key.

Secondarily, ensuring the correct end-of-life pathway is important i.e. ensuring that paper bags go in paper recycling and that plastic bags are recycled in an appropriate way. For paper bags clear messaging to be put in paper recycling (and not just recycling) is important. Correct recycling of plastic bags is a bigger challenge as different local authorities have different recycling schemes for LDPE. None the less, encouraging recycling of these is key and there is clear room for improvement (baseline 22%).

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1 Goal and Scope

This study was commissioned by Morrisons to compare the environmental impacts of the use of paper and plastic bags. The results are intended to be used by Morrisons to consider the type of bags they offer customers and to understand the impacts of customer decisions. This work has been carried out in compliance with ISO14040 and ISO14044 and the Product Environmental Footprint.

The goal of this study is to compare the environmental impacts of Morrisons' plastic bags for life and reusable paper bags, from cradle to grave. The plastic bags are made from predominantly recycled low density polyethlylene (LDPE), produced by JayPlas in the UK, whilst the paper bags are bleached fibre form paper, made by AB Group Packaging in the UK using paper from Billerud Korsnäs in Sweden. The paper and plastic bags have almost the same volume (~18 litres) and are therefore assumed to substitute each other in the ratio 1:1.

The LDPE bags contain 94% recycled material, which comes from the sorting and processing of back of store plastic. At end-of-life, some bags will be recycled, but the majority are assumed to go to incineration with heat and electricity recovery. Paper bags are made from virgin wood which is turned into fibre form paper then folded and glued to form the bag. The contrary end-of-life pathway is assumed for the paper bags, with the majority going to recycling and some going to incineration.

For the paper bag scenario, the back of store plastic still exists and must be processed. For this reason, two paper scenarios are included in the analysis – one considering just the paper bag and ignoring the back of store plastic (termed "paper") and one considering both the paper bag and the processing of the equivalent amount of back of store plastic as used in the plastic scenario (termed "paper + film"). A true comparison of the same system boundaries would compare the plastic scenario with the paper + film scenario.

The default allocation system used in the model is avoided burden (the producer of any recyclable material is responsible both for the recycling activity and any credits/burdens associated with the disposal; any input of secondary material has a burden of primary material associated with it). For comparison, results using the cut-off allocation method are also given (no credit is given at end-of-life and there is no associated burden of producing any secondary material used). The system boundaries considered for both the avoided burden and cut off methods are given in **Error! Reference source not found.** and Figure 2. The processes excluded in the cut-off approach are semi-transparent. Processes falling under the production category are shown in blue, while those falling under the end-of-life are shown in green.

1.1 Functional unit

The functional unit is "production and disposal of 98,902,544 bags (volume 18 L) sold in Morrisons' stores over a period of one year". The number of bags is determined by using an average weekly bag consumption (personal communication, Natasha Cook, 10 Nov) multiplied by 52 to ascertain the demand for a whole year.

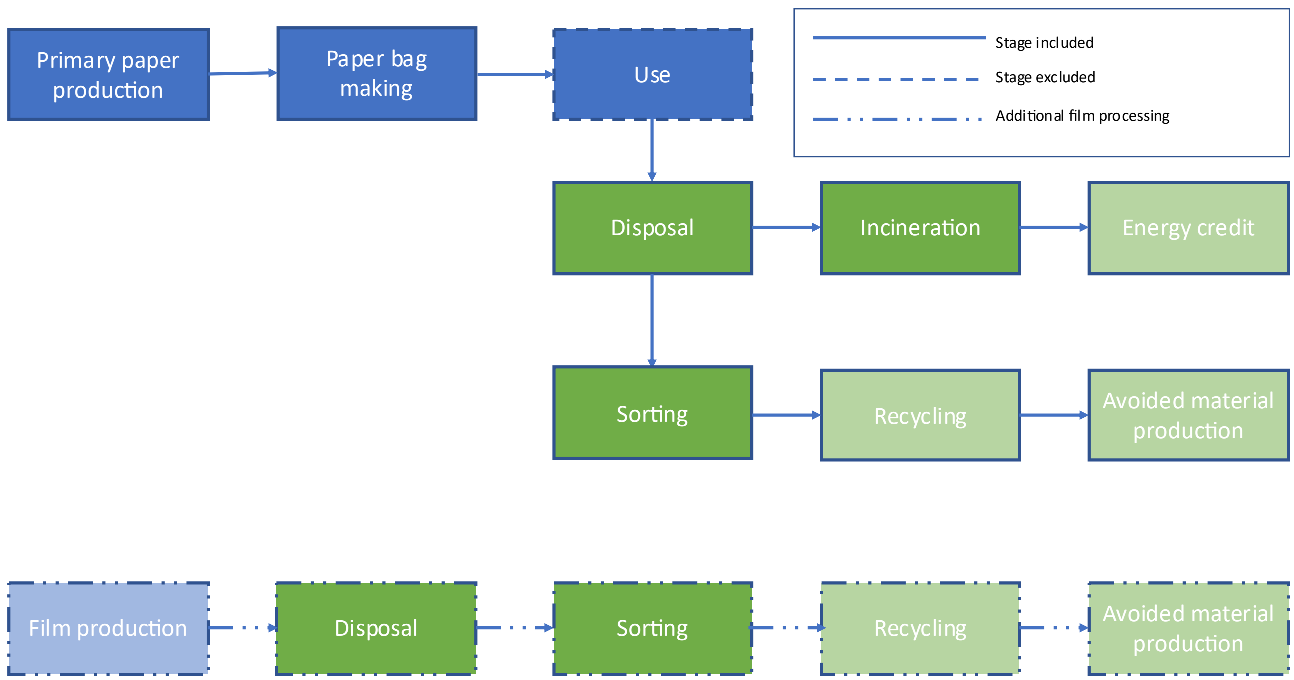

Figure 1: Block diagram of the paper system showing the system boundary. Processes included in the paper scenario have a solid outline; the paper + film includes both processes with a solid outline and those with a dash-dot outline. All processes shown (except use) are included in the avoided burden method, whereas the cut off method excludes those that are semi-transparent.

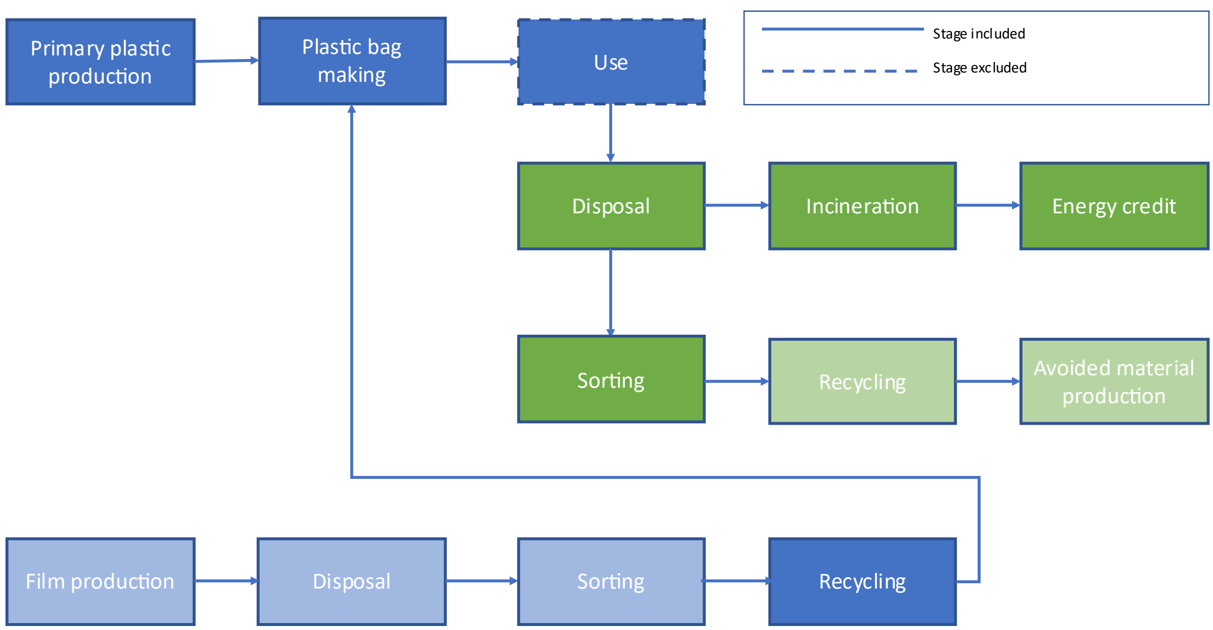

Figure 2: Block diagram of the plastic system showing the system boundary. All processes shown (except use) are included in the avoided burden method, whereas the cut off method excludes those that are semi-transparent.

2 Life Cycle Inventory

The life cycle inventory is given in Table 1 and Table 2.

Raw data was collected directly from players in the supply chain wherever possible. Remaining data and processes used for modelling were taken from the Ecoinvent 3.6 database unless stated otherwise. The recycling rates in Table 1 are taken from the Government Statistical Service (2020) for paper and WRAP (2016) for plastic.

Multifunctionality is solved by a mix of allocation and system expansion with the latter applied where possible. The end-of-life is modelled so that the products of recycling (material) and/or incineration (heat and electricity) are credited to the system in the avoided burden approach. Allocation by mass is applied for all transport except on route from Morrisons' depots to the stores, where allocation by volume is applied as the trucks on this route transport a variety of goods with different density and the transport is volume limited.

Although the default approach is avoided burden, the cut-off approach is used for sensitivity analysis, in which each process in the table has been substituted with its Cut-Off substitute. The point of Cut-Off is the sorting of the material (see Figure 1 and Figure 2). The producer of the waste is responsible for delivering the material to the sorting facility and sorting it, and this sorted material is available for the consumer burden free. Secondary production starts with collection of this sorted material.

Table 1: Basic information about the two types of bags

Property	Plastic bag	Paper bag
Material	LDPE	Bleached paper
Mass [g]	39	80
Recycled content [%]	94	0
Recycling rate [%]	22	79

Table 2: Life cycle inventory used in the study

Activity		Process	Amount	Comments
Paper bags				
Paper production		Kraft paper, bleached {RER}| production | APOS, U	80 g/bag	The process has been modified, as discussed in section 2.1 and Table 3.
Back of store film		Packaging film, low density polyethylene {GLO}| market for | APOS, U	1 kg/ 1 kg of film needed in the plastic scenario	This is included in the paper + film scenario
Paper bag making		Making of a bag from paper	1 p/bag	The process has been made using the available processes in SimaPro: Paper bag ink, Adhesive, Shrink Wrap and Electricity
	Paper bag ink	Ink for bags	1.6 g/p of "Paper bag making"	The process has been made using the available processes in SimaPro: Bag ink (without water) and water for ink.
	Bag ink (without water)	Printing ink, offset, without solvent, in 47.5% solution state {RER}| market for	0.41 kg/kg of "Paper bag ink"	

		printing ink, offset, without solvent, in 47.5% solution state | APOS, U		
	Water for ink	Water, deionised {Europe without Switzerland}| market for water, deionised | APOS, U	0.59 kg/kg of "Paper bag ink"	
	Adhesive	Adhesive for paper bags	2.15 g/p of "Paper bag making"	The process has been made using the available processes in SimaPro: wheat starch, water, calcium and polyvinyl acetate
	Wheat starch	Wheat starch, from wet milling, at plant/UK Economic	0.15 kg/kg of "Adhesive for paper bags"	
	Water for the adhesive	Water, deionised {Europe without Switzerland}| market for water, deionised | APOS, U	0.7 kg/kg of "Adhesive for paper bags"	
	Calcium in the adhesive	Calcium chloride {RER}| market for calcium chloride | APOS, U	0.02 kg/kg of "Adhesive for paper bags"	
	Polyvinyl acetate	Vinyl acetate {RER}| production | APOS, U	0.13 kg/kg of "Adhesive for paper bags"	
Shrink wrap used as secondary packaging for paper bags		Packaging film, low density polyethylene {GLO}| market for | APOS, U	0.35 g/1 p of "Paper bag making"	
Hydro electricity used in paper bag making		Electricity, high voltage {GB}| electricity production, hydro, run-of-river | APOS, U	1.5 Wh/1 p of "Paper bag making"	Assumption that 50% of the electricity comes from hydro, run-of-river type.
Wind electricity used in paper bag making		Electricity, high voltage {GB}| electricity production, wind, 1-3MW turbine, onshore | APOS, U	1.5 Wh/1p of "Paper bag making"	Assumption that 50% of the electricity is wind from 1-3 MW turbines.
Waste incineration of paper		Waste paperboard {CH}| treatment of, municipal incineration with fly ash extraction | APOS, U	0.21 kg/ 1 kg of total waste paper	The process has been modified to include the energy recovery credits. See section 2.4
Avoided burden of production of recycled paper		Paper, woodfree, uncoated {RER}| paper production, woodfree, uncoated, at non-integrated mill | APOS, U	1 kg/ 1kg of produced recycled paper	An assumption is made that recycled paper offsets the virgin paper in 1:1 proportion.
Production of recycled, woodfree, coated paper		Paper, woodfree, uncoated {CA-QC}| paper production, woodfree, uncoated, 100% recycled content, at non-integrated mill | APOS, U	1.355 kg/1 kg of waste paper.	The energy source changed to match the geographic location, assuming the recycling takes place in UK. The underlying deinked pulp

			process changed. The amount of recycled paper made from recycled paper based on yields of underlying processes (Wernet et al. 2016).
Pulp making from waste paper	Waste paper, unsorted {CA-QC}| treatment of waste paper to pulp, wet lap, totally chlorine free bleached | APOS, U	0.79 kg/ kg of Paper, woodfree, uncoated {CA-QC}| paper production, woodfree, uncoated, 100% recycled content, at non-integrated mill | APOS, U 1 kg of waste paper used to make 1.076 kg deinked pulp as per (Wernet et al. 2016)	Input as per original process. The pulp making process has been modified to better reflect the British heat and electricity mix.
Plastic bags			
Virgin LDPE production	Polyethylene, low density, granulate {GLO}| market for | APOS, U	0.06 kg/ 1 kg of plastic bag	The amount reflects the virgin content in a bag
Production of plastic bag from sorted and virgin plastic	Polyethylene, high density, granulate, recycled {Europe without Switzerland}| polyethylene production, high density, granulate, recycled | APOS, U	39 g/bag	The process has been modified using the actual water, electricity and gas usage of the facility. The necessary transport is included in the process. An additional input of antifoam included. See section 2.2 for details.
Sorted back of store plastic	Waste polyethylene, for recycling, unsorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | APOS, U	0.99 kg/ 1 kg of plastic bag	The input of the electricity and heat values adjusted as per data from Jayplas. The input value based on data on loses provided by Jayplas.
A negative avoided burden of back of store recycling	Polyethylene, low density, granulate {GLO}| market for | APOS, U	1.1 kg/ 1 kg of sorted plastic	The input value based on information provided by Jayplas.
The incineration of plastics with credit	Waste polyethylene {CH}| treatment of, municipal incineration with fly ash extraction | APOS, U	0.78kg/1 kg waste plastic	The additional avoided burden of electricity and heat generated have been accounted for.

Sorting of plastic bags	Waste polyethylene, for recycling, unsorted {Europe without Switzerland}| market for waste polyethylene, for recycling, unsorted | APOS, U	1.17 kg of waste plastic/1 kg of recycled granulate	The input amount recalculated as per losses reported in the database.
The recycling of waste plastic bags	Polyethylene, high density, granulate, recycled {Europe without Switzerland}| polyethylene production, high density, granulate, recycled | APOS, U	1 kg/1 kg of recycled plastic	
Avoided burden of plastic recycling	Polyethylene, low density, granulate {GLO}| market for | APOS, U	1 kg/1 kg of produced granulate	

2.1 Paper bag production

The base process for paper production is "Kraft paper, bleached {RER}| production | APOS, U". Certain changes have been applied to reflect better the production process, as listed in Table 3.

Table 3: Changes applied to the Ecoinvent process for Kraft paper production to model the paper making

Aspect	Original process	Alteration made	Comments
Electricity mix	Electricity, medium voltage {RER}| market group for | APOS, U	Electricity, medium voltage {SE}| market for | APOS, U	The change reflects the average grid electricity in Sweden.
Sulfate pulp origin	Sulfate pulp, bleached {RER}| sulfate pulp production, from hardwood, bleached | APOS, U	Sulfate pulp, bleached {RER}| sulfate pulp production, from softwood, bleached | APOS, U	The sulfate pulp is changed to be from softwood, pine, using the process "Pulpwood, softwood, measured as solid wood under bark {SE}| softwood forestry, pine, sustainable forest management | APOS, U"
Electricity for sulfate pulp making	Electricity, high voltage {RER}| market group for | APOS, U	Electricity, high voltage {SE}| market for | APOS, U	The change reflects the average grid electricity in Sweden.

The bag making process was modelled using information from AB Group Packaging. The inputs to the process (other than the paper), per bag, are listed in Table 4.

Table 4: Inputs of the paper bag making process

Input	Amount (per bag)
Shrink wrap	0.35 g
Adhesive	2.15 g
Ink	1.6 g
Electricity	3 Wh

The shrink wrap is used to wrap paper bags in packs for transportation and is modelled using the process "Packaging film, low density polyethylene {GLO}| market for | APOS, U".

Adhesive:

The precise composition of the adhesive could not be determined; however it is known that it is wheat starch based and contains about 85% water and starch combined and the remaining constituents are polyvinyl acetate and a calcium compound (K. Hodgkiss 2020, personal communication, 22nd December). The assumed composition of the adhesive, along with the processes used for each component are presented in Table 5. The composition of each component is assumed based on Gadhave et al. (2019).

The production of adhesive from the components is considered negligible. The main environmental burden is assumed to be associated with preparing the chemicals for the adhesive, not the actual production of the adhesive from the components.

Table 5: Assumed composition of adhesive

Component	Weight percentage	Process used
Water	75	Water, deionised {Europe without Switzerland}| market for water, deionised | APOS, U
Wheat starch	10	Wheat starch, from wet milling, at plant/UK Economic
Polyvinyl acetate	13	Vinyl acetate {RER}| production | APOS, U
Calcium	2	Calcium chloride {RER}| market for calcium chloride | APOS, U

Ink:

Ink is modelled using "Printing ink, offset, without solvent, in 47.5% solution state {RER}| market for printing ink, offset, without solvent, in 47.5% solution state | APOS, U" and "Water, deionised {Europe without Switzerland}| market for water, deionised | APOS, U" as the solvent.

Electricity:

Based on information from AB Group Packaging, the electricity need is taken as 3 Wh/ bag. The electricity mix is 100% renewable and comes mainly from wind and hydro energy, however the precise composition could not be determined. A 50-50 split between wind and hydro is therefore assumed, with details presented in Table 6. The impacts of this electricity are negligible for the bags, therefore the exact split between renewable electricity types is not important.

Table 6: Electricity demand of the paper bag making process

Component	Process	Amount
Hydro power	Electricity, high voltage {GB}| electricity production, hydro, run-of-river | APOS, U	1.5 Wh
Wind power	Electricity, high voltage {GB}| electricity production, wind, 1-3MW turbine, onshore | APOS, U	1.5 Wh

In the scenario where paper + film scenario, the film processing is modelled in exactly the same way as the plastic bag production, except this process ends with an avoided burden of producing polyethylene film, modelled as “Packaging film, low density polyethylene {GLO}| market for | APOS, U”.

2.2 Plastic bag production

The bag manufacturing is modelled using a modified version of Polyethylene, high density, granulate, recycled {Europe without Switzerland}| polyethylene production, high density, granulate, recycled | APOS, U. The following changes have been applied:

- European electricity mix has been substituted with Electricity, low voltage {GB}| market for | APOS, U and the amount has been changed according to the data from Jayplas. The same was applied to heat. The propane input to the process has been removed.
- The underlying water usage and wastewater treatment changed according to the data obtained from JapPlas.
- The input of sorted film to the process is scaled so that 5% of the initial input does not end up in the product and is sent to municipal solid waste market, without any credits. Although 80% of the sorted film is converted to bags and the remaining 15% are used to make other products, the total of 95% of the plastic is allocated to the bags. This reflects well the usability of the 95% of the material and avoids expanding the system further, without specific knowledge about the system to be accounted for. The additional input of antifoam is added according to the information from Jayplas. The remaining chemicals are assumed to be already included in the process.
- The virgin material input is modelled using “Polyethylene, low density, granulate {GLO}| market for | APOS, U”. Overall, 1 kg of bags is taken to require 0.06 kg of virgin polyethylene and about 0.99 kg of secondary, sorted, LDPE granulate. This therefore assumed no losses specifically related to the virgin input and 5% loss of sorted secondary LDPE as explained above.

The sorting process is modelled using “Waste polyethylene, for recycling, unsorted {Europe without Switzerland}| market for waste polyethylene, for recycling, unsorted | APOS, U” and by changing the underlying process “Waste polyethylene, for recycling, unsorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | APOS, U”. The following modifications were made:

- 10% material losses. This material is left after sorting and is sent to energy recovery facility. The ERF is modelled using Waste polyethylene {CH}| treatment of, municipal incineration with fly ash extraction | APOS, U, whereby a credit of 1.5428 kWh of Electricity, medium voltage {GB}| market for | APOS, U is added, as well as 10.694 MJ of Heat, district or industrial, natural gas {RER}| market group for | APOS, U. Those figures are as per the unlinked process (Wernet et al. 2016). As per avoided burden approach, the system receives a burden of consumption of primary material for recycling. In case of plastic scenario, this is bag-of-store film used in the Morrisons’ depots. The production of the back of store film is modelled using “Packaging film, low density polyethylene {GLO}| market for | APOS, U”.
- The underlying electricity and heat consumption have been substituted with the electricity demand obtained from (personal communication Mike Maxwell 5th Feb 2021).

2.3 Transport modelling

Table 7 presents the approach used to model the foreground transport processes, with the comments section being explained in Table 8. The transport distances for the vast majority of the routes have been calculated using Google Maps, finding the fastest route between two locations, or on the basis of information supplied by the respective stakeholders. The transport distances on route from the local warehouses to the stores are calculated using the data from Morrison’s in the following way: The distance between the warehouses and the stores was first established in a straight line using the pgeocode library in Python. Then, a sample of 20 routes was taken and the true distances calculated using the postcodes and Google Maps (choosing the "Fastest route option" irrespective of distance). The ratio of true distances to the straight-line distances was averaged to give about 1.3. All distances were then calculated by multiplying the straight-line distance by 1.3. The average distance for plastic and paper bags was calculated as a weighted average using the number of bags of both types delivered per week.

The distance the paper bags travel between the warehouses, as well as the distance of delivered/collected plastic from multiple facilities is calculated as a weighted average distance between different warehouses and the respective facilities.

The transport undertaken by Morrisons' trucks is modified to account for the true payloads in one way and on the return. The process is modified using the HBEFA 4.1 database, assuming an average traffic situation and temperature distribution for Germany and considering Articulated trucks with EURO 6 emissions standard running on diesel. All the entries of the inventories have been adjusted using the mentioned database, Ntziachristos et al. (2019) and the formulas provided by ecoinvent in the respective entries, except for road and road maintenance entries, where no specific formula could be found. The transport is volume-limited and hence allocated by volume, based on the number of pallets used for each type of bag. The truck collects material from stores, such as crates, pallets and food waste. This payload has been considered by assuming an average mass of 2 tonnes on the way back. The transport is however fully allocated among the products being transported one way.

A similar approach is used for the transport of sorted plastic to the wash plant and of washed plastic to the granulation facility, to account for higher than usual payload.

Table 7: Foreground transport routes and associated processes.

Route	Vehicle details	Distance one way [km]	Process used	Comments
Paper Scenario				
Karlsborg-Kemi	Truck with trailer, 50-60t, HVO 19.3	83	Transport, freight, lorry >32 metric ton, EURO5 {RER}| transport, freight, lorry >32 metric ton, EURO5 | APOS, U	1)
Kemi-Tillbury	Ro-Ro ship	2493	Transport, freight, inland waterways, barge tanker {RER}| processing | APOS, U	2)
Tillbury-Paper bag manufacturing site	Truck with trailer, 34-40t	355	Transport, freight, lorry >32 metric ton, EURO5 {RER}| transport, freight, lorry >32 metric ton, EURO5 | APOS, U	1)

Paper manufacturing site - Main Morrison's depot	Articulated truck, >32t	241	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	2)
Main Morrison's depot - Local depots	Articulated truck, >32t. The weight of an empty vehicle estimate to be 18 tonne, the average payload estimated to be 7 tonne (both ways)	232	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	4)
Local depot - store	Articulated truck, >32t. The weight of an empty vehicle estimate to be 18 tonne, the average payload estimated to be 7 tonne (both ways)	78	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	4)
Transport from customer to the end-of-life facility	Truck, 16-32 t	100	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	3)
Plastic Scenario				
Jayplas manufacturing site - Local Morrison's depots	Articulated truck, 15.25 tonne empty weight. Average paylaod of 17 tonnes (both ways)	217	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	2)
Local Morrison's depots - Store	Articulated truck, >32t. The weight of an empty vehicle estimate to be 18 tonne, the average payload estimated to be 7 tonne (both ways)	78	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	4)
Transport from customer to the end-of-life facility	Truck, 16-32 t	100	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	3)
Transport of back-of-store film from local Morrison's depots to Jayplas sorting centre	Articulated truck, 15.25 tonne empty weight. Average payload of 17 tonnes (both ways)	217	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	2)

Transport of sorted plastic to the wash plant	Articulated truck, 15.25 tonne empty weight. Average paylaod of 28 tonnes (both ways)	78	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	1)
Transport of washed plastic to the granulation facility	Articulated truck, 15.25 tonne empty weight. Average paylaod of 28 tonnes (both ways)	77	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	1)
Transport of granulate to the bag manufacture site	Articulated truck, 15.25 tonne empty weight. Average payload of 17 tonnes (both ways)	142	Transport, freight, lorry >32 metric ton, EURO6 {RER}| transport, freight, lorry >32 metric ton, EURO6 | APOS, U	2)

Table 8: Explanations of the comments column in Table 7.

1)	The mentioned process was changed based on the emissions provided by the respective party
2)	Process chosen to best fit the emissions/ details of the transport based on data provided by the respective party
3)	The transport route based on assumptions
4)	The mentioned process was changed based on the details provided by Morrison's and allocated by volume

2.4 End-of-life

The end-of-life of plastic is modelled slightly differently to the production of recyclate at the start of the cycle. This is due to the fact that both paper and plastic bags are not disposed of in one, particular place and are not processed in one particular facility, hence the ‘market' of activities in Simapro is more applicable.

The sorting activity is modelled using “Waste polyethylene, for recycling, unsorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | APOS, U” and the production of recycled granulate is modelled using “Polyethylene, high density, granulate, recycled {Europe without Switzerland}| polyethylene production, high density, granulate, recycled | APOS, U” with the avoided burden modelled as “Polyethylene, low density, granulate {RER}| production | APOS, U”.

The incineration of “Waste polyethylene {CH}| treatment of, municipal incineration with fly ash extraction | APOS, U”. Additional credits of 1.5428 kWh of “Electricity, medium voltage {GB}| market for | APOS, U” and 10.694 MJ of “Heat, district or industrial, natural gas {RER}| market group for | APOS, U”, as in case of the energy recovery of the remaining material at the production stage.

The paper recycling is modelled using “Paper, woodfree, uncoated {CA-QC}| paper production, woodfree, uncoated, 100% recycled content, at non-integrated mill | APOS, U”. The energy inputs have been substituted with processes specific where possible to Great Britain, and, if not available, to Europe without Switzerland. The same applied to the underlying process for the deinked pulp production. The avoided burden is assumed to be “Paper, woodfree, uncoated {CA-QC}| paper production, woodfree, uncoated, 100% recycled content, at non-integrated mill | APOS, U”.

3 Life Cycle Impact Assessment

SimaPro 9.1 was used to model the system. The ReCiPe 2016 Midpoint (H) impact assessment method is used as the impact assessment method. The method contains 13 out of 14 impact categories recommended for the Product Environmental Footprint. The remaining category “Eutrophication – terrestrial” is assumed to be covered by Marine eutrophication, Terrestrial acidification, Freshwater eutrophication and Terrestrial ecotoxicity.

4 Results and Discussion

Results concentrate on global warming potential and water consumption, however all impacts calculated are also given.

4.1 Environmental Impacts

Figure 3 shows the impacts of the three scenarios (plastic, paper without the back of store plastic and paper with back of store plastic) using an avoided burden approach. In each category the highest impact is normalised to 100; whilst this enables easy comparison within a category, categories (and relative importance of categories) cannot be compared. The plastic bags have the highest global warming impact, water consumption and fossil resource scarcity, as well as the largest impact in some ecotoxicological categories. The high ionizing radiation for the paper is predominantly due to the nuclear electricity used in Sweden and the high land use is due to the wood production.

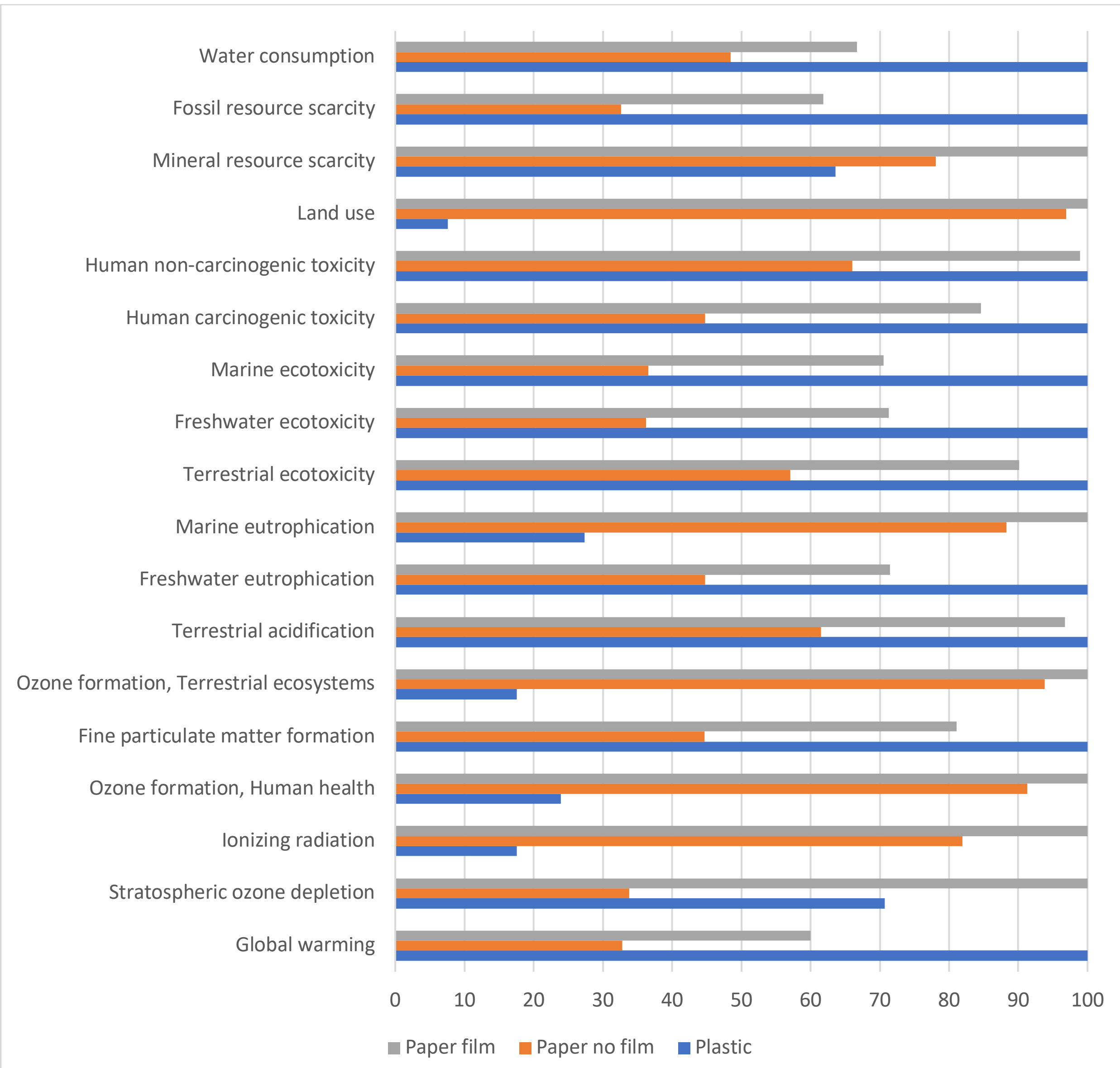

Figure 3: Impacts of the three scenarios: paper + film, paper (without film) and plastic, using an avoided burden approach. In each category the highest impact is normalised to 100.

Although both paper with and without the back of store plastic have been included in Figure 3 and Figure 4 for completion, we recommend using the paper with film numbers to compare to the plastic option as this gives a fair like-for-like comparison. In future graphs the paper without back of store plastic is not included for this reason.

The avoided burden approach includes the whole system, and is therefore a good comparison of the global impacts. However, the cut-off approach is a truer representation of the impacts that Morrisons are responsible for. We have included both for comparison.

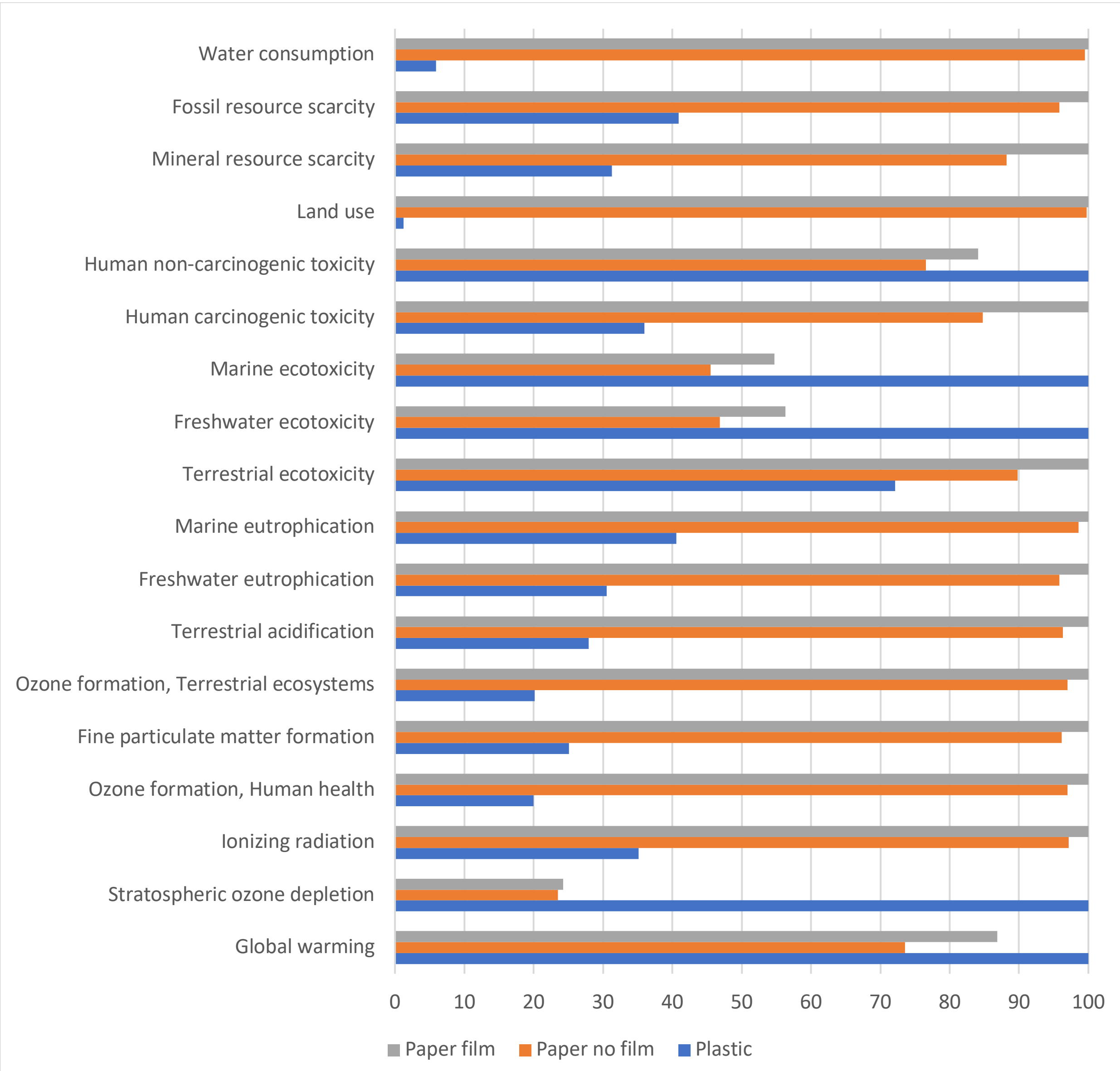

Figure 4: Impacts of the three scenarios: paper + film, paper (without film) and plastic, using the cut-off approach. In each category the highest impact is normalised to 100.

Figure 4 shows the same analysis as Figure 3, but this time using the cut-off method. The plastic bags still have the highest global warming potential, but this time the paper scenarios are much closer – 87% for the paper with film and 74% for paper without film (c.f.60% and 33% respectively for the avoided burden approach). This is because the cut-off method favours the use of recycled materials, as is the case for plastic and not for paper.

The plastic is significantly better for water consumptions using the cut off method (only 6% of the paper scenarios)

4.2 Global Warming Potential (carbon footprint) and Water Consumption

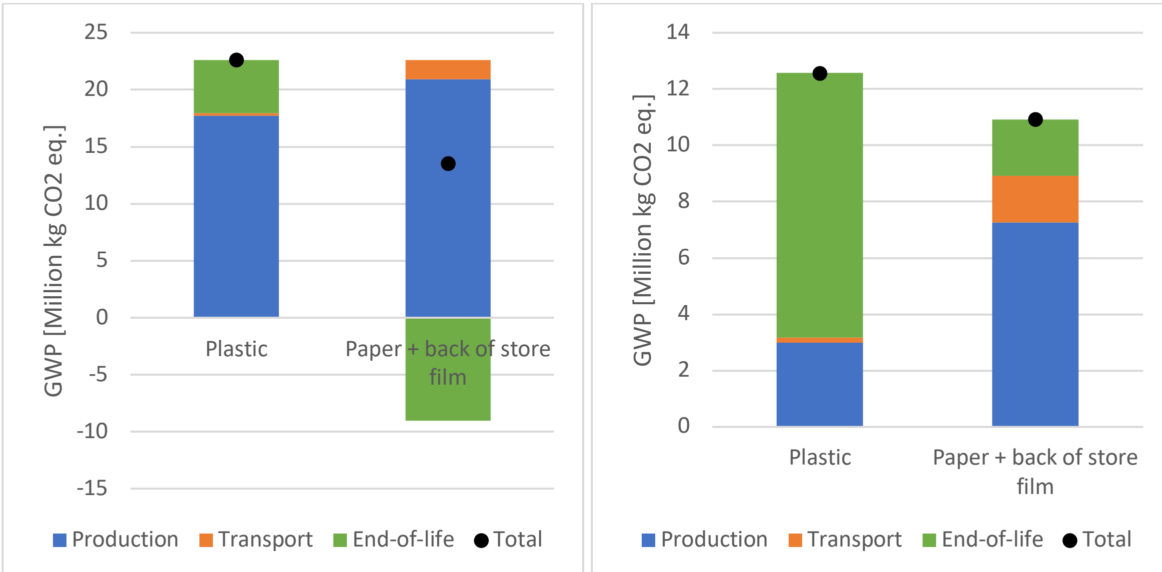

Figure 5: Breakdown of global warming potential - left: avoided burden approach; right: cut-off approach

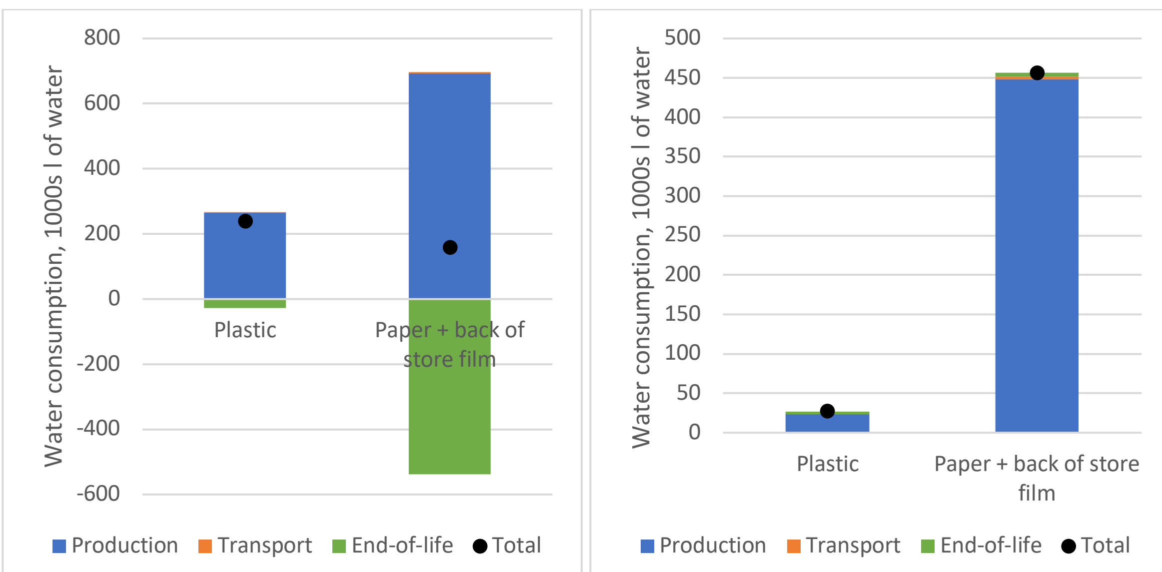

Figure 6: Water consumption breakdown - left: avoided burden approach; right: cut-off approach

Figure 5 and Figure 6 show the breakdown of global warming and water consumption respectively. In both cases the avoided burden approach is on the left and the cut-off approach on the right. The black dot shows the total impact – this is lower than the coloured bars due to the credit gained at end-of-life in some cases. The transport footprint is greater for the paper than the plastic. The

4.3 Sensitivity Analysis – Biogenic Carbon

Biogenic carbon is carbon that is sequestered from the atmosphere during plant growth. If the biomass product is later incinerated or decomposed, this biogenic carbon is released back to the atmosphere. A sensitivity analysis was performed on the biogenic carbon dioxide flow in the system. This has been done by modifying the ReCiPe 2016 Midpoint (H) method by assuming the emission of biogenic carbon dioxide (Called "Carbon dioxide, biogenic" in SimaPro 9.1) is associated with an equivalent of 1 kg of carbon dioxide in the Global Warming category. On the other hand, the consumption of 1 kg "Carbon dioxide, in air" in the comportment "Raw" is associated with a decrease of global warming potential by 1 kg of CO2 equivalent. The latter substance is the input to the wood extraction process, i.e. the amount of carbon dioxide consumed by the trees.

The carbon footprint of the paper scenario is higher using the avoided burden approach when biogenic carbon is taken into account (19.7 million kg CO2e when biogenic carbon is taken into account, versus 13.6 million kg CO2e without biogenic carbon). This is due to the way the avoided burden approach works, and is one reason we do not recommend including biogenic CO2 in avoided burden calculations. In effect, whilst CO2 is taken in by the trees, when the paper is recycled (instead of more virgin paper being produced), this actually stops new trees being planted and taking in CO2 to make more paper. Using the cut-off method, where 'avoided material production' is not taken into account, inclusion of biogenic carbon reduces the global warming potential due to the CO2 uptake by the trees.

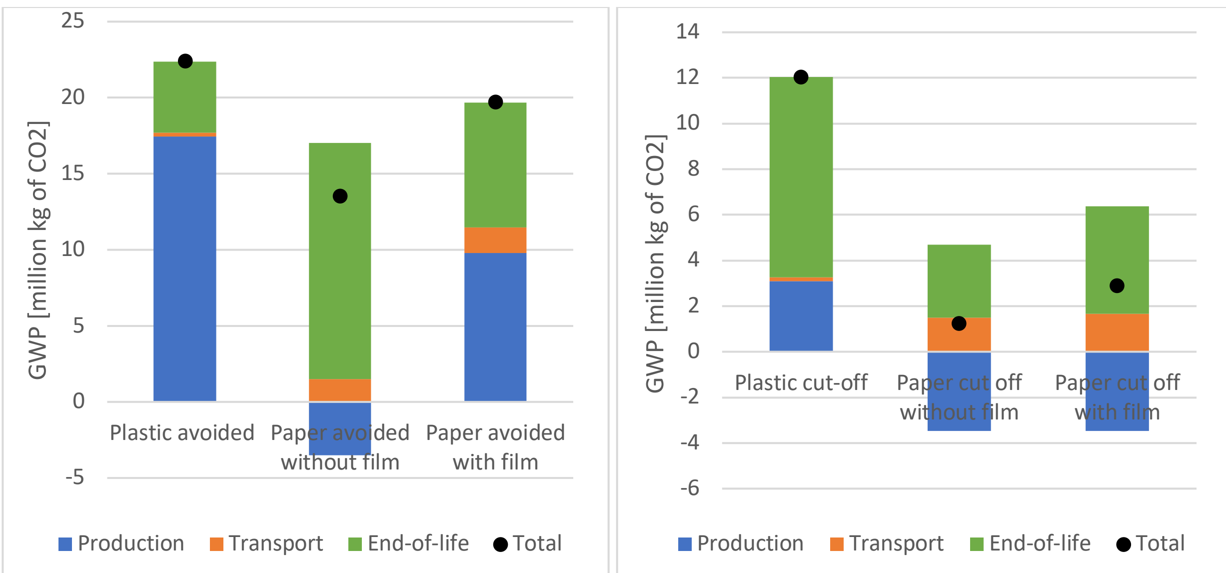

Figure 7: Global warming potential when biogenic carbon dioxide is considered - left: avoided burden approach; right: cut-off approach

4.4 Sensitivity Analysis – Recycling Rate

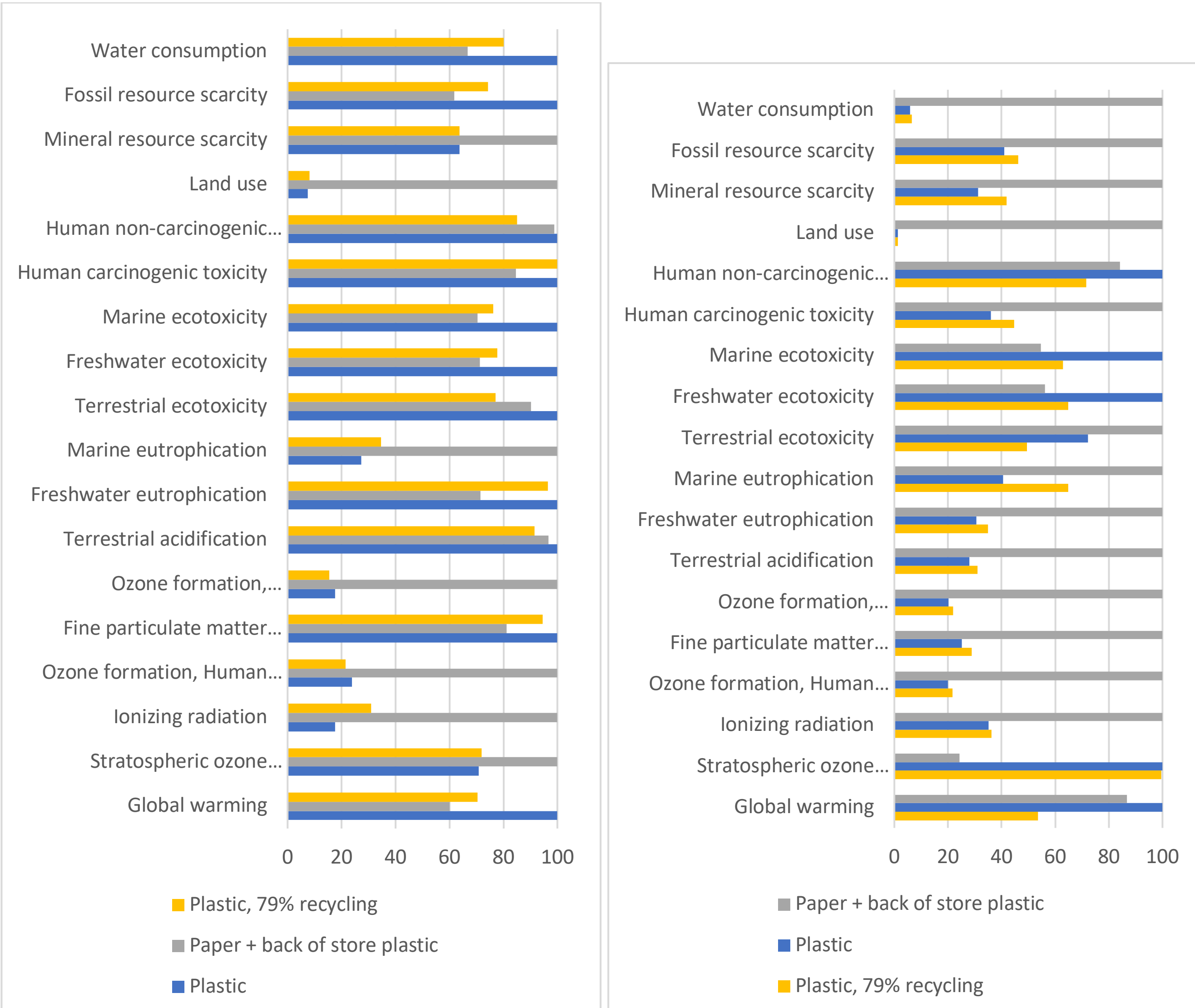

Figure 8: Sensitivity analysis on recycling rate of plastic bags; left: avoided burden approach and right: cut-off approach

Error! Reference source not found. shows the impacts when the recycling of plastic is increased to 79% (the same as the proportion of paper that is recycled in the default case). The global warming potential is reduced by approximately 30% and 45% for the avoided burden and cut-off approaches respectively. In the case of the cut-off method this means the plastic has a lower global warming potential than the paper with back of store plastic.

4.5 Sensitivity Analysis – Electricity source

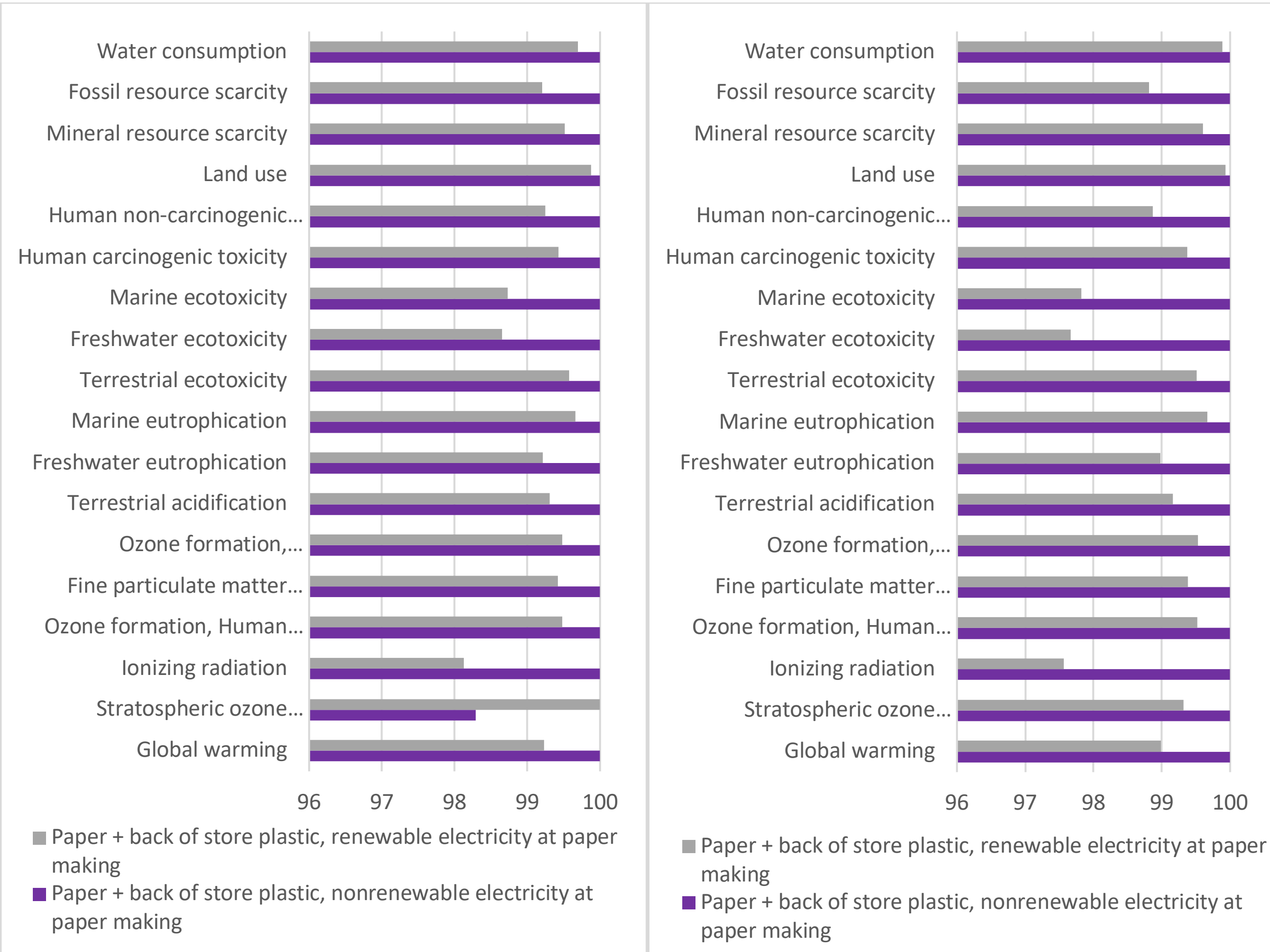

Figure 9: Sensitivity analysis around source of electricity in the paper making process; left: avoided burden approach and right: cut-off approach cut-off approach

The sensitivity analysis around the electricity source for paper making was done by substituting the processes responsible for the electricity with “Electricity, low voltage {GB}| market for”. The default GB electricity mix is then substituted with a mix identical to the one applied to paper bag making presented in Table 6. The heat source remains as in the default scenario. Where an energy recovery facility is modelled, the avoided burden remains of the same quantity and quality. Figure 9 shows the results of this analysis. Note the scale on the graph; the impacts in all cases are less than 3% different. This is due to the small amount of electricity used in paper making. The source of electricity at the paper mill therefore has very little impact.

In contrast to the paper making, the source of electricity used by JayPlas for the plastic recycling (Figure 10 and Figure 11) impacts results more, however in most impact categories the difference is less than 8%. The negative value for ionizing radiation when using the avoided burden approach is due to the avoided burden credit – in this scenario JayPlas processes the back of store plastic without emitting any radiation (due to the renewable electricity mix of solar and wind), however the avoided burden credit of incineration gives credit for average UK electricity which includes nuclear. The system therefore saves more nuclear than it uses.

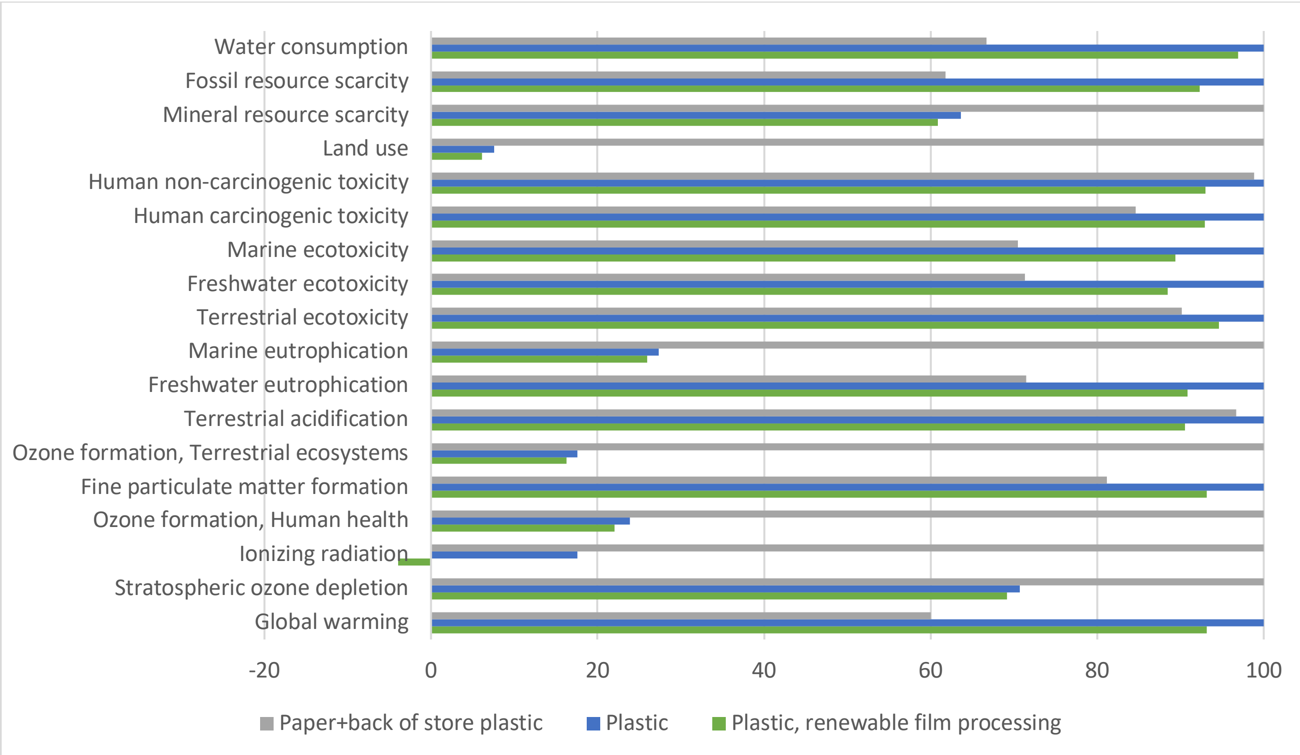

Figure 10: Sensitivity analysis around electricity source at back of store plastic processing, avoided burden approach

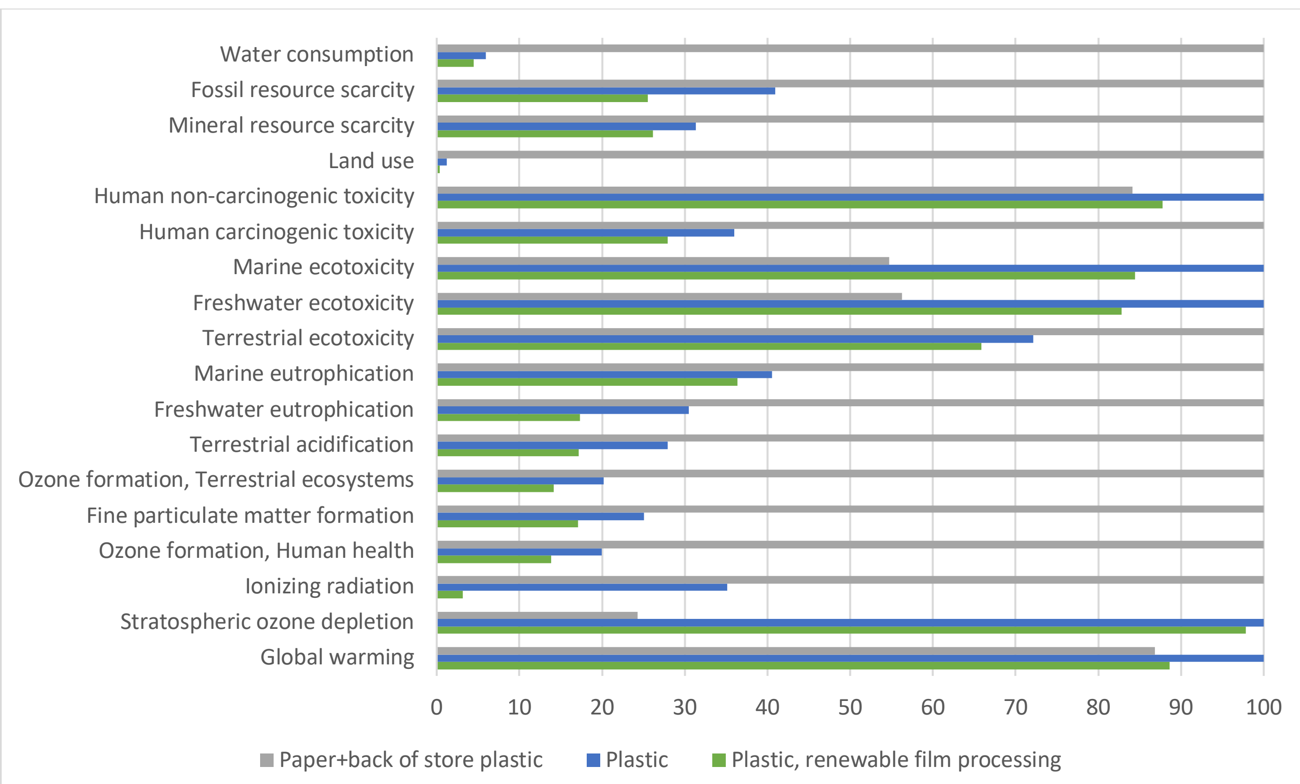

Figure 11: Sensitivity analysis around electricity source at back of store plastic processing, cut-off approach

4.6 Sensitivity Analysis – Bleached v unbleached paper

Sensitivity analysis was carried out to assess the potential impact of changing bleached paper to unbleached paper. To model the latter, the “Kraft paper, unbleached {RER}| production” process was used, where, similar to as done for bleached paper, the wood inputs were all converted to Swedish pine and the Swedish electricity mix was applied. The end-of-life of the paper remains unchanged. Figure 12 shows that both the water consumption and global warming potential decrease if unbleached paper is used, as do many of the other impact categories.

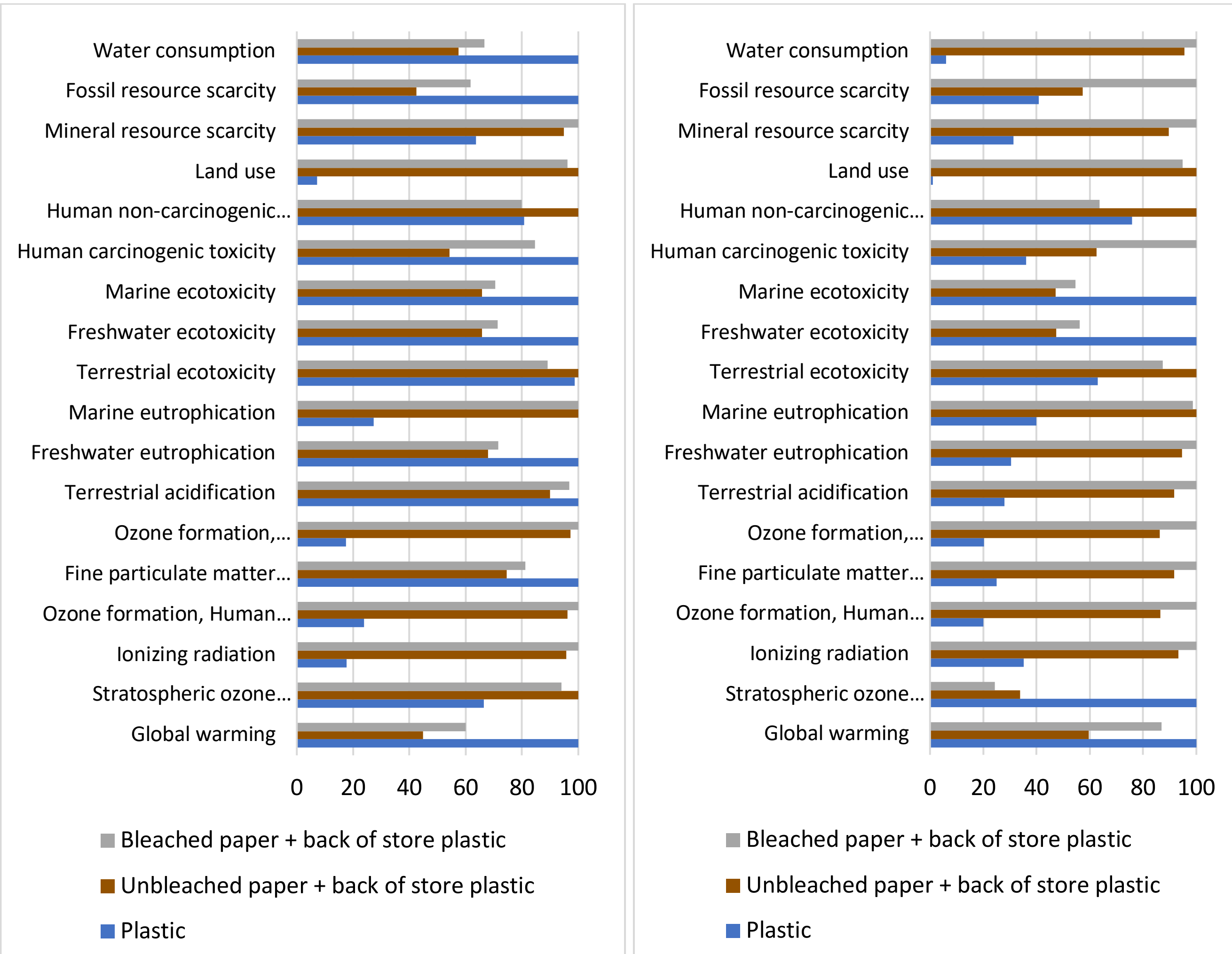

Figure 12: Comparison of bleached and unbleached paper vs plastic; left: avoided burden approach and right: cut-off approach

4.7 Data quality

A matrix describing the data quality is shown in Table 9. All processes are assessed on the basis of 6 criteria and averaged to obtain the general appropriateness of the data, based on the recommendations of the PEF (Product Environmental Footprint), with a score of 1 meaning very good quality and a score of 5 – very poor quality. Due to lack of data on completeness, almost all processes have been scored as having “Very poor” completeness, to obtain a conservative score. All processes fall into the “Good quality” rating as described by the PEF. The PEF recommends that at least 70% of the contributions to each environmental footprint have a score lower than 3.0, which has been fulfilled in this study.

Table 9: Data quality scores for the processes used in the study

	Completeness	Methodological appropriateness and consistency	Time representativeness	Technological representativeness	Geographical representativeness	Parameter uncertainty	DQR
Paper production	5	1	1	3	1	3	2.3
Back of store film	5	1	1	3	4	3	2.8
Paper bag making	5	1	1	3	1	3	2.3
Paper bag ink	5	1	1	3	1	3	2.3
Bag ink – without water	5	1	1	3	2	3	2.5
Water for ink	5	1	1	3	2	3	2.5
Adhesive	5	1	1	3	1	4	2.5
Wheat starch	5	1	1	3	1	3	2.3
Water for the adhesive	5	1	1	3	2	3	2.5
Calcium in the adhesive	5	1	1	3	2	3	2.5
Polyvinyl acetate	5	1	1	3	2	3	2.5
Shrink wrap used as secondary packaging for paper bags	5	1	1	3	4	3	2.8
Hydro electricity - paper bag making	5	1	1	2	1	3	2.2
Wind electricity - paper bag making	5	1	1	2	1	3	2.2
Waste incineration of paper	5	1	1	3	2	3	2.5
Avoided burden of production of recycled paper	5	1	1	3	2	3	2.5
Production of recycled, woodfree, coated paper	5	1	1	3	4	3	2.8
Pulp making from waste paper	5	1	1	3	4	3	2.8
Virgin LDPE production	4	1	1	3	4	3	2.7
Production of plastic bag from sorted and virgin plastic	5	1	1	3	2	3	2.5
Sorted back of store plastic	5	1	1	3	2	3	2.5
A negative avoided burden of back of store recycling	5	1	1	3	4	3	2.8
Incineration of plastics with credit	5	1	1	3	2	3	2.5
Sorting of plastic bags	5	1	1	3	2	3	2.5
The recycling of waste plastic bags	5	1	1	3	2	3	2.5
Avoided burden of plastic recycling	5	1	1	3	4	3	2.8

5 Discussion and Recommendations

The results in Section 4 show that in the majority of cases, the paper bag (taking into account the processing of back of store plastic) has lower impacts than the plastic bag. Ozone formation, ionizing radiation and land use are all higher for the paper scenario (due to the Swedish electricity mix and the growing of trees). If the proportion of plastic bags that are recycled increases then the global warming potential drops and becomes very similar to the paper scenario.

Using an unbleached bag (assuming the same weight of paper is used) decreases both the global warming potential and the water consumption.

Each of the default life cycles is determined for a year's supply of bags. Every process in the life cycle depends on the number of uses, Hence, the environmental impact of a bag that is reused once (i.e. used twice) is half of the default impact. Figure 13 shows the drop in global warming potential as bags are reused. Reusing a bag has the biggest impact on global warming potential of all the sensitivity analysis conducted i.e. the single most important thing to do is to reuse the bag. Once a bag as been reused approximately 5 times, the global warming potential becomes reasonably steady.

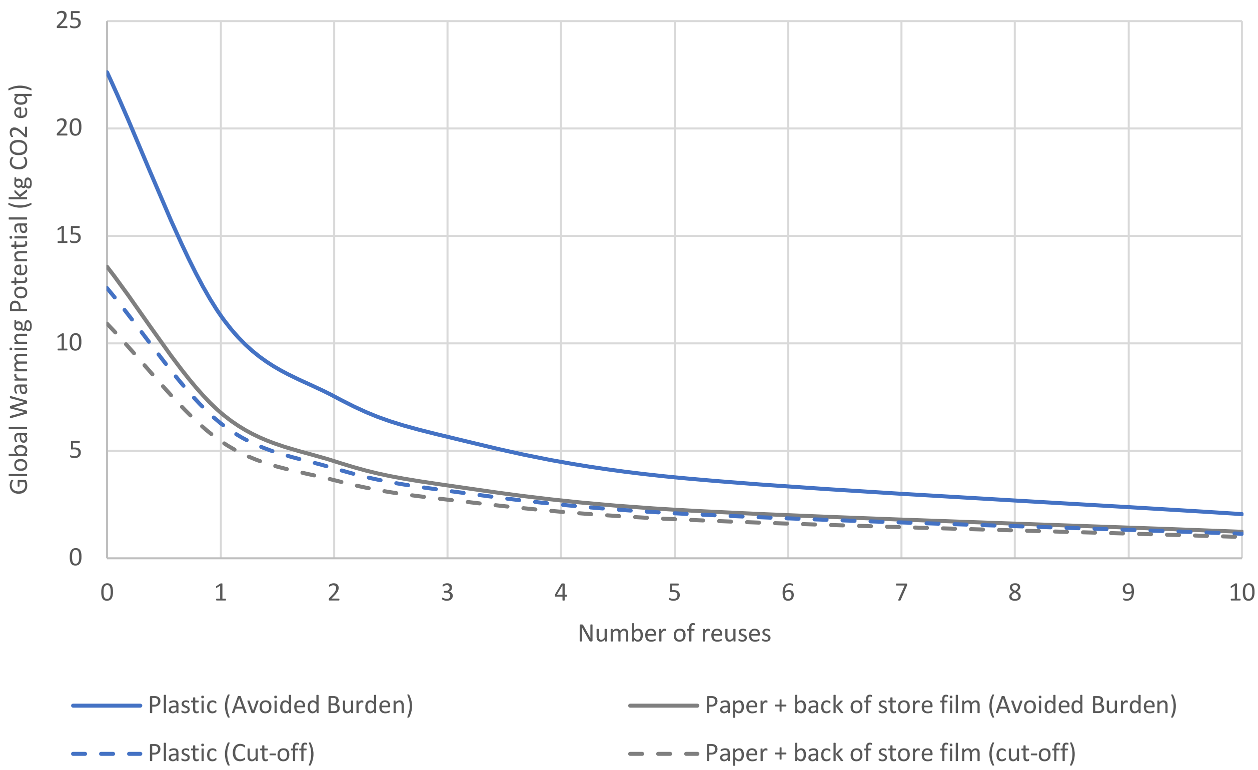

Figure 13: Decrease of global warming potential as bags are reused.

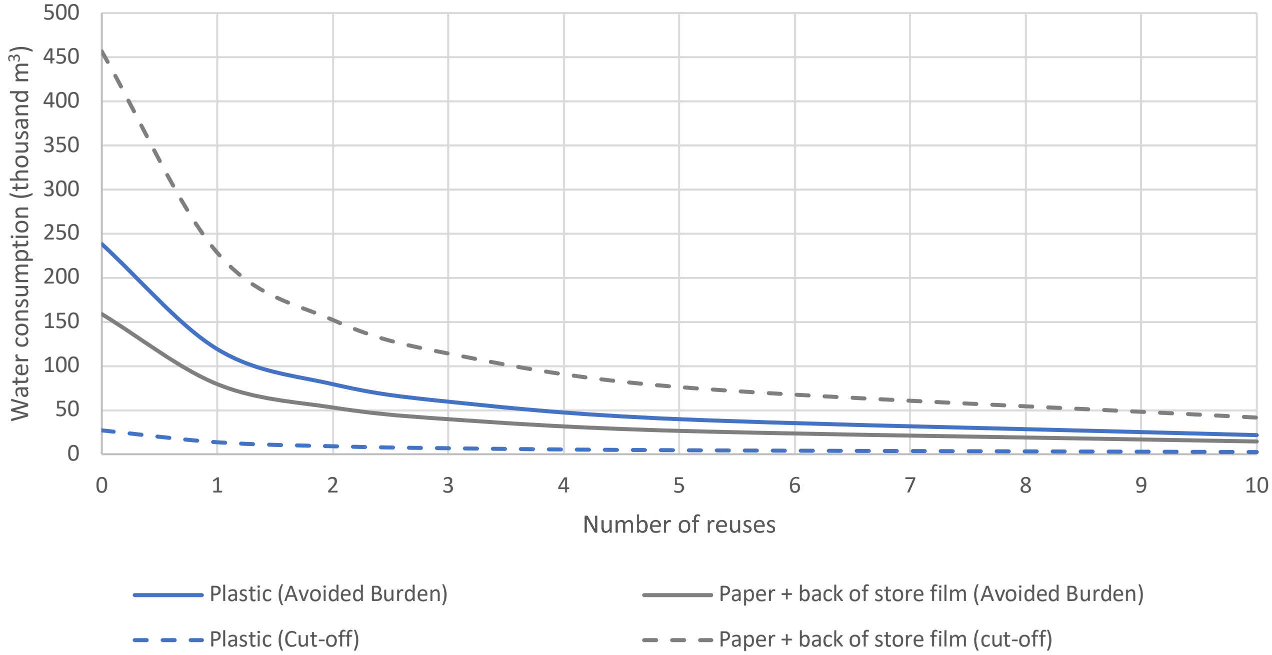

Figure 14: Decrease in water consumption as bags are reused

Figure 14 shows the change in water consumption with reuse of bags. Again, after around 5 reuses the impact becomes reasonably stable.

These results highlight the importance of a bag-for-life being reused. The more times a bag is reused, the smaller the footprint per use. At the very least we should be aiming for all bags to be used at least 5 times. Signposting of customers to remind them to bring bags to store, and using language that encourages reuse should be of high priority.

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