EcoCover™, Woody Mulch and LDPE Primary Energy and Greenhouse Gas Emissions

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DATE: February 2011

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Acknowledgements

The author wishes to acknowledge the contribution of Reg Lewthwaite, project establishment and the woody mulch data collection and review.

EcoCover™, Woody Mulch and LDPE – Primary Energy and Greenhouse Gas Emissions

1. Executive Summary

This project has conducted a comprehensive life cycle assessment based on primary data of the resource inputs into the production of EcoCover, a mulch manufactured primarily from waste paper (77-81% recycled/waste content by weight). A literature review was conducted to determine the embodied primary energy and greenhouse gas emission factors for each input.

The primary energy required to manufacture one hectare of EcoCover and deliver it on site is 161,700 MJ/ha and greenhouse gas (GHG) emissions are 5,450 kgCO_2e/ha. The largest contributor to both the energy and GHG emissions is the PVA adhesive accounting for 80% and 68% of the respective energy and GHG results.

As 7,250 kg/ha of waste paper is diverted from the landfill a credit is given for the avoided landfill emissions, less the foregone carbon sequestration. Taking the avoided landfill emissions into account, EcoCover has an overall carbon credit of 6,200 kgCO_2e/ha. Note that the carbon credit has been generated from avoided landfill emissions, by diverting waste paper from the landfill and into the EcoCover mat. These carbon credits have no monetary value as they are not recognised under the Emissions Trading Scheme (ETS) legislation.

Two alternative commonly used mulches were also investigated, woody mulch and low density polyethylene (LDPE) plastic film. Woody mulch has the same greenhouse gas emissions as EcoCover 5,450 kgCO_2e/ha (prior to applying EcoCover's landfill carbon credit) and lower primary energy at 79,300 MJ/ha. Just over half (55%) of woody mulch's energy and GHG emissions arise from transport.

LDPE has the lowest primary energy of 23,670 MJ/ha (15% of EcoCover) and greenhouse gas emissions of 900 kgCO_2e/ha. This is 17% of EcoCover's manufacturing GHG emissions. However when the avoided landfill emissions are also taken into account EcoCover has a carbon credit.

2. Introduction

This report has been prepared to determine the primary energy and greenhouse gas emissions or carbon footprint for the product EcoCover, using life cycle assessment methodology.

EcoCover is a patented laminated mulch, manufactured primarily from waste paper sandwiched between 50% recycled kraft paper and bound together with PVA adhesive.

EcoCover has a wide range of applications including: many horticultural operations (e.g. strawberry row crops); public and private landscaping; native revegetation, and soil erosion protection. To help understand the results the energy and greenhouse gas emissions for woody mulch, typically used in landscaping, and LDPE plastic film, typically used in field and row production have also been determined on a per hectare basis.

3. What is Life Cycle Assessment?

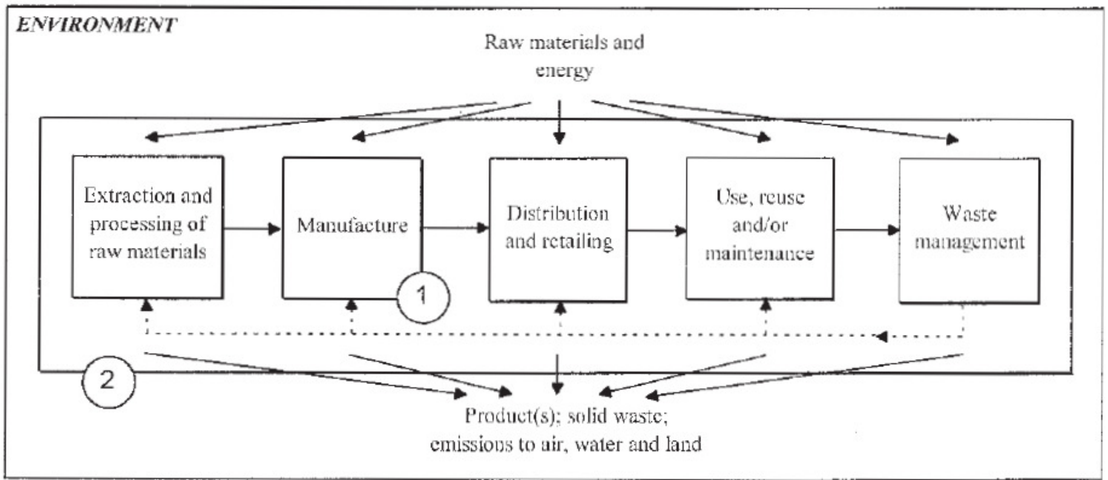
3.1 Overview

The examination of a product or services life cycle started in response to increased consumer and government environmental awareness. The science emerged from studies that were conducted to determine a product's total energy use. These studies not only examined the direct or consumer energy that it took to manufacture a product but also took into account the energy to manufacture and deliver all inputs such as chemicals, fertilisers, and capital equipment.

Life cycle studies were an extension of these and became vital to support the development of eco-labelling schemes and to quantify environmental claims.

Linked with environmental concerns is the question of sustainable production. A whole production approach needs to be adopted that not only includes the production process itself but also raw materials, total energy use, environmental impacts throughout the supply chain, and how the final product is used, disposed of or recycled. Consideration of these components has lead to the concept of 'cradle to grave' assessments of environmental impacts (Cowell, 1999).

This concept is illustrated in Figure 1. The conventional approach to environmental assessment only considered the processing system, as illustrated by System 1. However, to assess sustainability it is necessary to consider the raw materials and product disposal, as shown by System 2. This creates the 'cradle to grave' analysis for environmental impacts of a product or service under analysis (Cowell, 1999). A product system is characterised by its function and includes unit processes, elementary flows, product flows across the system boundaries (either into or out of the system) and intermediate product flows within the system (ISO 14041). The life cycle of a product is all the activities utilised in extraction of raw materials, design and formulation, production, processing, packaging, transportation, use and disposal of a product (European Environment Agency, 1997).



Source: Hodgson *et al.*, 1997.

Figure 1 Generic Flow Diagram for Life Cycle Thinking and LCA

The functional unit of analysis is service driven so different systems providing the same service may be able to be compared (Cowell, 1999). However the limitation of LCAs noted below (Section 3.2) needs to be considered when making such comparisons.

To have confidence in the data collected and results of an LCA study, the ISO Standards 14040 to 14043 should be followed.

3.2 Comparison Between Products

Caution is needed when making comparisons between different products, the same environmental impacts must be selected, and the same methodology and functional unit used (ISO 14042).

ISO 14042 recommends analysing the results of an LCA for sensitivity. This measures the influence which changes to inputs/outputs have on the indicator results, and uncertainty which determines the statistical variability in data sets, when a comparison between two products is required. It may be necessary to undertake other studies to provide full information on environmental impacts when making comparative statements. The undertaking of sensitivity and uncertainty analysis, so as to compare products, is only possible when you have a complete set of raw data for each product.

The European Environmental Agency (1997) recommends that LCAs are not used to claim a product or service is environmentally friendly or superior to another. It is possible to claim that using a specified set of criteria one product is better than another in certain aspects of its performance. However if making such claims it is very important not to over-claim, that accurate data and unbiased information is used, and the assessment has been peer reviewed.

4. Study Goal and Scope

4.1 Goal of the Study

The aim of the project is to develop a resource use inventory for the manufacture of EcoCover's mulch mat. The inventory will then be used to prepare the LCA environmental categories of resource use (total primary energy) and greenhouse gas emissions (carbon footprint).

While the first objective is to determine the product's resource use and greenhouse gas emissions, the second objective is for EcoCover to better understand their production process which will assist monitoring and delivering improved efficiencies.

4.2 Functional Unit

The functional unit is to cover one hectare (10,000 m^2) with mulch. The three mulches are EcoCover, LDPE film and woody mulch.

4.3 System Boundary

4.3.1 EcoCover Included

The system boundary includes the impacts associated with:

- The extraction, refinement, formulation, and transport to the EcoCover factory of fuel and materials,
- Fuel use includes LPG and electricity. Electricity included fugitive losses in conversion and distribution,
- Materials include sorted waste paper, kraft paper and PVA adhesive,
- Transport of kraft paper by ship between Australia and New Zealand,
- Transport of waste paper to the EcoCover factory by truck,
- Transport of EcoCover by truck to the mulch site.

The use of a waste product from a previous system presents an interesting question about where the system boundary should be drawn between the first virgin product and the waste co-product. In the case of waste paper people would often allocate the impacts of collecting the used material and transporting it to the recycling facility to the first use of the paper. Then the recycling activities and everything subsequent to that is allocated to the next system, in this case EcoCover.

However it is better to follow the guidelines described by Weidema (2001). In this situation where waste paper is not fully utilised, i.e. waste paper is still being sent to landfill, rules 1 and 3 apply (Weidema, 2001). This means that the waste paper's intermediate treatment (sorting at the recyclers) is ascribed to the waste paper and a credit is given for avoided waste treat (paper sent to a landfill). Part of the paper that would have been sent to landfill would have remained as long term sequestered carbon; this is deducted from the landfill credit.

4.3.2 EcoCover Excluded

The components of the life cycle which have been excluded are:

- Pins to anchor the EcoCover down,
- The embodied energy and emissions from capital equipment,
- Carbon sequestered in the soil (EcoCover commenced in 2008 a 5 year research project on this specific question),
- The laying out on site and use phase.

4.3.3 Woody Mulch Included

The system boundary includes the impacts associated with:

- The extraction, refinement, formulation, and transport to the chipping site of fuel,
- Fuel use includes diesel of the chipper,
- No materials are consumed,
- Transport to the chipping site and transport of fresh mulch by truck to the depot for aggregation,
- Transport by truck of aged woody mulch to the mulch site.

4.3.4 Woody Mulch Excluded

The components of the life cycle which have been excluded are:

- The embodied energy and emissions from capital equipment,
- Carbon sequestered in the soil,
- The spreading of mulch and the use phase.

4.3.5 LDPE Included

The system boundary includes the impacts associated with:

- The extraction, refinement, formulation, and transport to the LDPE factory of fuel, electricity and materials in China. Electricity included fugitive losses in conversion and distribution,
- Resin manufacture,
- Film extrusion,
- Transport of LDPE by ship between China and New Zealand,
- Transport of LDPE to the NZ supplier by truck,
- Transport of LDPE by truck to the mulch site.

4.3.6 LDPE Excluded

The components of the life cycle which have been excluded are:

- Pins to anchor the plastic down,
- The embodied energy and emissions from capital equipment,
- The laying out on site and use phase.

5. Methodology

EcoCover NZ was provided with a comprehensive survey that they completed on their production and resource use. Information on woody mulch was collected from a number of interviews with mulching contractors and information on LDPE was based on a literature review.

5.1 Fuel Primary Energy Use and GHG Emissions

Total energy use is calculated using primary energy values. This is the sum of consumer energy plus all the energy used or lost in the process of transforming energy into other forms and in bringing the energy to the final consumers. Consumer energy is defined as the amount of energy consumed by the final user, for example the kilowatt-hours recorded on the electricity meter or the actual energy value of fuel available to an engine.

When calculating total energy use it is necessary to use primary energy, so that both direct and indirect energy sources are being accounted for on the same basis. Table 1 summarises the fuel and electricity primary energy and GHG emissions. A full description is included in Barber (2009).

Australia and China have very similar electricity fuel mix profiles as both rely heavily upon conventional thermal power stations burning coal and natural gas. As no electricity LCA GHG emission factor could be found for China it was assumed to be the same as Australia.

Table 1 Summary of fuel energy and GHG emission factors

Fuel type	Unit	Consumer energy (MJ/unit)	Fugitive energy coefficient	Primary energy (MJ/unit)	GHG (gCO_2eq/ unit)
Diesel	litres	37.9	1.19	45.2	3,108
LPG	kg	49.5	1.13	55.9	3,357
IFO 380 (shipping)	kg	42.99	1.19	51.30	3,680
Avg NZ electricity (2008)	kWh	3.6	2.36	8.5	238
Avg Aust. elec (2004)	kWh	3.6	3.26	11.8	1,076 [2]

Source: Barber (2009) except where otherwise noted
2, Brown et al., 2007

Transport is normally a small component of a product's life cycle emissions. However for woody mulch it is a significant component and so consequently justifies spending additional time on ensuring the accuracy of the transport energy use and emission factors.

Most studies use transport emission factors based on the weight and distance travelled (t-km). This however can be extremely inaccurate both for shipping and road transport. The use of a t-km factor assumes a linear relationship between fuel use, distance and weight; this is not correct. Ships use virtually the same amount of fuel per day (all other things being equal) irrespective of how much cargo is on board due to their minimum requirements and need for ballast. Likewise truck fuel use varies between completely empty or fully laden by between just 16% and 36% depending upon the size of the truck (Defra, 2008).

A transport model was developed based on the Defra reports (2006 and 2008) to determine fuel use for trucks based on the distance and percent of laden load. GHG emissions were then calculated using the GHG emission factor for diesel (Table 1). Shipping fuel use was based on the AgLINC Shipping Model developed by AgriLINK NZ and Lincoln Universities AERU, and using Wild's (2008) fuel use figures in TEU's[1] per day. The transport distances are shown in the respective inventory tables.

5.2 EcoCover

5.2.1 Waste Paper Sorting

Waste paper is sorted at a recycling facility in Auckland. Electricity use is 0.3 GJ/t (Sundin, et al., 2002). This is 83 kWh/t and based on NZ's electricity emission factor 20 $kgCO_2e/t$.

5.2.2 Kraft Paper

Kraft paper with 50% recycled content is sourced from Australia. A number of studies have quantified the energy and GHG emissions of kraft paper, often in comparison studies with plastic grocery bags. FEFCO (European Federation of Corrugated Board Manufacturers) and CCB (Cepi ContainerBoard) (2009) provides the most comprehensive data on energy inputs and is based on 25% recycled paper content. The primary energy use is 9,050 MJ/t and using the fuel LCA emission factors described by Barber (2009) and the Australian electricity emission factor GHG emissions are 745 $kgCO_2e/t$.

This compares to other studies that found similar emissions including 810 $kgCO_2e/t$ (excluding landfill emissions and sequestration) James and Grant (2005) and the EcoInvent v2.2 LCI database of 845 $kgCO_2e/t$.
As rolls of kraft paper cannot be changed during production, if there is insufficient paper on a roll it will be replaced before starting a new production run. This paper is given away to car spray painting companies and used as masking paper. The production and transport emissions for this unused paper have not been included as they are allocated to the spray painter.

5.2.3 PVA Adhesive

PVA with 50% solids, which is mixed with water to 20% solids, is used in EcoCover to adhere the waste paper and kraft paper together. The emission factor for PVAc 3370 with 46% solids is 3.36 $kgCO_2e/kg$ (Spine database). The primary energy input, including the crude oil and natural gas embodied in the adhesive as well as the energy used during manufacturing, is 117 MJ/kg (Spine database).

[1] TEU is a container size, twenty foot equivalent unit.

5.2.4 Landfill Methane Emissions

By diverting waste paper away from the landfill methane emissions are avoided, which represents the alternative route to EcoCover production.

Paper that is not collected for recycling is disposed of at landfills. There the organic waste is broken down by bacterial action in a series of stages that result in the formation of carbon dioxide and methane. The carbon dioxide component is not included in the greenhouse gas calculations as it is considered part of the short-term carbon cycle. The quantity of methane released is, however, included and estimates are based on figures from the NZ GHG Inventory 1990–2008 (MfE, 2009b).

By diverting the paper to EcoCover, methane production at the landfill is avoided and can therefore be included as an avoided burden or credit for the final EcoCover product.

The quantity of methane released is calculated using the base equation and values:

$$MSW \times DOC_{organic} \times DOC_F \times F \times 16/12 \times (1-R) \times (1-OX) \times GWP_{CH4}$$

Table 2 New Zealand Greenhouse Gas Inventory Landfill Emission Values

Symbol	Description	Value
MSW	Municipal solid waste (kg)	
$DOC_{organic}$	Degradable organic carbon kg C/kg waste	0.40
DOC_F	Fraction of DOC dissimilated	0.50
F	Fraction by volume of CH_4	0.50
16/12	Conversion from C to CH_4	1.33
R	Fraction recovered CH_4 in landfill gas	0.41
OX	Oxidation factor	0.10
GWP_{CH4}	Global warming potential of methane	25.0

Source: Ministry for the Environment (2009a)

In 2006, 66% of New Zealand municipal solid waste sites had a landfill gas (LFG) methane recovery system (MfE, 2008). Their average collection efficiency was 41%. The 2006 national average value for recovered methane also happens to be 41% (calculated by dividing recovered CH_4 54.0 Gg by gross generation 132.1 Gg) and is the figure used in the calculation below.

$$\begin{aligned} \text{Landfill } CH_4 \text{ emissions} &= (0.40 \times 0.5 \times 0.5 \times 16/12) \times (1 - 0.41) \times (1 - 0.1) \\ &= 0.07 \text{ kg } CH_4/\text{kg paper} \\ &= 1.77 \text{ kg } CO_2\text{eq/kg paper} \end{aligned}$$

5.2.5 Landfill Carbon Sequestration

The United States Environmental Protection Agency (2006) estimates that landfill carbon sequestration of paper waste material is 0.044 metric tonnes of carbon equivalent per tonne of office paper (converted from 0.040 short tons). Converted to carbon dioxide, landfills sequester 160 $kgCO_2$/ t paper in the long term. These estimates were based on laboratory experiments conducted by Barlaz (1998) where the residual carbon that was left in the reactors was assumed to represent carbon that would remain undegraded or stored over the long term in landfills.

5.3 Woody Mulch

The two inputs into woody mulch are wood and diesel. Diesel is used by the chipper and for transport. The greenhouse emission factor for wood is assumed to be zero. The wood used for mulch is either from a waste stream or landscape clearing.

The chipper is assumed to have an 85hp diesel motor that is running at 85% power output and 90% throttle. Fuel use is calculated as being 17 L/hr. Based on interviews with mulching companies it takes approximately 20 minutes to chip $8m^3$. At this rate fuel use is 0.7 L/m^3.

Mulch is stockpiled at a depot before being taken to where it will be used. It was assumed that there was a 10% decrease in volume between fresh mulch and mulch that had been aged for a couple of months.

To cover one hectare with a 100mm thick layer of woody mulch requires $1{,}000m^3$ of mulch. Mulch has a bulk density of approximately $0.3t/m^3$.

It was considered that in most commercial cases there is no alternative use or disposal route for the type of wood turned into woody mulch. There will always be a use for woody mulch, even if it is just given away. Unlike waste paper, its use as a mulch has not otherwise diverted it from being sent to the landfill. Therefore woody mulch does not generate carbon credits due to avoided landfill emissions.

The vegetation chipped for mulch is not suitable as a wood chip for incineration and there is no industrial incineration to energy plants in NZ.

If the cleared vegetation was not chipped and removed it may be burned in the field, although this is unlikely in most situations due to council regulations about smoke. If burning was avoided then mulch could be credited with the avoided methane and nitrous oxide emissions from burning. For completeness the quantity of these emissions was calculated using the IPCC (2007) methodology for GHG emissions from fire. Burning produces 150 $kgCO_2e$/t dry matter (69 $kgCO_2e$/t fresh vegetation).

The results are shown in Section 6.2 to show what the avoided impact would be from not burning.

Woody mulch would also not be disposed of at a landfill as it would turn it from a product with an economic value as a mulch to a cost for disposal. Again for completeness the avoided methane emissions and foregone carbon sequestration were calculated and the results shown in Section 6.2. The same methodology was used as described in Sections 5.2.4 and 5.2.5. Landfill emissions are 1.12 kgCO_2e/kg wood and carbon sequestration is 0.77 kgCO_2e/kg wood.

Transport is a major component of woody mulch LCA emissions. The methodology is described in Section 5.1.1 and the distances are shown in the woody mulch inventory (Section 6.2).

5.4 Low Density Polyethylene (LDPE)

Low density polyethylene resin is manufactured from the polymerisation of ethylene. This is a product of the petrochemical industry produced by cracking using naphtha (derived from crude oil) and natural gas. LDPE has a bulk density of 0.92 g/cm^3.

LDPE resin has greenhouse gas emissions of 2.10 kgCO_2e/kg (ELCD database). The primary energy value is 72.2 MJ/kg.

The resin is then extruded into a film using 3.1 MJ/kg (0.86 kWh/kg) of electricity (Spine database). Based on a Chinese electricity emission factor of 1.08 kgCO_2e/kWh greenhouse gas emissions are 0.93 kgCO_2e/kg LDPE.

To cover 1 ha requires 10,000 m^2 of plastic. In this analysis anything required to pin the plastic down or extra plastic for overlapping and burying has not been included.

6. Life Cycle Inventory and Impact Assessment

6.1 EcoCover

The energy, material inputs, transport and production profile of EcoCover is shown in Table 3.

Table 3 EcoCover Resource Use Inventory

	quantity	units	description	quantity per ha	units
Energy					
Electricity	30	kWh/hr		833	kWh
LPG	6.6	kg/hr		183	kg
Materials					
Waste paper	420	t/yr		7,246	kg
50% recycled kraft paper	46	t/yr		794	kg
PVA 50% solids	64	t/yr		1,104	kg
Transport					
Kraft paper shipped from Australia	2,370	km	20 t/TEU, 70% ship loading factor	794	kg
Waste paper recycling depot to EcoCover factory	20	km	60% laden wt, 1.4 t/load, <7.5t truck	5.4	No. of trips
EcoCover factory to waste recycler (return)	20	km	0% laden wt, <7.5t truck	5.4	No. of trips
EcoCover factory to mulch site	10	km	65% laden wt, 3.7 t/load, 7.5 – 17t truck	2.0	No. of trips
Mulch site return	10	km	0% laden wt, 7.5 – 17t truck	2.0	No. of trips
Production					
EcoCover dry weight	0.73	kg/m^2		7,250	kg

Based on the resource use inventory the total primary energy of EcoCover is 161,750 MJ/ha. 80% of the energy is embodied or used in the manufacture of PVA.

The greenhouse gas emissions from the manufacturing and delivery to the mulching site of EcoCover is 5,455 kgCO_2e/ha. The carbon credit for diverting waste paper from a landfill, less the carbon that would have been sequestered long term, results in an overall carbon credit of 6,200 kgCO_2e/ha. Note that the carbon credit has been generated from avoided landfill emissions, by diverting waste paper from the landfill and into the EcoCover mat. These carbon credits have no monetary value as they are not recognised under the Emissions Trading Scheme (ETS) legislation.

Figure 2 shows the distribution of emissions per hectare of EcoCover from each input. Note that the negative numbers are carbon credits; this is for the avoided landfill emissions and the overall EcoCover product.

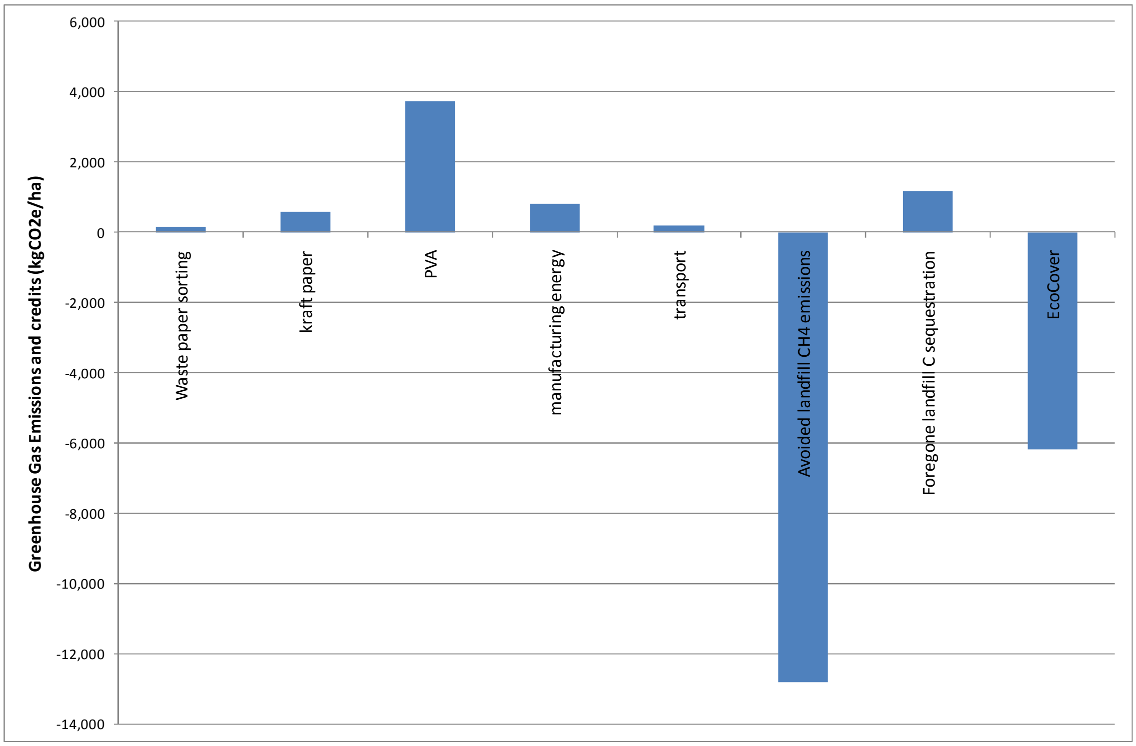


Figure 2 EcoCover Greenhouse Gas Emissions per Hectare

6.2 Woody Mulch

The energy, transport and production profile of woody mulch is shown in Table 4.

Table 4 Woody Mulch Resource Use Inventory

	quantity	units	description	quantity per ha	units
Energy					
Diesel	0.7	L/m^3	chipper – 85hp	780	litres
Transport					
Depot to chipping site	10	km	0% laden wt, 7.5 – 17t truck	138	No. of trips
Chipping site to depot	10	km	45% laden wt, 2.4 t/load, 7.5 – 17t truck	138	No. of trips
Depot to mulch site	10	km	100% laden wt, 9.6 t/load, >17t truck	31	No. of trips
Mulch site to depot	10	km	0% laden wt, >17t truck	31	No. of trips
Production					
Fresh wood chips	1,100	m^3/ha	300 t/ha	1,100	m^3
Woody mulch	1,000	m^3/ha	330 t/ha	1,000	m^3

Based on the resource use inventory the total primary energy of woody mulch is 79,320 MJ/ha. 55% of the energy is required for transport, with the rest used by the chipper.

The greenhouse gas emissions of woody mulch are 5,450 kgCO_2e/ha, which is the same as the manufacturing and transport emissions for EcoCover.

If the wood had been diverted from the landfill then avoided emissions would be 368,000 kgCO_2e/ha and the foregone sequestered carbon would be 253,000 kgCO_2e/ha. Due to the large amount of carbon in wood the landfill dwarfs the chipping and transport emissions.

If the wood would have otherwise been burnt on site then chipping the wood into a mulch avoids 22,800 kgCO_2e/ha in the form of avoided methane and nitrous oxide emissions from the fire.

6.3 Low Density Polyethylene (LDPE)

One hectare of 30µm LDPE plastic requires 276 kg of resin. It is manufactured in China and then shipped to NZ.

Table 5 LDPE Resource Use Inventory (30µm)

	quantity	units	description	quantity per ha	units
Material					
Resin	276	kg/ha	manufactured in China	276	kg
Film extrusion	276	kg/ha	manufactured in China	276	kg
Transport					
Plastic film shipped from China	29,420	km	20 t/TEU, 70% ship loading factor	276	kg
Port to supplier	20	km	41% laden wt, 1.0 t/load, <7.5t truck	0.3	Share of trip
Return	20	km	0% laden wt, <7.5t truck	0.3	Share of trip
Supplier to mulch site	10	km	12% laden wt, 0.3 t/load, <7.5t truck	1	No. of trips
Return	10	km	0% laden wt, >17t truck	1	No. of trips
Production					
LDPE	10,000	m^2/ha	276 kg/ha	10,000	m^2

Based on the resource use inventory the total primary energy of 30 µm LDPE delivered to the mulch site is 23,670 MJ/ha. 84% of the primary energy is embodied in and required to manufacture the resin, with a further 12% to extrude the film and 4% for transport.

The greenhouse gas emissions are 900 kgCO_2e/ha, 64% are from the resin manufacture, 28% during extruding and 8% in transport.

A thicker 50µm film has a primary energy value of 39,450 MJ/ha and greenhouse gas emissions of 1,500 kgCO_2e/ha.

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