Carbon Footprint Analysis of a Retail Paper Shopping Bag:

The Bebak Bag

Report for Earthbags Australia Pty Ltd

July 2010

Dr Martin Anda, David Goodfield, Joanne Stewart, Les Westerlund

School of Environmental Science

Murdoch University

Document History

Ver	Date issued	Description	Reviewed by	Approved by	Date Approved
1	26 July 2010	Final Report	Dr Chris Lund	Martin Anda	26 July 2010
2	9 August 2010	Final Report	Client	Martin Anda	9 August 2010

Document information	
Project director	Dr Martin Anda - School of Environmental Science
Authors	Dr Martin Anda, Ms Joanne Stewart Mr David Goodfield, Mr Les Westerlund – Environmental Technology Centre Dr Chris Lund (Peer Reviewer) Climate Change Response Pty Ltd
Project manager	Martin Anda
Organisation	Earthbags Australia Pty Ltd
Project	Carbon Analysis of Bebak Bag
Document	Report on Carbon Analysis of Bebak Bag

Acknowledgements

Peer review by Dr Chris Lund of Climate Change Response Pty Ltd.

Executive Summary

Earthbags Australia Pty Ltd (Earthbags) has developed a heavy-duty woven paper fibre shopping bag, called the "Bebak Bag," which is designed to compete with the popular polypropylene green bag. It is understood this new bag is due to be launched in the Australian market in July 2010 as an eco-friendly bag that requires significantly less energy to produce and is less harmful to the environment when disposed of appropriately.

The purpose of this study was to compare the carbon footprint of the Bebak Bag with its polypropylene equivalent and the slightly larger woven high density polyethylene bag. This was done by building an abridged carbon inventory of the manufacturing process from plantation timber through to delivery to an Australian sea port. Several key assumptions have been made to complete this process which are detailed in the report.

Initial findings are that the Bebak Bag is likely to produce on average between 0.37 kg and 0.41 kg of greenhouse gas emissions during its production and disposal phases. In comparison to a similar study for polypropylene fibre "Green Bags", and assuming they are of a similar size, this results in a reduction in emissions of between 12% and 21% less emissions based on use over a twelve month period.

The study found that the Bebak Bag required less energy, and therefore emitted less greenhouse gases, to produce and deliver but only by adhering to some key restraints. These were notably: the recycling of water used in the pulping of the timber fibre and the manufacture of the raw paper; and the correct composting of the disposed bag at the end of its useful life.

Other key strategies to preserve or enhance the Bebak Bag's smaller footprint were the greater use of renewable energy in the production process, the increased use of recycled paper, and the substitution of diesel as a road transport fuel with biodiesel or other sustainable fuel.

As the initial findings show only a marginal difference between the Bebak bag and a similar polypropylene bag (<30% in this preliminary carbon footprint analysis), it is recommended that further and more detailed analysis be undertaken for the bag to be promoted as a low-carbon product. This would need to source more detailed and accurate data and could therefore take up to 6 months to complete given the difficulty of obtaining such data.

Table of Contents

1 Introduction

1.1 Project overview

To ascertain whether the new shopping bag can be promoted as a low-carbon product Earthbags has commissioned Murdoch University to conduct an initial carbon footprint analysis of its Bebak Bag. This preliminary study could be followed by a more detailed carbon life-cycle inventory analysis in the future.

The energy from fossil fuels that is required to produce, distribute and dispose of a product can generally be regarded as its embodied energy or embodied carbon. A cradle-to-grave, or life cycle analysis (LCA), provides a reliable, scientifically accepted way to ascertain this. The focus on embodied carbon emissions in retail products and associated packaging is increasing in the global community. Several large chains of supermarkets and retail stores in Europe, and particularly in the UK, are taking measures to reduce packaging and make their packaging products more sustainable and less carbon intensive.

In order to determine the carbon footprint of the Bebak Bag a carbon inventory was developed from data and detail related to the supply of raw material and the production process. . A comparison was then able to be made with independently published lifecycle assessment results for other comparable synthetic bags.

1.2 Report components

This report outlines the initial investigation of the carbon inventory undertaken and the consequent findings. The carbon footprint analysis included the following tasks:

1. Review of applicable national and international standards including AS/NZS ISO 14040:1998 *Environmental Management- Life cycle assessment - Principles and Framework.*
2. Review of product manufacturing process, materials, resources and energy used.
3. Modelling of the preliminary carbon inventory of the product to determine the carbon footprint.
4. Comparison with available benchmark data for similar products and possible production scenarios. These include:
   - a high density woven polyethylene bag of a similar size and volume;
   - a Kraft paper bag designed for single use;
   - a polypropylene bag in current use at retail outlets;
5. Analysis and report of results with recommendations.

1.3 Limitations of the study

Due to the level of detail and timeframe allowed for investigation this review can only provide an estimate of carbon emissions associated with the bag production process. An accurate review of emissions would require more detailed knowledge of material, energy and water input processes and outputs in each production location. A number of estimates and assumptions have been made to perform the calculations and these are detailed in the relevant sections. Similarly, the comparative data supplied by published reports is limited in detail. Furthermore, it cannot be guaranteed that the assumptions made and data used in previous studies were made on exactly the same basis as those made in the study of the Bebak Bag. Therefore, while the results may indicate that the carbon footprint of the Bebak Bag appears to be lower than the comparable synthetic bags, only a detailed lifecycle assessment of all the bags, in the same study, with common assumptions would be sufficient to support public publicity of the claim.

1.4 Level of assurance

Due to the amount and level of detail in the data provided and sourced, the carbon inventory has been calculated with a confidence level of +/- 40%. This is equivalent to the accuracy normally used in a Level 1 initial desktop energy audit conforming to Australian Standard AS3598:2000.

2 Methodology

2.1 LCA Standards

The carbon footprint analysis carried out in this study was informed by the LCA process that is generally conducted in accordance with AS/NZS ISO 14040:1998 *Environmental Management- Life cycle assessment - Principles and Framework.* The present study follows the LCA framework recommended:

1. Goal and scope definition
2. Inventory Analysis
3. Impact assessment
4. Interpretation

2.2 Goal and scope

The goal of the project is to calculate the total Greenhouse Gas emissions during the production process of the bags. A discussion of disposal methods and greenhouse gas impacts is also included. The scope was determined by selecting an appropriate functional unit, determining the relevant system boundaries, defining the production process and determining the data requirements.

2.3 Functional unit

The functional unit for the study of the Bebak Bag was the carrying capacity of one bag for 2 years. The supplier has advised that each bag has a life of 2 years[1] and it is assumed that the bags would be used once per week. Therefore there would be a total of 104 uses per bag. Base don physical measurements, the bag is assumed to be 340 mm in width and height and 185 mm deep with an approximate volume of 21.4 litres.

In order to compare these bags to other similar products a normalisation process has been undertaken on the basis of the carrying capacity and number of times used per annum. This is explained further in Section 5.

2.4 Methods employed

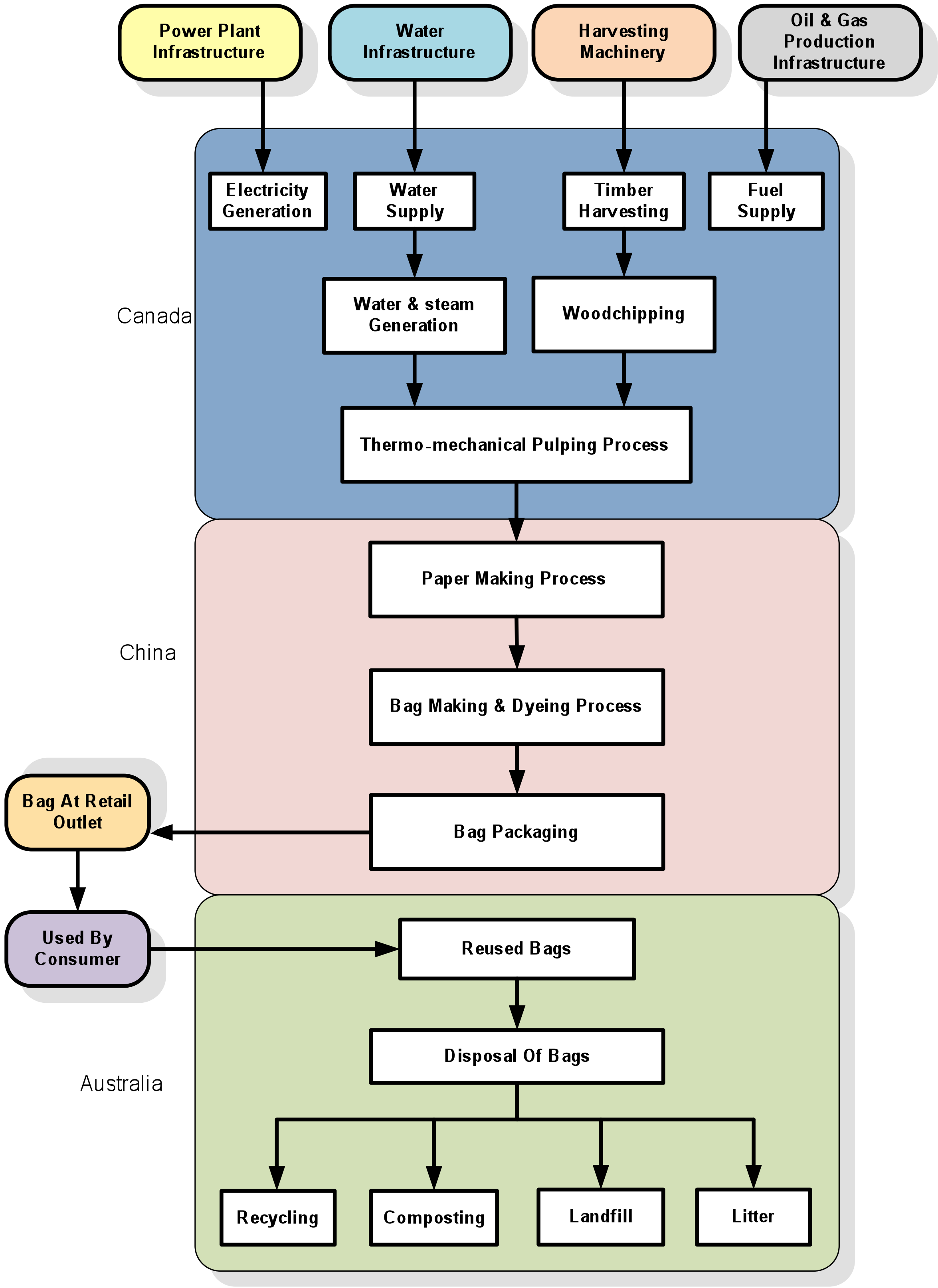
The analysis was divided into three main stages: timber processing in Canada, paper and bag processing in China, and use and disposal in Australia. A system boundary was established to ascertain the points in the process to be included in the study. Inputs to each manufacturing process were identified such as electricity, water and transport requirements between locations. Data was then collected for each input of the process. A conversion factor for the relevant greenhouse gas emissions was then applied and emissions calculated for each input.

[1] It should be noted that the LCA results are critically dependent on the lifetime of the bag, so if the bag has to be replaced before the two year period the carbon footprint will be higher.

2.5 System boundaries

The system boundaries were determined to ensure the starting point for data collection and emissions to be included was clear. Processes and emissions associated with infrastructure were not included in the study. Only those inputs that were directly related to the manufacturing process, such as electricity, water and fuel, were included in the study. It is therefore an abbreviated lifecycle assessment. The system boundaries are depicted in Figure 2 below.

Figure 1 System boundaries



2.6 Paper making process

This section includes a brief discussion of the carbon emissions issues of papermaking. First the sustainability of the forestry in Canada is essential to consider, then the mechanical production of the paper pulp, and finally focusing on the thermal mechanical pulping process itself. Zellstoff Celgar Ltd, the Canadian source of wood fibre has had their operation rigorously audited and received an accredited "Chain of Custody Certificate."

Papermaking can be composed of the several stages;

- **The forestry of the sustainable pine plantations;**
- Clearing; fertilisers; chain sawing; pruning; watering; cartage to the mill, wood-chipping good pine and seconds from milling**.**
- **Pulp production, which can include:**
  Chemical production; fuel production; energy from the grid; transport of pulp to the mills; transport of chemicals to the mill; and water and steam generation.
- **Paper production,** including -
  Transport of wood chips to the mill; of chemicals; of fuels.
  Tissue, printing and writing paper production;
- **Chemical production** to dissolve lignins and manufacture of whiter paper, including the use of starches, titanium, and brighteners.
- **Fuel and energy in production.**
- **Energy –** grid with generation from hydro, nuclear, coal, geothermal, or other.
- **Paper Distribution** to wholesalers and distributors
- **Disposal –** Littering, landfill, and incineration or composting.

In this study 50,000 bags of finished product correlates to 8 tonnes of manufactured pulp. The source of the pulp is sustainably managed forests in Canada. The logs are cut and trucked to the mill for timber processing and wood chipping; then made into paper bales in Canada; trucked to the port; shipped to China; trucked inland; processed into paper tissue; processed into a woven string; weaved into sheets of paper material ; cut and made into bags by sewing; boxed for loading into containers; trucked to the port in China; then finally shipped to Australia.

Mechanical Pulp Mills

Early mills used grinding rollers to grind wood into pulp. This could be stone groundwood pulp (SGW) or pressure groundwood pulp (PGW). More modern paper mills use tough metal discs called refiner plates to grind the wood into fibre called refiner mechanical pulp 'RMP'. Mechanical pulping uses considerably more energy to power electrical motors to turn the large grinders. The fibre yield is higher, up to 95% conversion, but it makes a brown paper with a substantial proportion of lignin still included chemically in the paper.

With thermal mechanical pulp (TMP) the pulp is heated with steam. This explodes the fibre apart and has been shown to produce a similar yield of up to 95% fibre. However, this also allows the lignin, chemicals and fibre to be separated better. The lignins and secondary by-products can be reused to generate energy as heat to generate steam for the overall process. The final product is a whiter purer fibre but a yield of only 50%. From one perspective, the wood is used as a source of energy to help purify the initial brown lignin and fibres into a range of up to 50% less by weight of pure fibres. It is important to reuse the energy in the steam and have a series of energy conversion processes to optimise the process in grades or levels of temperature uses.

The stock of whitish fibre is then processed into paper or concentrated into bales for later processing. The bales are left at about 20% moisture to reduce the costs of energy and evaporation. The waste effluents could further be treated with aerobic and anaerobic processes to naturally reduce the levels of pollutants.

In this case study, the bales are made in Canada and then shipped to China for making into a tissue paper. No data could be sourced on this company in China. However, the bales would be further processed and diluted into a 1% paper and 99% water solution. Other bonding agents and filler can be used in the brew. This suspension of paper fibres is sprayed onto a moving screen to create a thin film of paper. As the paper is dried and pressed, the fibres interlock together and hydrogen bonding starts to form. The paper would continue to be pressed and heated until dry and rolled off onto reals of paper. The hydrogen bonding and fillers help bond and smooth the paper while being 'nip' pressed in the rollers. The final paper would need to be about 97% paper and less than 7% moisture. They make rolls from one to several metres wide depending on the machines.

The manufacturing water would be continually recycled and re-diluted with new pulp until it builds up too much contamination and needs to be rejected as waste effluent. The waste effluents could further be treated with aerobic and anaerobic processes to naturally reduce the levels of contamination.

The fibre is then ready for the colouring – dying operations. No details were supplied as to whether or not this was done during tissue manufacturing or after. Natural dyes could be added to the pulp for colouring during the manufacturing process. It depends on the base colour of the stock as to how much colour is needed. A browner base stock would need a lot more ink to change its colour to another primary colour. A lighter, whiter stock could be more easily coloured into a range of colours. More information is needed to derive a better evaluation of the process.

In summary: this process uses fibres from sustainably grown trees in Canada; made into pulp bales in Canada, using up to 90% of energy from the wood and lignins, deriving a lot less (up to 50%) fibre into a whiter fibre. Thus it is estimated that 16 tonnes of trees would make 10 tonnes of damp pulp; (8 tonnes of waste fibre and lignins); into 8 tonnes of air dried paper. The damp bales (20% moisture approx.) are exported to China for processing into tissue paper, coloured and then made into string fibres for further manufacturing into shopping bags.

3 Carbon footprint analysis

3.1 Data collection

Earthbags provided the following information in relation to the processing of 50,000 bags, which is the size of a standard order.

Timber and Pulp Processing (Canada)

- The pulp is sourced from Zellstoff Celgar, a pulp mill in British Columbia, Canada.
- The pulp is prepared mechanically using chips that are ground up with ridged metal discs called refiner plates and are steamed while being refined resulting in thermo-mechanical pulp (TMP).
- The pulp is transported from a port in Canada to a port in China, which is a distance of 8,900 km.

Paper Processing (China)

- The pulp is imported into China by Asia Pulp and Paper.
- The pulp is trucked from the port to the paper mill in China which is 1,300 kilometres away.
- The pulp is then coloured to the base colour of the bag using vegetable dye.
- Tissue paper is then manufactured from the pulp using conventional methods. The water is recycled for further use. The amount of water used to produce enough paper for 50,000 bags is 8 kilolitres.
- The amount of pulp used to make 50,000 Bebak bags is 8 tonnes.
- The paper is then trucked by road to Ningbo, which is 1,500 kilometres away.

Bag Processing (China)

- The paper is then stripped on fine blades using 15 small motors of 1,500 kilowatts each.
- These stripped rolls are then twisted using spinning 4 machines of 2,000 watts each.
- The twisted strands are then woven into large sheets using one machine with a motor size of 2,000 watts.
- These sheets are then cut manually into their respective sizes
- The bags are then sewn together by hand on 30 sewing machines that are 1,000 watts each.
- The bags then have the logos applied by hand using a stencil and vegetable dye
- Bags are then packaged into cardboard boxes each containing 100 bags, and loaded into a 40 foot long container.
- The bags are then shipped from Ningbo 7,200 km to Australia in a 40 foot container.

Use and Disposal (Australia)

- The bags have a life span of approximately 24 months under normal shopping conditions

- The bags can then be disposed of via the green bins, the yellow recycle bins, or composted as recommended and then used as fertilizer in the garden.

Further data was collected from a variety of sources to ascertain the amount of energy used in processes, the amount of water required for pulp and paper processing and the amount of carbon dioxide emitted in relation to each input. These are indicated in the calculation information.

3.2 Assumptions

Due to the lack of detailed data many assumptions were made regarding the volumes of inputs and processes. These include the following:

- Fifty per cent of the harvested timber will be processed into pulp for bag production, the other fifty per cent being used for energy supply. Therefore 16 tonnes of plantation timber is required to make 8 tonnes of dry pulp. This assumption is tested in further sensitivity analysis in Section 3.4.
- It is assumed the harvesting equipment is standard equipment used in North America and Canada and a typical value for forestry management and harvesting has been used in the calculation. Greenhouse gas emissions attributable to forest management and harvesting are assumed to be 0.0234 tonnes per tonne of dry pulp in accordance with findings by the Heinz Centre (Gower and McKeon-Ruedinger, et al., 2006)
- The timber will only need to be trucked 100 kilometres (200 kilometre round trip) to the pulping mill. This assumption is also tested in accordance with findings by the Heinz Centre discussed in Section 3.4.
- Only 16 kilolitres of water is included in the pulp process in Canada based on the expectation that it is recycled and minimal energy use is required.
- The steam used in the pulp process in Canada is 90% carbon neutral according to the information provided on the Zellstoff (Mercer International) website. This is due to the bio-energy source of using the lignin from the timber supply. The grid energy required is assumed to be 200 kWh [3].
- Grid electricity is used for pulp grinding in Canada which requires 2.4 MWh per tonne for TMP [4].
- The eight tonnes of dry pulp once hydrated weighs 10 tonnes and is shipped to China in that form.
- The hydrated pulp is processed in China into 8 tonnes of paper with an electricity requirement of 330 kWh per tonne [4].
- The paper stripping machines run for eight hours for each 8 tonne batch
- The paper twisting machines run for twenty-four hours for each 8 tonne batch
- Sewing machines are used for only 30 seconds per bag
- Grid electricity is used in the production process in China
- The bags are containerised and transported 1,500 km from the bag processing plant to the port in China.
- Final transport to an Australian port is 7,200 km by sea.

3.3 Calculations

Based on the data collected the carbon emissions were calculated for a batch of 50,000 bags, which is the usual size of an order. This resulted in a total of 13,568 kg of carbon emissions per batch or 0.27 kg per bag. The data and calculations are provided in Table 1 below.

Table 1 Carbon emission calculation

	Item/Process	Quantity	Unit	Conversion factor Ref:	**Emissions kg CO_{2-e} per 50,000 bags**
	Forestry management and tree harvesting	16 tonnes of timber, to make 8 tonnes of pulp	tonnes	0.0212 Following the paper trail – Heinz Center	187
1	Tree harvesting - 16 tonnes [1] and Transport to mill of 16 tonnes.	100	km (each way)	59 grams CO_{2-e} /t/km [2]	188.8
2	TMP Conversion to pulp - Steam	200	kWh	0.6 kg CO_{2-e} /kWh [5]	120.0
	- Electricity	2.4	MWh/t [4]	0.6 kg CO_{2-e} /kWh [5]	1,440.0
	- Water use (energy to pump)	16	kL	1.2 kWh/kL [6]	19.2
3	Transport – mill to Canada port by road	600 10 tonnes	km	59 grams CO_{2-e} /t/km [2]	354.0
4	Transport – to China port by sea	8,900	km	10 grams CO_{2-e} /t/km [2]	890.0
5	Transport – China port to mill by road	1,300	km	59 grams CO_{2-e} /t/km [2]	767.0
6	Converting pulp to paper - water use	8	kL	1.2 kWh/kL [6]	9.6
	- electricity	8 330	t kWh/t	1.0 kg CO_{2-e} /kWh [7]	2,640.0
7	Transport – mill to manufacturing plant by road	1,500	km	59 grams CO_{2-e} /t/km [2]	708.0
8	Bag manufacture				
	- paper stripping	15 machines		@ 1.5 kW each	180.0
		8	hr	1.0 kg CO_{2-e} /kWh [7]	
	- paper twisting	2 machines		@ 3 kW each	1,200.0

		200	hr	1.0 kg CO_{2-e} /kWh [7]	
	- bag sewing	30 machines		@ 1kW each	416.7
		3 machines		@ 1.5 kW each	
	- bag weaving	340	hr		1,530.0
	- paper cutting	1	Machine	4 kW	
		100	hr		400.0
	- pack and boxing	1	min	per bag	
				(estimate)	100.0
9	Transport – to China port by road	1,500 8 tonnes	km	59 grams CO_{2-e} /t/km [2]	708.0
10	Transport – China Port to Australia	7,200	km	10 grams CO_{2-e} /t/km [2]	576.0
				Sub-total	12,334.5
				Contingency 10%	1,233.4
				Total	13,567.9
				Total kg per bag	0.27

3.4 Sensitivity Analysis

Research by the Worldwatch Institute[2] found that 1 tonne of paper can require 2 to 3 tonnes of timber. As the above calculation assumes that only 2 tonnes of timber is required per tonne of pulp, a second calculation was conducted to test the effect of using 3.5 tonnes per tonne of pulp.

Also the calculation above assumes that the pulp mill is only 100 kilometres away from the timber source. Findings in studies by the Heinz Centre indicate that this distance could be much greater depending on the location of the mill. Therefore a calculation including a round trip distance of 500 kilometres was also included.

Based on this analysis including the added energy required to process the timber to pulp resulted in the total carbon emissions of 0.31 kg per bag prior to disposal.

3.5 Disposal

Carbon dioxide, methane and nitrous oxide are emitted from the anaerobic breakdown and decomposition of the bags under review when disposed of *en masse* in landfill sites. Previous research indicates that paper, in the presence of moisture, will generate significantly more of these carbon emissions than will polypropylene and polyethylene bags under similar conditions, although the latter will take a considerably longer period to complete this breakdown.

Although methane and nitrous oxide are emitted in much smaller quantities than is carbon dioxide they have a greenhouse potential many times that of carbon dioxide. It is essential, therefore, that the new Bebak bag is supplied on the basis that in its disposal it is not likely to end up in landfill. Should it do so it is likely to compromise the eco-friendliness of the product.

[2] Abramovitz, J. and A.T. Mattoon. 1999. *Paper Cuts: Recovering the Paper Landscape*, The Worldwatch Institute. World Watch Paper 149. p 26.

For the purpose of the study it is assumed that the bags are disposed of in accordance with the following assumptions.

- Disposal methods include landfill (5%), recycle (24%), litter (1%) and composting (70%).
- 3500 kilograms of CO2-e are emitted per tonne of paper landfill [3]
- no emissions are created from recycling the bags
- the full weight of littered bags are converted to carbon dioxide, and
- twenty percent of the weight of composted bags are converted to carbon dioxide and lost to the atmosphere.

On that basis a further 100 grams of CO2 equivalent emissions are created per bag bringing the total to 0.37 kg per bag for the base case and 0.41 kg per bag including extra timber and distance to pulp mill.

4 Interpretation

Based on the base case analysis above a large proportion of the carbon emissions prior to disposal, approximately 64 per cent, is due to the electricity used to convert timber to pulp and then to paper and bag making. A further 22 per cent is due to road transport and 12 per cent is due to sea transport between Canada, China and Australia. Energy associated with water use is calculated to be less than 1 per cent due to recycled water being used and 2 per cent is related to forest management and harvest.

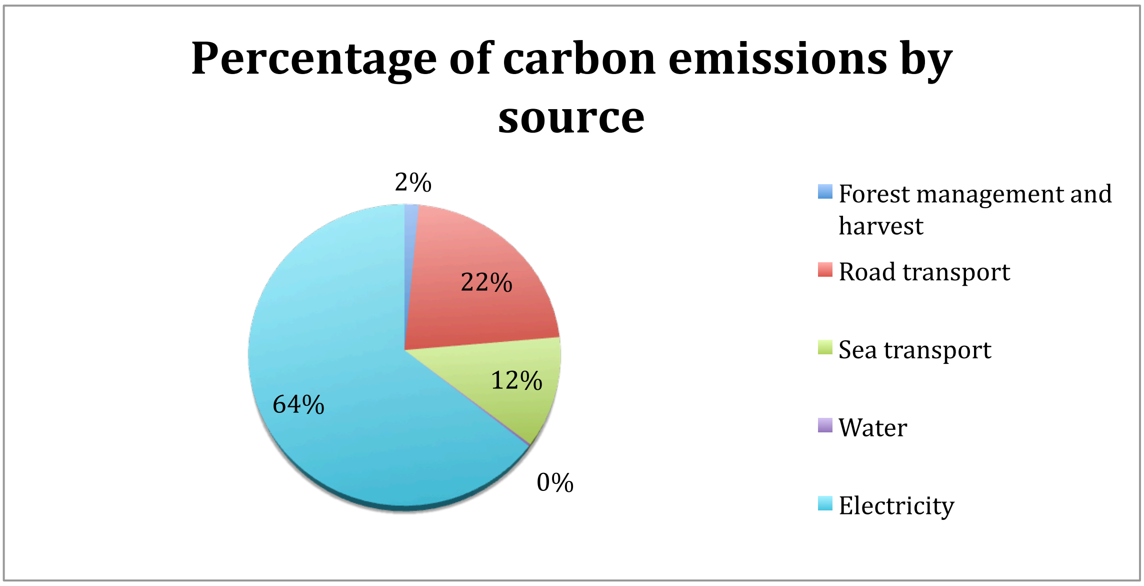


Chart 1: Carbon emission sources

The high carbon emissions from the energy is due to the amount of electricity used in the pulp and paper processing stages and bag production and the reliance on fossil fuels to produce that energy. It is noted that emissions from grid electricity in Canada are taken as 0.6 $kgCO_2$-e / kWh which is 0.4 kg less than in China due to

[3] Based on estimates in The International Council of Forest and Paper Associations (ICFPA) 2005. *Calculation Tools for Estimating Greenhouse Gas Emissions form Pulp and Paper Mills*, version 1.1. NC, USA. P. 13

Canada's mix of renewable energy sources, particularly hydroelectricity. Less reliance on fossil fuels to produce this energy would substantially reduce the carbon footprint in producing the Bebak bag.

The Chart below depicts the proportion of carbon emission sources prior to disposal based on processes used to manufacture the Bebak Bag.

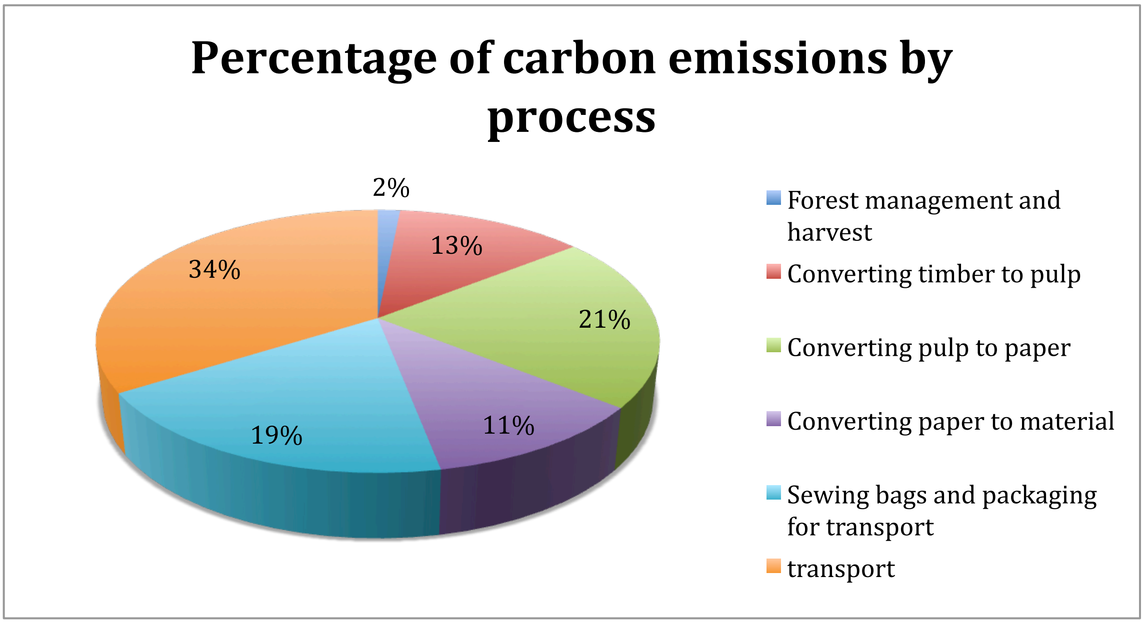


Chart 2: Emissions by process

5 Comparison of products

James and Grant (2005), who are leading authors in this area of research, prepared a study of several shopping bags including a polypropylene fibre "Green Bag" and a Kraft paper bag. The study included a lifecycle assessment of each bag with a similar scope to the Bebak bag study. As the bags had different holding capacities and lifespan James and Grant conducted a normalising calculation to account for these factors. This resulted in a comparison of the bags according to the quantity of bags required to be used per annum to carry a week's load of shopping (60 - 80 items) over a period of twelve months adjusted for their life expectancy.

Therefore to compare the Earth bag with the others the same calculation has been conducted. It is assumed that the carrying capacity of the Bebak bag is comparable to the PP fibre "Green bag".

As is indicated in Table 2 to carry the equivalent amount of weekly shopping over a twelve-month period the Earth bag produces carbon emissions of 1.54 kg per annum and appears to perform favourably compared to the other two bags. If additional timber and transport is required, as per the sensitivity analysis, the Bebak bag would emit 1.71 kg per annum.

While the Kraft paper bag produces the least emissions (0.06 kg) during production and disposal, the need to purchase more of them and its limitation to one use results in a higher carbon emission output (30.2 kg) over twelve months.

Table 2 Comparison with other bag products

Product	**Relative Capacity**	**Expected life**	**Quantity of bags per annum adjusted for life expectancy**	**Emissions kg CO_{2-e} per bag**	**Emissions attributable to use of bag over 12 months ***
Polypropylene fibre "Green bag"	1.2	2 years (104 uses)	4.15	0.47 kg	1.95 kg
Kraft paper bag	1	1 use	520	0.06 kg	30.2 kg
Bebak paper bag	**1.2**	**2 years (104 uses)**	**4.15**	**0.37 to 0.41 kg**	**1.54 to 1.71 kg**

6 Conclusions and recommendations

This study indicates that the woven paper Bebak shopping bag by Earthbags Australia Pty Ltd produces in the order of 20 per cent less carbon emissions during its manufacture and disposal than the Polypropylene fibre "Green bag" of comparable size and durability.

Several assumptions have been made in coming to this conclusion. One such assumption is in the transport element. Our research indicates that moving the products by sea from one nation or continent to another does not substantially increase its carbon footprint. This is due to the magnitude and volume of freight moved at any one time by a container ship over large distances. What is clear, however, is that moving product by road does have a significant effect in increasing the carbon footprint. Alternative locations for production closer to port or using cleaner fuels such as biodiesel are necessary to preserve lower carbon emissions.

Assuming the Canadian plantation timber is continuously managed sustainably with replacement stock there will be reduced carbon emissions from the timber supply. However, consideration needs to be given to the total demand and the quantity of plantations that can be sustained without impacting on surrounding biodiversity and ecosystem services.

Research clearly indicates that the substantially larger volume of water used in manufacturing paper products, as opposed to polymer based ones, is a significant environmental issue. This study is concerned with carbon foot-printing and it is only the energy required to move the water that is to be considered. However, both plants in Canada and China do state that high proportions of the water are recycled many times over.

Disposal of paper is also a significant environmental issue. Plastic products remain within land-based and marine ecosystems for considerably longer periods before decomposition and have manifest environmental impact (see for example the devastating results of plastic bags lower rate of biodegradability after disposal in the Pacific Ocean http://en.wikipedia.org/wiki/Great_Pacific_Garbage_Patch). These negative impacts of plastic bags in the marine environment have been clearly described by Moore, 2008[12].

Although paper does biodegrade at a much faster rate in landfill systems it does produce quantities of the greenhouse gases that this study is taking account of. It is recommended, therefore, that obvious steps be taken to ensure that the sale or distribution of the Bebak Bag on the basis of their environmental credentials is done so along with promotion of appropriate disposal. One suggestion is that collection points be made at each store and that the bags are then composted correctly thereafter.

The use of renewable energy to create the power to manufacture the paper pulp and ultimately manufacture the bag would greatly reduce the Earth Bag's embodied carbon. Utilising renewable energy systems, particularly, in the Chinese stages of production, would greatly enhance the Earth Bag's environmentally friendly credentials.

For these reasons it is recommended that further and more detailed analysis be undertaken for the bag to be promoted as a low-carbon product.

7 References

1. Mercer International website, sourced online at http://www.mercerint.com/s/CarbonFootprint.asp

2. World Shipping Council, 2009. The Liner Shipping Industry & Carbon Emissions Policy, sourced online at http://www.worldshipping.org/pdf/liner_shipping_co2emissions_policy_september.pdf

3. Martin, N et al, 2000. *Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas Emissions in the U.S. Pulp & Paper Industry*, a paper prepared by the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory, Ca., U.S.A. dated July 2000, p6.

4. Natural Resources Canada, 2010. Thermomechanical Pulp Mill, sourced online at http://oee.nrcan.gc.ca/publications/infosource/pub/cipec/pulp-paper-industry/section-03.cfm?attr=20

5. US Department of Energy, 2010. Country Analysis Brief, sourced online at http://www.eia.doe.gov/cabs/canada/background.html

6. Water Corporation of Western Australia http://www.watercorporation.com.au/_files/PublicationsRegister/6/2009AR_FULLVERSION.pdf

7. US Department of Energy, 2010. Country Analysis Brief, sourced online at http://www.eia.doe.gov/cabs/China/Background.html

8. US Department of Energy, 2010. Country Analysis Brief, sourced online at http://www.eia.doe.gov/cabs/China/Background.html

9. James K. & Grant, T., 2005. *LCA of Degradable Plastic Bags*, a paper for the Centre for Design at RMIT University, Melbourne, Australia, sourced online at http://www.cfd.rmit.edu.au/programs/life_cycle_assessment/lca_of_degradable_plastic_bags

10. Gower S. T., A McKeon-Ruediger, et al. 2006. *Following the Paper Trail: The impact of magazine and dimensional lumber production on Greenhouse Gas emissions: A case study. The Heinz Center, Washington DC.*

11. Abramovitz, J. and A.T. Mattoon. 1999. *Paper Cuts: Recovering the Paper Landscape*, The Worldwatch Institute. World Watch Paper 149.

12. Moore C J. 2008. *Synthetic polymers in the marine environment: A rapidly increasing, long-term threat*, Environmental Research, Volume 108, Issue 2, October 2008, Pages 131-139

	Process/Activity	Location	Distance	Method	Assumptions	Calculation	Emissions rates	Emission kg CO2-e/ 50,000 bags
			kms					
					Based on harvesting 16t plantation timber to make 8t dry pulp			
1a	Forestry management and harvesting				2% of GHG per tonne of finished magazine attributable to forest mgt and harvesting [9]	1.17 tonnes of GHG *2% = 0.0234* 8t pulp	0.0234 per tonne of dry pulp	187.20
1b	Transport to Mill	Zellstoff Celgar Ltd - Castlegar, Canada	200	Machinery	proximity to pulping mill	16 tonnes	59 grams CO_{2-e} /tonne/km [2]	188.80
		Castlegar						
1c	Conversion to pulp - Steam				Steam 90% carbon neutral (ref: Zellstoff)	10% total energy req'd to strip lignins is 0.9 GJ/t or 200kWh equivalent [3]	0.6 kg CO_{2-e} /kWh [5]	120.00
	- Electricity				Grid electricity - for pulp grinding	2.4 MWh/t for TMP [4]	0.6 kg CO_{2-e} /kWh [5]	1,440.00
	- Water use (energy to pump)				Process startup water only	Startup of 16 cu m/t of water recycled - x kWh/kL ref to come	1.2 kWh/kL [6]	19.20
2	Transport	mill to Canada port	600	Road		10 tonnes raw pulp	59 grams CO_{2-e} /tonne/km [2]	354.00
3	Transport	Canada port to China port	8,900	Sea	1 x 40 ft container carrying 10 ton raw pulp		10 grams CO_{2-e} /tonne/km [2]	890.00
4	Transport	China port to mill	1,300	Road	10 tonnes raw pulp		59 grams CO_{2-e} /tonne/km [2]	767.00
5	Colouring pulp	China mill						
	Converting to tissue paper - Water Use				1kL/tonne of pulp	8 tonnes pulp using 8kL water [#]	1.2 kWh/kL [6]	9.60
	- Electricity					8 tonnes raw pulp @ 330 kWh/t [4]	1.0 kg CO_{2-e} /kWh [7]	2,640.00
6	Transport	China mill to Ningbo mnfr. Plant	1,500	Road		8 tonnes finished paper	59 grams CO_{2-e} /tonne/km [2]	708.00
7	Paper stripping	paper stripping			8 hrs per 8 tonne batch *	15 machines x 1.5 kW	1.0 kg CO_{2-e} /kWh [7]	180.00
8	Paper twisting	paper twisting			200 hr	2 machines x 3 kW each	1.0 kg CO_{2-e} /kWh [7]	1,200.00
		bag weaving			340 hr	3 machines @ 1.5 kW each		1,530.00
9	Bag sewing							
		paper cutting			100 hr	1 machine @ 4 kW		400.00
10	Boxing bags	bag sewing			30 sec/bag x 50,000 @ variable speed (ave. 50%) *	1 kW	1.0 kg CO_{2-e} /kWh [7]	416.67
11	Transport	Mnfr plant to China port	1500 **	Road		8 tonnes finished bags	59 grams CO_{2-e} /tonne/km [2]	708.00
12	Transport	China port to Australia	7,200	Sea	1 x 40 ft container carrying finished bags	8 tonnes finished bags	10 grams CO_{2-e} /tonne/km [2]	576.00
							Total CO2 emissios per 50,000bags	12,334.47
					Contingency		10%	1,233.45
								13,567.91
							Kg per bag before disposal	0.27
	Disposal method	% mode						
	Disposal (landfill)	5%			3500 kgs of CO2-e per ton of landfill [10]	3500 / 1000 x 0.16 kg weight of bag	0.6	0.03
	Recycle	24%			no emissions - paper making			-
	Littering	1%			160 grams x 3 (converted to CO2)		0.5	0.00
	composting	70%			160 grams x 3 x 20% emissions (assume 20% Co2 lost to atmoshphere and energy inp		0.1	0.07
		100%						
							Kg per bag including disposal	0.37