Environmental benefits of recycling

NSW
GOVERNMENT

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& Water

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Abbreviations

C & I	Commercial and Industrial
C & D	Construction and Demonstration
DECCW	The Department of Environment, Climate Change and Water NSW
LCA	Life Cycle Assessment

1 Introduction

The aim of the Environmental Benefits of Recycling (EBR) Study (October 2009) is to develop tangible measures to express the environmental benefits associated with the recycling of various materials. It measures the estimated energy, water, greenhouse gas and landfill savings of recycling programs. Through this study, the Department of Environment, Climate Change and Water (DECCW) aims to provide a transparent and objective evaluation of the environmental benefits and impacts of recycling 21 waste materials from residential, commercial and industrial (C&I) and construction and demolition (C&D) sources in New South Wales. In determining environmental impacts the study has adopted, where feasible, methods acceptable to the federal Department of Climate Change under greenhouse gas quantification and offsetting schemes such as Greenhouse Friendly.

This study is based on a scientific and transparent Life Cycle Assessment (LCA) methodology. It has used an international best practice LCA methodology to assess the potential environmental impacts of recycling. The following report seeks to document the results of the LCA study undertaken, in accordance with the international standard ISO14040 (2006).

2 Background

Recycling in general

In New South Wales (NSW) there is strong public support for recycling which has been encouraged by governments and industry alike. This support has been based on the assertion that 'recycling is good' because it has a positive impact on the environment through the saving of resources and a reduction in the impacts resulting from landfill.

Implicit in the assertion is the assumption that the total environmental impact of recycling is less than the impact of traditional waste disposal such as landfill. The belief that 'recycling is good' is founded on the more obvious benefits of avoiding landfill processes and the notion that material is reused and therefore does not need to be extracted from the environment. These benefits are indeed present for many recycling processes, however recycling almost always has an environmental impact of its own. This recycling impact is typically associated with collection methods, such as trucks and sorting facilities, and material reprocessing methods, such as aluminium smelters or paper reprocessors. Once these impacts become part of the consideration, the statement 'recycling is good' becomes more difficult to validate.

In order for recycling to be environmentally advantageous, benefits such as virgin material substitution and avoided landfill and material recovery need to offset recycling related impacts such as material collection and reprocessing. Only by objectively assessing the impacts associated with the various components of a recycling process and its alternative landfill process (landfill is the predominant waste disposal practice in Australia) can it be concluded that a recycling process is environmentally beneficial.

Rather than accepting the assertion 'recycling is good', this study undertakes the assessment necessary to determine if recycling is environmentally preferable across a range of material types. In addition to determining if recycling is beneficial, the LCA method used also quantifies benefits across a range of environmental indicators.

Prior studies

This study is not unique in attempting to quantify the benefits of recycling a range of waste materials. It builds upon the initial *Benefits of Recycling Study*[1] and the subsequent *Environmental Benefits of Recycling Calculator*[2], by expanding the list of recyclable materials and adding landfill savings as an environmental benefit. Both these studies sought to quantify and then disseminate benefits associated with recycling, and both employed an LCA methodology.

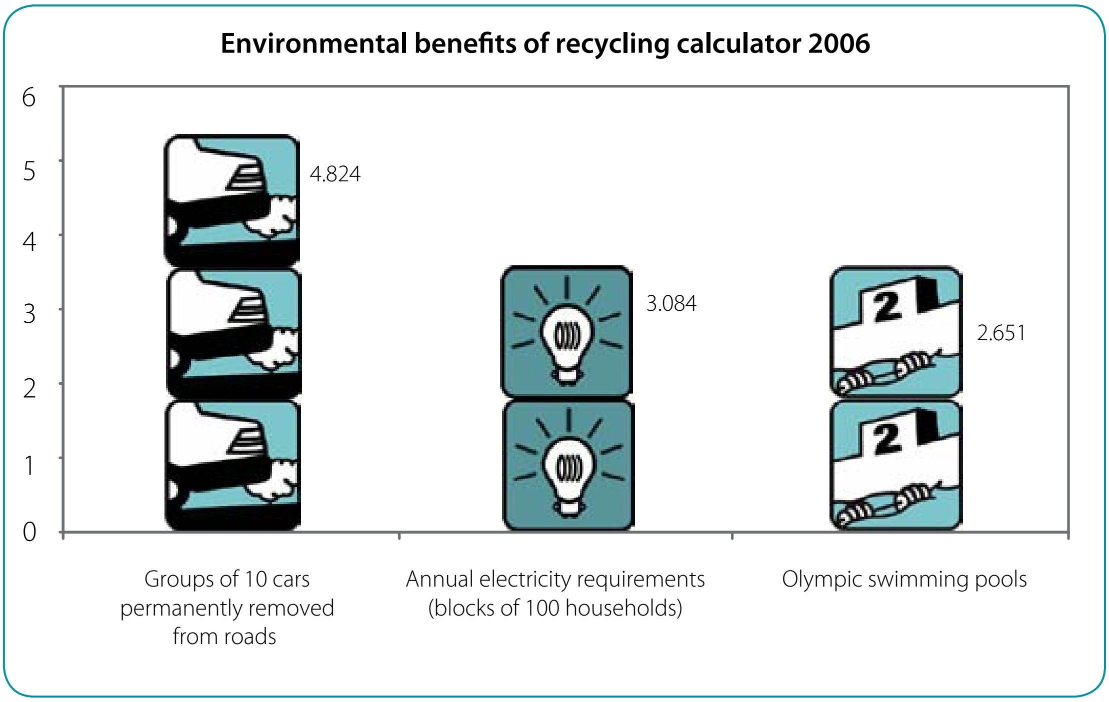
In Victoria, numerous recycling related studies have been undertaken. In particular the *Life Cycle Impact Data for Resource Recovery from Commercial and Industrial and Construction and Demolition Waste in Victoria* (Grant and James 2005) uses LCA to assess benefits associated with C&I and C&D waste streams, and the Stage 2 Report for *Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria* (Grant, James et al. 2001) used LCA to understand a range of waste scenarios related to packaging waste. *Life Cycle Assessment of Waste and Resource Recovery Options* (Grant, James et al. 2003) reviewed a range of packaging material disposal options, using LCA, of which recycling was a key focus.

This study builds on and expands the above studies. By combining and adding new materials and collection systems, it provides a widest range of material assessments than the above studies.

Environmental Benefits of Recycling Calculator

DECCW has developed a Microsoft Excel based calculator (2006) to help communicate recycling benefits to councils, industry and business. This calculator allows users to input quantities of waste material recycled which are then analysed and the resulting environmental benefits displayed. Figure 1 shows a typical results chart for a recycling process, illustrating the simplified impact units employed.

Figure 1. Sample output from the Environmental Benefits of Recycling Calculator



This study has updated the principles behind the calculator by expanding the range of materials considered (increased from 7 to 21 material types), and by improving transparency of calculations used to determine environmental impacts.

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[1] Department of Environment and Conservation (NSW) (2005). Benefits of recycling.

[2] Department of Environment and Conservation (NSW) (2006). Environmental benefits of recycling calculator.

3 Scope

This report considers the recycling benefits and impacts of 21 materials by commonly used recycling pathways (Table 1). For most materials, two collection pathways were considered:

i) kerbside collection of commingled waste which must be sorted prior to transfer to the material reprocessor; and
ii) direct transfer of segregated wastes from C&I and C&D sources to the material reprocessor.

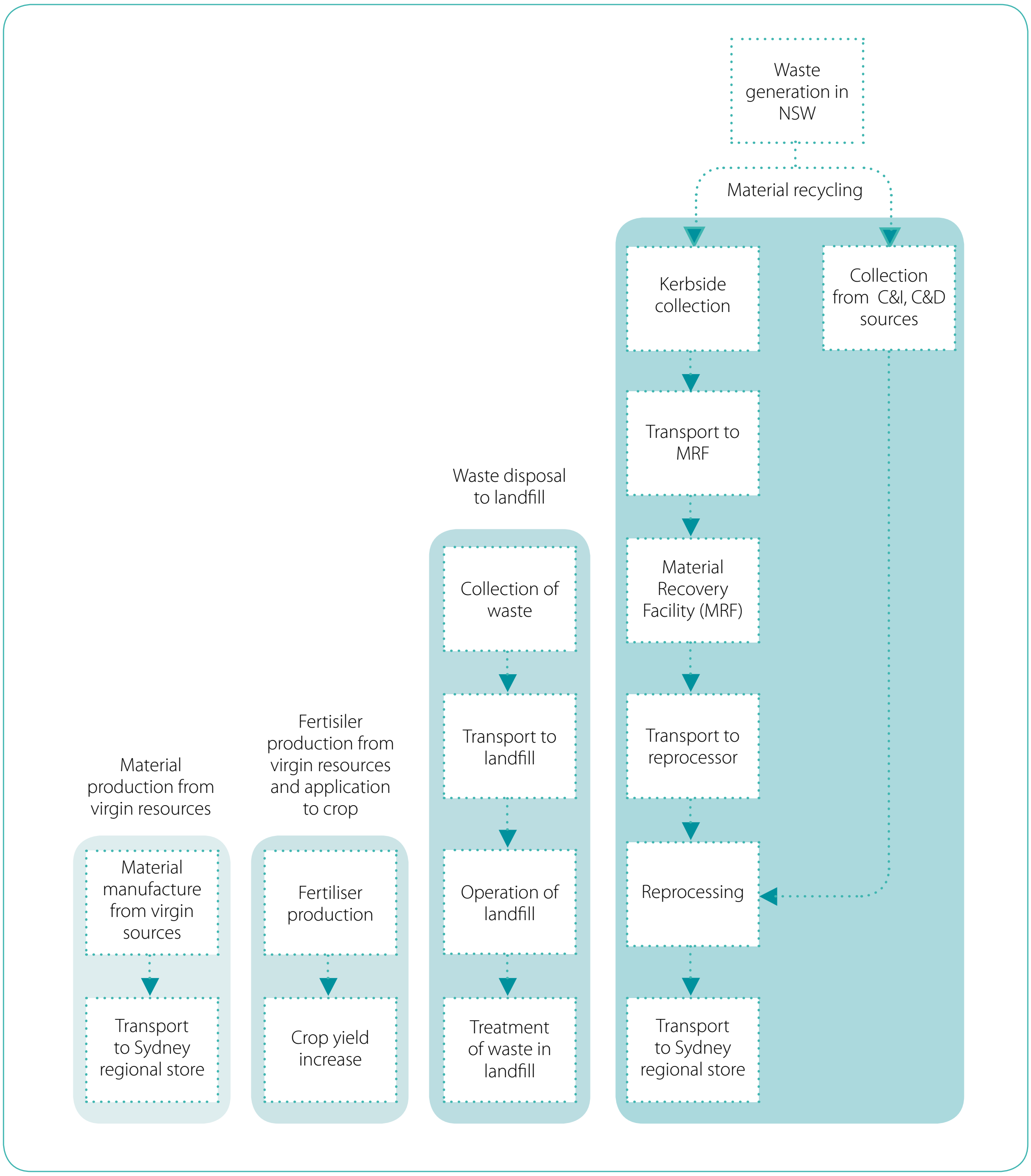
Table 1. Materials studied

Metals	1a. Aluminium cans 1b. Aluminium (other than cans) 2. Copper 3a. Packaging steel (steel cans) 3b. Steel
Concrete, brick and asphalt	4. Asphalt 5. Brick (modelled as 'Brick and Tile') 6. Concrete 7. Plasterboard
Paper and cardboard	8. Cardboard/paper packaging 9. Newsprint/magazines 10. Liquid paper board 11. Office Paper
Organics	12. Timber pallets/packaging 13. Mixed food and garden organics 14. Garden organics
Glass	15. Glass containers 16. Sheet/laminated glass
Plastics	17. PET #1 18. HDPE #2 19. PVC #3 20. Mixed plastics #7 21. Rubber tyres

System boundary for the study

The system boundary in an LCA describes those process units considered in determining the environmental impacts of the product or process being studied. In this study the system boundary for the study begins at the point of waste generation (Figure 2) and encompasses processes required to either recycle the waste material or treat it in landfill. Also included within the system boundary are processes associated with material production from virgin resources and the production and use of fertilisers. These additional systems are included to enable the study to quantify the benefits associated with material recovery and the use of organic compost as a fertiliser alternative (applicable to organic material composting). Figure 2 System boundary for LCA

Figure 2. System boundary for LCA



Reference unit

The reference unit of an LCA defines how different products will be compared. The reference unit for this study is defined as 'the management of one tonne of waste material in a typical residential, commercial/industrial and construction/demolition waste stream in NSW'.

Results reported throughout the study are stated in terms of this reference unit.

Environmental indicators

Potential environmental impacts associated with the systems described above are defined as shown in Table 2.

Table 2. Environmental indicators

Indicators	Unit	Description
Greenhouse gases	tonnes CO_2e	Climate change effects resulting from the emission of carbon dioxide (CO_2), methane or other greenhouse gases into the atmosphere – this indicator is represented in CO_2 equivalents (tonnes CO_2e). Alternately it can also be represented in terms of the number of black balloons (50g of CO_2e) or the number of automobiles permanently removed from the road. The family vehicle is assumed to emit 4.16 tonnes over its lifetime. Unit: cars permanently retired.
Cumulative energy demand (CED)	GJ LHV	All energy use including fossil, renewable, electrical and feedstock (incorporated into materials such as plastic). CED is measured in terms of giga-joules of fossil energy (low heating value) (GJ LHV). Alternately, CED can also be represented by the amount of electricity consumed in an average Australian household each year (6000 kWh). Unit: houses p.a.
Water use	kL H_2O	Net water use – potable, process, cooling measured in kilolitre units. Water quality, water depletion and biodiversity. This is also represented by the number of Olympic sized swimming pools (2500kL volume). Unit: swimming pools.
Solid waste[1]	tonnes	Solid wastes from production and reprocessing. Impacts depend on the character of the waste – a mixture of final waste to landfill and production waste from the supply chain. It is also represented by number of average sized wheelie bins (55kg capacity). Unit: wheelie bins.

Intended applications

The results from this study will be used by the DECCW to assist councils, industry and businesses to estimate, extend and communicate the environmental benefits of their recycling programs. It should be noted that the study covered many materials and not all recyclers provided enough information for modelling their recycling process, so assumptions and publicly available data have been used in some cases. Although the results of this report provide reasonable estimates of the benefits of overall recycling activities in the residential, C&I and C&D sectors, results should not be used for the comparative assessment of specific waste management technologies.

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[1] The space saved in landfill by diverting waste streams to recycling facilities have been taken into account in the calculator. Waste densities figures after compaction have been used in the calculator as presented in Zero Waste SA (2004). This study has been chosen for this purpose as it covers a large range of waste types, and is based on on-site measurements.

Data quality requirements

Data sets used in the study varied in terms of quality. In general, the bulk of data used were from existing studies undertaken in Victoria and NSW, which were adapted to suit current energy mixes.

Effort was made to collect data directly from recyclers in New South Wales, however very few responses were received and those that were, were often incomplete. As a result, data sets used reflect best available data from the literature. Detailed data assessment by material type are available on DECCW website.

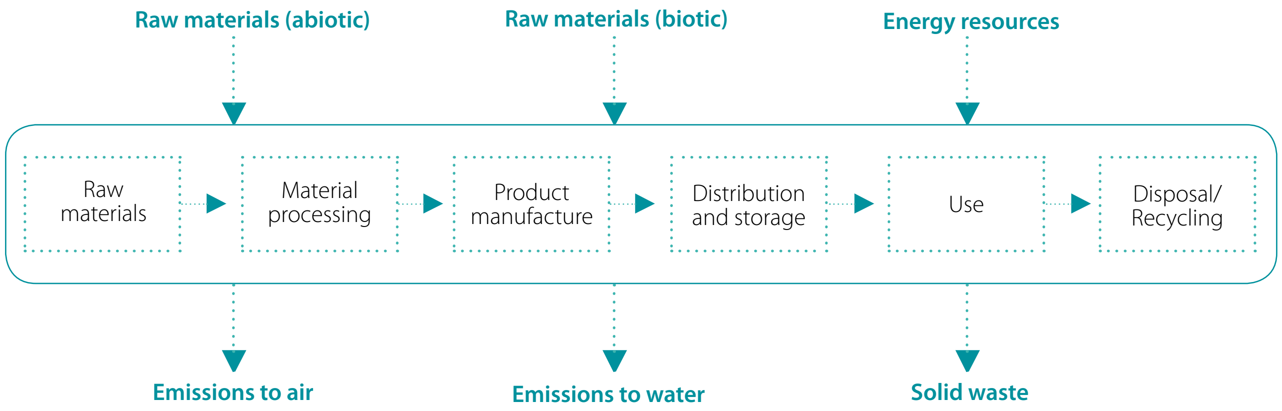
4 Methodology

Life Cycle Assessment

LCA is the process of evaluating the potential effects that a product, process or service has on the environment over the entire period of its life cycle.

Figure 3 illustrates the life cycle system concept of natural resources, energy coming into the system and products and emissions leaving the system.

Figure 3. Life cycle system concept

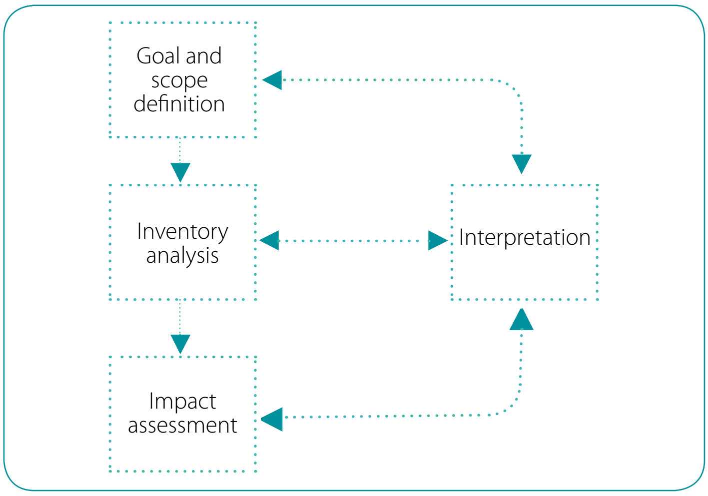


The International Standards Organisation (ISO) has defined LCA (AS/NZS 1998) as:
'a technique for assessing the environmental aspects and potential impacts associated with a product by:

- compiling an inventory of relevant inputs and outputs of a product system
- evaluating the potential environmental impacts associated with those inputs and outputs, and
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.'

The technical framework for LCA consists of four components, each having a crucial role in the assessment. They are interrelated throughout the assessment and in accordance with the current terminology of the ISO. These components are goal and scope definition, inventory analysis, impact assessment and interpretation (see Figure 4).

Figure 4. The components of an LCA



Source: AS/NZS (1998)

Goal and scope definition

At the commencement of the LCA, the goal and scope of the study must be clearly defined. The goal should state unambiguously the intended application/purpose of the study, the audience for which the results are intended, the product or function that is to be studied, and the scope of the study. When defining the scope, consideration of the functional unit, system boundaries and data quality requirements are some of the issues to be covered.

Inventory analysis

Inventory analysis is concerned with the collection, analysis and validation of data that quantifies the appropriate inputs and outputs of a product system. The results include a process flow chart and a list of all environmental inventories (inventory table) associated with the product under study.

Impact assessment

The primary aim of an impact assessment is to identify and establish a link between the product's life cycle and the potential environmental impacts associated with it. The impact assessment stage consists of three phases that are intended to evaluate the significance of the potential environmental effects associated with the product system.

Interpretation

Interpretation is a systematic evaluation of the needs and opportunities to reduce the environmental burden, such as changes in product, process and service design, and reductions in raw material and/or energy use.

LCA software

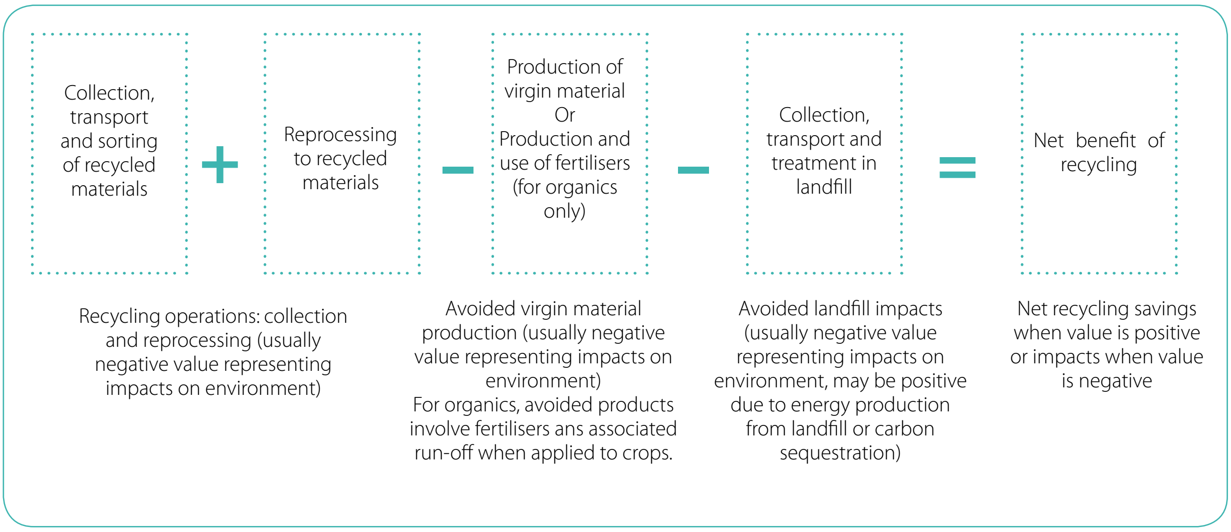
The LCA in this study was undertaken using the SimaPro® software package. SimaPro® is the most widely used LCA software in the world. Introduced in 1990 in response to industry needs, the SimaPro® product family facilitates the application of LCA, using transparent and comprehensive analysis tools (process trees, graphs and inventory tables).

Quantifying the benefits of recycling

In LCA, system expansion is one method that can be used to address recycling. It involves expanding the system boundary of the study to incorporate not only the recycling process itself, but avoided processes such as treatment of waste in landfill, material production from virgin sources and virgin fertiliser production and use (in the case of organic composting). Figure 2 describes the processes considered and illustrates the expanded inclusion of processes.

By analysing the expanded system it is then possible to determine a net impact of recycling by taking a consequential approach. A consequential approach considers that by undertaking recycling other alternative activities are not undertaken as a consequence. In other words, by undertaking recycling, impacts are incurred associated with collection and reprocessing of waste materials and process impacts are avoided, such as the production of virgin material (because recycling generates recovered material), and the collection and treatment of waste in landfill (because the recycling of waste means it no longer has to be treated in landfill). This approach is translated into the equation that is used to determine the net benefits (or impacts) of recycling in Figure 5.

Figure 5. Method for calculating net environmental savings in the recycling process



Recycling operations: collection and reprocessing (usually negative value representing impacts on environment)

Avoided virgin material production (usually negative value representing impacts on environment)
For organics, avoided products involve fertilisers ans associated run-off when applied to crops.

Avoided landfill impacts (usually negative value representing impacts on environment, may be positive due to energy production from landfill or carbon sequestration)

Net recycling savings when value is positive or impacts when value is negative

5 Inventory

Material flow information was collected for each of the materials considered. Attempts were made to collect information from recyclers in NSW, however a poor response rate was achieved. As an alternative to local data collection, process data from Victorian and past NSW studies were used (Grant, 1999; Grant, 2005; Grant, 2001; Grant, 2003).

Wherever possible, recycling data was adjusted to suit local conditions. Transport, in particular, was adjusted to suit a Sydney metropolitan environment.

In general, it is believed that recycling process data collected in Victoria would be transferable to a NSW context, provided adjustment is made for transport and electricity supply differences.

A summary of materials considered is shown in Table 3. The table describes key assumptions regarding the recycling route modelled and avoided products considered. In some cases recycling systems were not modelled due to lack of available data. In these cases 'recommended substitute' materials are suggested in the event the reader requires a guide as to how recycling of these materials might perform.

A detailed inventory of material flows and data sources are available on the DECCW website.

Table 3. Materials included in the study

Materials modelled in this study						
#	**Material**	**Municipal collection considered**	**C&I, C&D collection considered**	**Recommended substitute material model**	**Recycling route modelled**	**Products avoided through recycling of material**
Metals						
1a	Aluminum cans	Yes	Yes		Reprocessing at aluminum smelter	Virgin aluminum
1b	Aluminum (other than cans)	No	Yes		Reprocessing at aluminum smelter	Virgin aluminum
2	Copper	No	Yes		Generic electrolytic recycling process	Virgin copper
3a	Packaging steel (steel cans)	Yes	No		Electric arc furnace	Virgin steel
3b	Steel	No	Yes		Electric arc furnace	Virgin steel
Concrete, brick and asphalt						
4	Asphalt	No	Yes		Combine with asphalt mix	Gravel, sand, bitumen and limestone
5	Brick (modelled as "Brick & Tile")	No	Yes		Crushed and screened	Gravel
	Tiles – NOT MODELLED Considered as part of combined "Brick & Tile" model developed			"Brick & Tile"		
6	Concrete	No	Yes		Crushed and screened	Gravel
7	Plasterboard	No	Yes		Screening, composting, blending	Soil (wood chips and fertiliser)
Paper and cardboard						
8	Cardboard/paper packaging (modelled as "Paper and board")	Yes	Yes		Pulping and re-incorporate into paperboard	Unbleached Kraft pulp
9	Newsprint/ magazines	Yes	Yes		Pulping and re-incorporate into paperboard	Semi-bleached Kraft pulp
10	Liquid paper board	Yes	No		Pulping and re-incorporate into paperboard	Unbleached Kraft pulp
	Other – NOT MODELLED "Paper and Board" model developed is based on industry averages, so incorporates a mix of feedstock and most common recycled materials (including "mixed paper")					

Materials modelled in this study						
11	Office paper	Yes	Yes		Pulping and re-incorporate into paperboard	Bleached Kraft pulp
Organics						
12	Timber pallets/packaging	No	Yes		Reusable material into new pallets, non-reusable as shredded timber into landscape mulch	Structural pine
13	Food organics	Yes	Yes		Composted	Fertilisers, crop yield, pesticide
14	Garden organics	Yes	No		Composted	Fertilisers, crop yield, pesticide
Glass						
15	Glass containers	Yes	Yes		Glass production	Sand, soda ash, lime, feldspar
16	Sheet/laminated glass	Yes	Yes		Impact blasting	River sand
Plastics						
17	PET #1	Yes	Yes		Separated, cleaned, re-granulated	Virgin PET
18	HDPE #2	Yes	Yes		Separated, cleaned, re-granulated	Virgin HDPE
19	PVC #3	Yes	Yes		Separated, cleaned, re-granulated	Virgin PVC
	LDPE #4 – NOT MODELLED PP #5 - NOT MODELLED PS # - NOT MODELLED Detailed process information not known. Expect impacts to be similar to offshore reprocessing as modelled in "Mixed Plastics"			Mixed Plastics		
20	Mixed plastics #7	Yes	Yes		Separated, cleaned, re-granulated	Virgin PP
21	Rubber Tyres	No	Yes		Cutting, extract metal, grind and sieve to produce crumb and granule size	Virgin Polybutadiene

Waste collection assumptions

In order to determine the impacts of waste collection systems and recycling collection systems, detailed transport models were developed for both kerbside collection and C&I and C&D collection. These models and their founding assumptions are described in the data assessment by material type available on DECCW website.
For more information see *EBR Study (2009) Collection System Assumptions* available on DECCW website.

Landfill assumptions

One of the key benefits associated with recycling is the avoidance of landfill. When determining the net benefits of recycling it is necessary to incorporate the impacts of landfill, which can be significant.

When organic waste (food, garden clippings, paper, timber) is treated in landfill, gases are emitted that contribute to green house gases emission. As organic matter breaks down in landfill both biogenic carbon dioxide (CO_2) and methane (CH_4) are emitted. Methane is the most important of these gases from a green house gases perspective because it has a high global warming potential (21–25 times that of CO_2). Biogenic CO_2 is not considered a source of anthropogenic green house gases because it is derived from natural sources and would be produced as part of natural cycles.

For more information see *EBR Study (2009) Treatment of Waste in Landfill* available on DECCW website.

Material Recovery Facility assumptions

An aspect of most kerbside recycling processes is the use of a Material Recover Facility (MRF) to sort and segregate materials. MRFs are often complex systems that consume energy and water in processing commingled inputs into streams of common material type.

For more information see *EBR Study (2009) Material Recovery Facility* available on DECCW website.

Assumptions on energy production

Many industrial processes described in this study use mains supplied electricity or natural gas to provide energy. Detailed assumptions regarding the greenhouse impacts associated with the consumption of natural gas and electricity from the mains supply systems are described.

For more information see *EBR Study (2009) Assumptions on Energy Production* available on DECCW website.

6 Results

The characterisation of the results for 1 tonne of waste material recycled is shown in Table 4. Results illustrate the net benefit (positive) or impact (negative) of recycling 1 tonne of a particular material waste. As mentioned in Section 3 (Scope), results have been calculated for both kerbside and C&I and C&D sources:

i) kerbside collection of commingled waste which must be sorted prior to transfer to the material reprocessor; and
ii) direct transfer of segregated wastes from C&I and C&D sources to the material reprocessor.

Cells that are shaded in Table 4 have not been calculated as part of this study.

Table 4. Net benefit of recycling 1 tonne of waste material

		Greenhouse Gases (tonnes CO2e)		**Cumulative energy demand (GJ LHV)**		**Water use (kL)**		**Solid waste (tonnes)**	
		Kerbside	C&I,C&D	Kerbside	C&I,C&D	Kerbside	C&I,C&D	Kerbside	C&I,C&D
1a	Aluminium cans	15.85	17.72	171.10	191.42	181.77	202.03	1.40	1.56
1b	Aluminium scrap	▨	17.72	▨	191.42	▨	202.03	▨	1.56
2	Copper	▨	3.43	▨	36.09	▨	5.97	▨	1.10
3a	Packaging steel	0.40	▨	7.31	▨	-2.29	▨	0.95	▨
3b	Steel	▨	0.44	▨	7.94	▨	-2.36	▨	1.00
4	Asphalt	▨	0.03	▨	2.38	▨	0.88	▨	1.06
5	Brick	▨	0.02	▨	0.28	▨	1.26	▨	1.07
6	Concrete	▨	0.02	▨	0.35	▨	1.28	▨	1.09
7	Plasterboard	▨	0.03	▨	0.55	▨	-0.03	▨	0.98
8	Cardboard/ paper packaging	0.60	0.63	9.32	10.76	25.41	28.28	0.64	0.74
9	Newsprint/ magazines	0.99	1.04	6.33	6.43	13.06	11.96	0.67	0.74
10	Liquidpaperboard	-0.30	▨	-3.22	▨	8.66	▨	0.31	▨
11	Office Paper	0.74	0.67	4.12	2.63	2.91	0.37	0.93	0.96
12	Timber pallets/packaging	▨	1.35	▨	10.73	▨	-0.04	▨	0.80
13	Food & garden organics	0.25	▨	0.18	▨	0.44	▨	0.35	▨
14	Garden organics	0.32	▨	0.47	▨	0.48	▨	0.61	▨
15	Glass containers	0.56	0.62	6.07	6.85	2.30	2.44	0.94	0.99
16	Sheet/laminated glass		0.02	▨	0.33	▨	0.01	▨	1.04
17	PET #1	0.95	1.18	48.45	55.49	-20.38	-22.56	0.78	0.77
18	HDPE #2	0.84	1.08	50.35	57.92	-3.31	-3.58	2.55	2.84
19	PVC #3	1.38	1.95	38.81	48.92	64.02	71.25	0.74	0.84
20	Mixed plastics #7	1.53	1.59	58.24	62.99	-11.37	-11.25	0.83	0.83
21	Rubber Tyres	▨	1.07	▨	64.08	▨	52.25	▨	1.07

* positive values are benefits, negative values are impacts

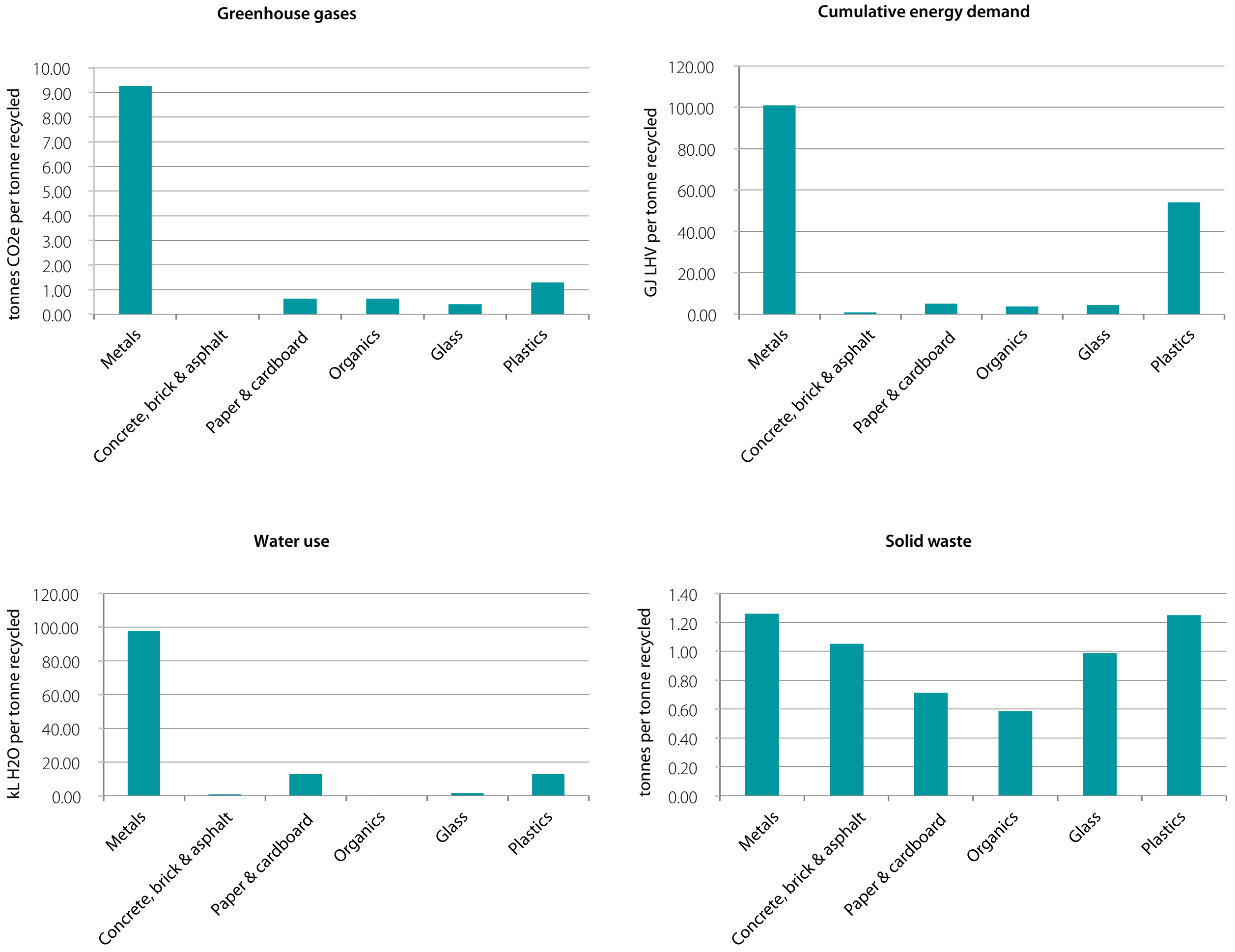
7 Discussion

Comparison of materials by category

Given the large range of materials assessed, it is difficult to meaningfully discuss results without grouping materials first. If results are grouped in accordance with the broad categories outlined in Table 1, some initial conclusions can be drawn.

Figure 6 shows the average (simple average of results shown in Table 4, for each category) net benefits achieved for each environmental indicator assessed when 1 tonne of waste is recycled. In general, metals recycling is shown to generate the greatest benefits across the indicators considered, dominating greenhouse gases, cumulative energy demand and water use. High benefits associated with metals are predominantly due to the high impacts associated with producing metals from virgin resources relative to the lower impacts associated with reprocessing (per tonne). Aluminium, in particular, is resource intensive to produce per tonne from virgin materials.

Figure 6. Average net benefit of recycling 1 tonne of waste by material category



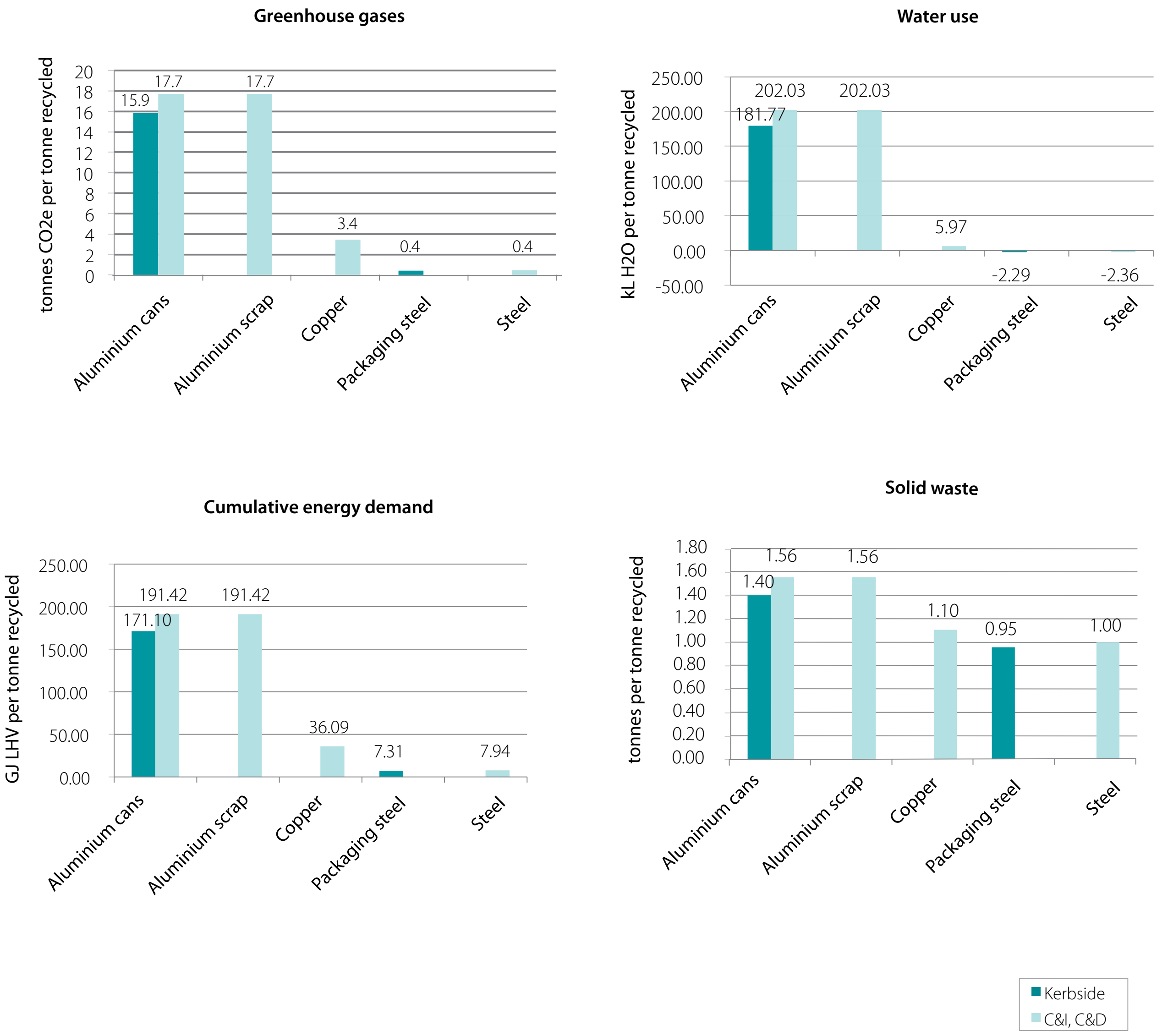
Other materials shown in Figure 6 are also shown to generate benefits from recycling, although not to the same degree as metals. Plastics, paper and board, organics and glass all generate significant benefits. Concrete, brick and asphalt generate reduced benefits from recycling, primarily due to their highly dense nature. Concrete, brick and asphalt are less resource intensive to produce from virgin resources, per tonne, making benefits from recycling lower per tonne, even given relatively low reprocessing impacts.

Comparison of materials within categories

Metals

Within the metals category there is a range of net benefits from recycling. Aluminium is particularly beneficial to recycle due to its high impact of production from virgin sources. Copper and steel are also beneficial to recycle in most indicators. Of note is that steel recycling generates a small water impact. This impact is due to steel production from virgin sources generating blast furnace slag which in turn is used in concrete production as a substitute for cement. When recycling is undertaken, this process no longer occurs, so concrete production must revert to cement in place of blast furnace slag. Relatively, cement production is a water intensive process, so this results in recycling actually increasing water use in the concrete industry. Although technically adequate from an LCA perspective, further investigation may be required to confirm that this would indeed be the result (it could be that the concrete industry would seek an alternative to blast furnace slag that is not cement).

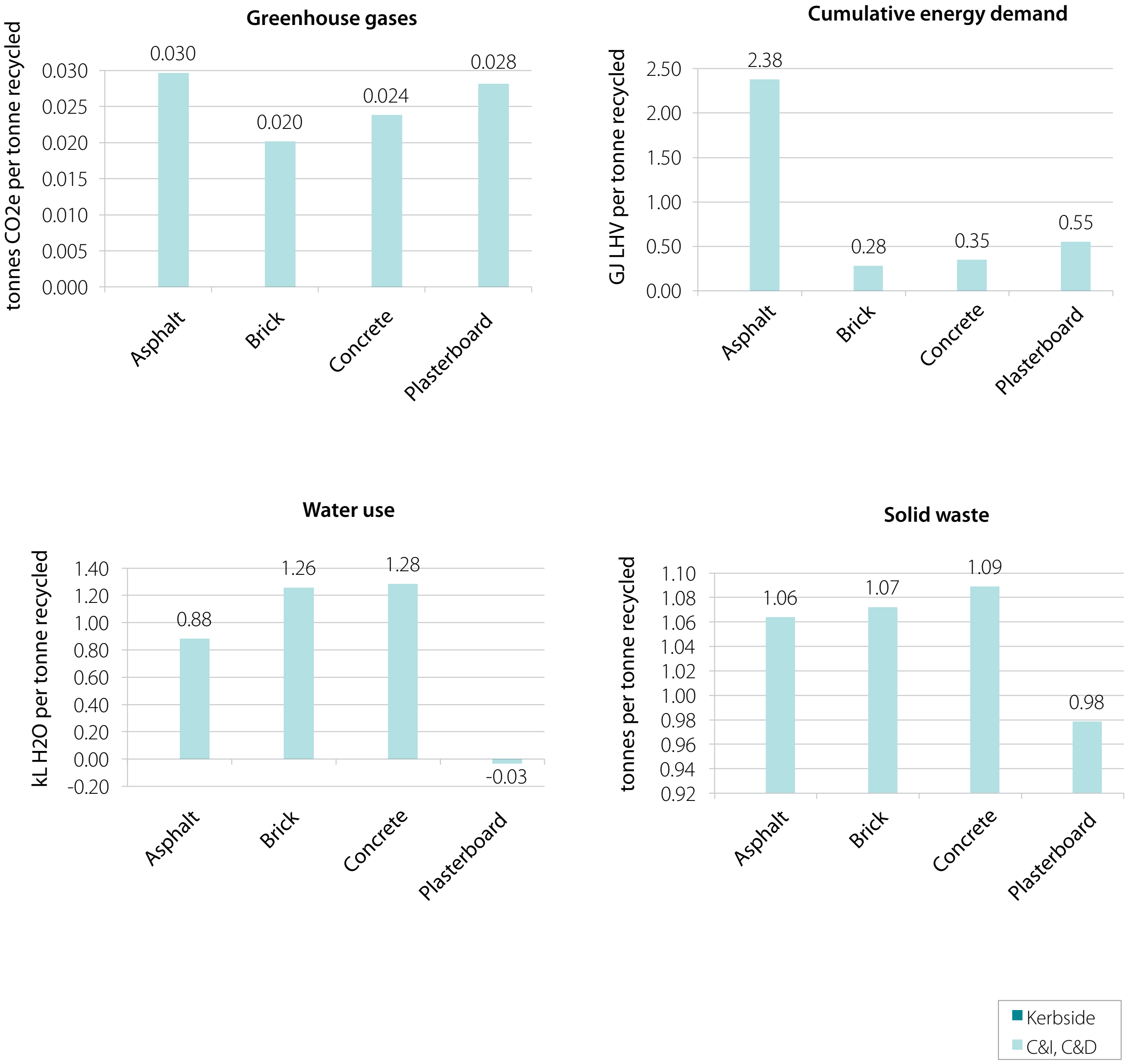
Figure 7. Average net benefit of recycling 1 tonne of metals waste



Concrete, brick and asphalt

The materials in this category are typically massive in nature and tend to have lower embodied energy contents per tonne. This results in the net benefits of recycling being lower than other materials, however this should not be interpreted as meaning that these materials are not worth recycling. Large quantities of these wastes are disposed of annually, making even small net benefits significant across large quantities potentially available for recycling. For example, over 1.7 million tonnes of waste concrete was recycled in 2006–2007 which is nearly 155 times the amount of aluminium recycled over the same period (NSW DECCW 2009).

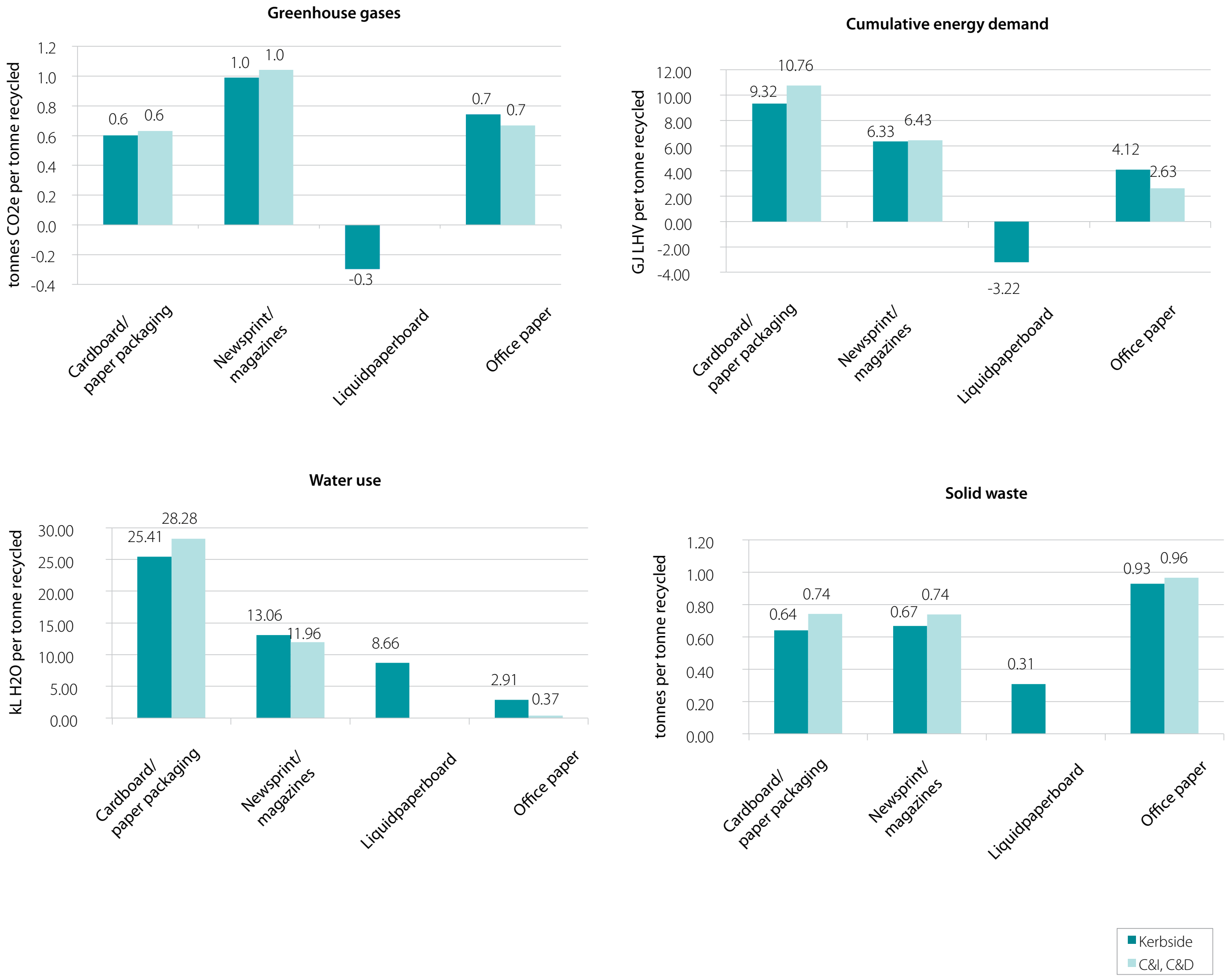
Figure 8. Average net benefit of recycling 1 tonne of concrete, brick and asphalt waste



Paper and cardboard

Paper and board materials generated positive net recycling benefits across most indicators (Figure 9) with the exception of liquid paper board (LPB). LPB stood out as a material with negative net benefits due to large reprocessing impacts. All other papers appeared to generate benefits across most indicators, however results are highly dependent upon assumptions made regarding paper degradation in landfill. Section 8 (Greenhouse gas sensitivity to landfill assumptions) explores this in more detail.

Figure 9. Average net benefit of recycling 1 tonne of paper and board waste



Greenhouse gases

Cumulative energy demand

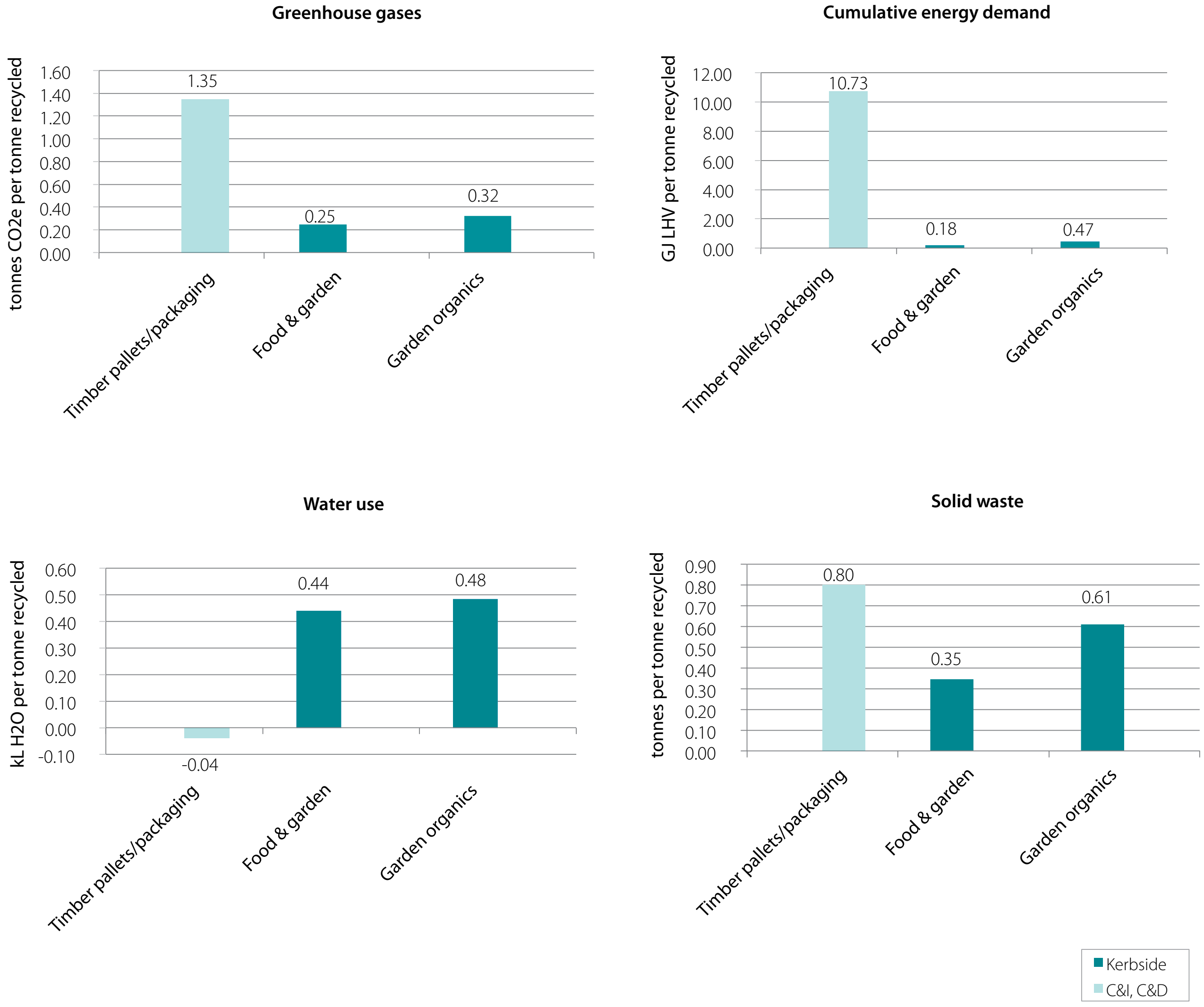
Water use

Solid waste

Organics

Reprocessing and recovering timber from pallet packaging was found to generate a net recycling benefit, as was the municipal collection and composting of organic materials (Figure 10). Benefits achieved for composting were derived primarily from the avoided impacts associated with landfill waste treatment, although some benefits were also derived from avoided fertilisers and crop yields.

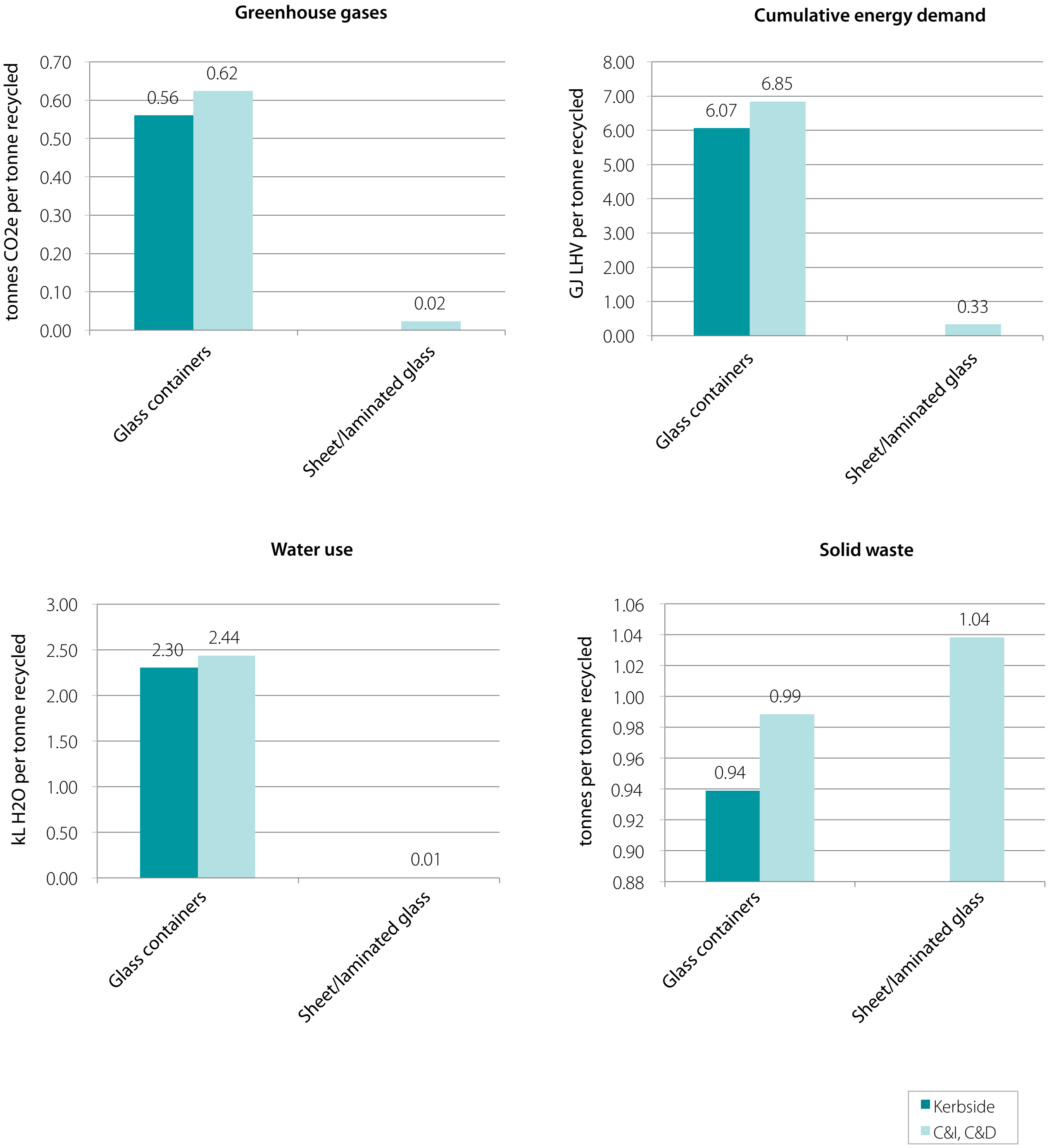
Figure 10. Average net benefit of recycling 1 tonne of organic waste



Glass

Net benefits from glass recycling were determined for both containers and laminated sheet glass. Laminated sheet glass generates lower benefits in general due to contamination of glass material making it only suitable as a substitute for fine sand aggregates (in asphalt or concrete). Glass containers can be sorted and contamination reduced, allowing them to be reprocessed into cullet for use in glass manufacture, hence the higher net benefit of recycling (Figure 11).

Figure 11. Average net benefit of recycling 1 tonne of glass waste



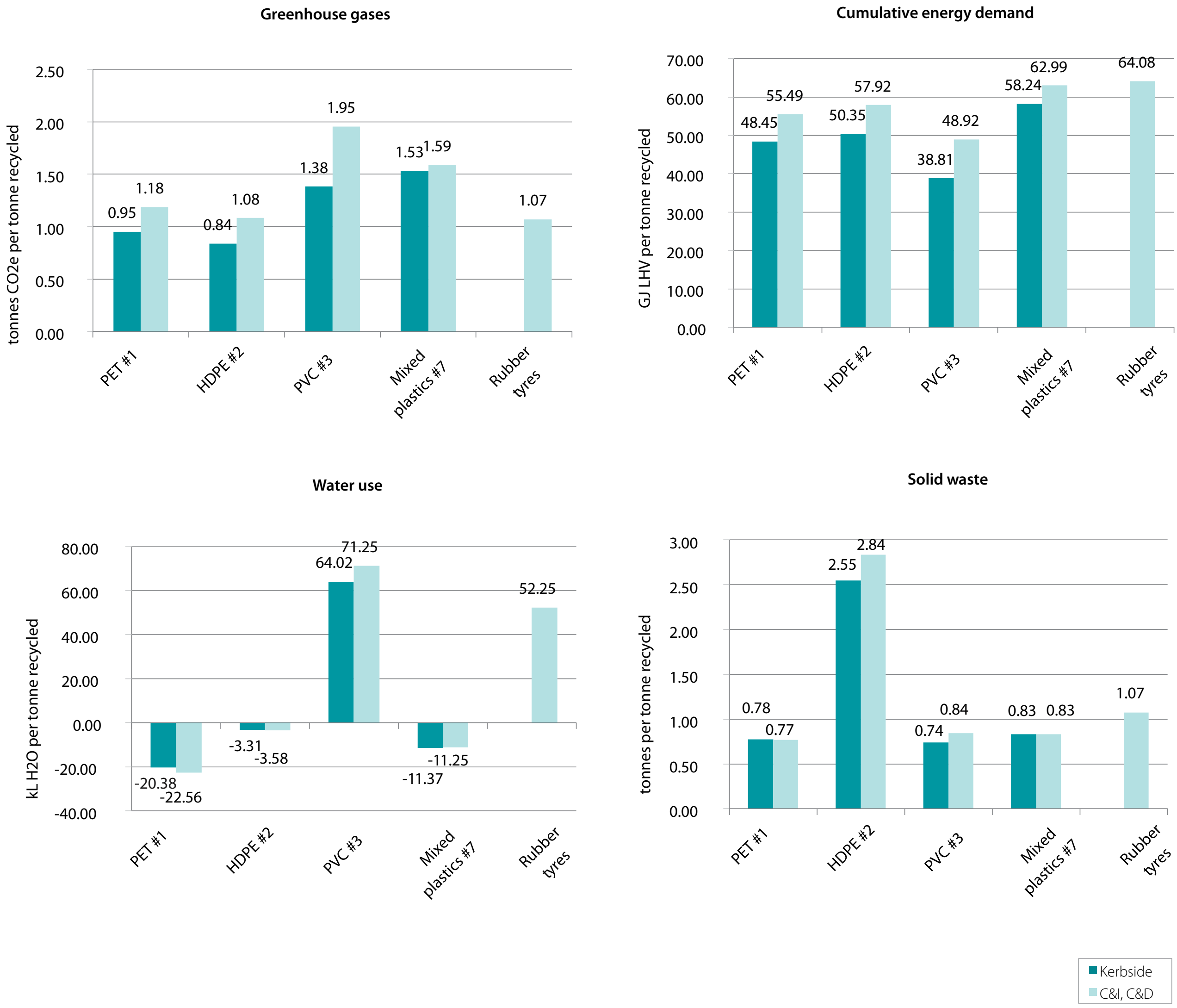
Plastics

Overall, plastics, including rubber tyres, generated significant net benefits when recycled (Figure 12). Water consumption for some plastics recycling processes was negative due to the washing processes required to prepare the recovered material for reprocessing.

Mixed plastics recycling benefits were shown to be positive, however little is understood of manufacturing processes applied to these materials. In this study it was assumed that mixed plastics are baled and sent to China where they are separated (most likely manually) then reprocessed using granulation and re-melt techniques similar to those applicable to HDPE.

Rubber tyre recycling was also shown to be beneficial. Although recycled rubber tyres can be reprocessed into many secondary products, in this study it is assumed that steel is recovered and that the rubber is crumbed for use as a substitute for synthetic polybutadiene.

Figure 12. Average net benefit of recycling 1 tonne of plastics waste



8 Greenhouse gas sensitivity to landfill assumptions

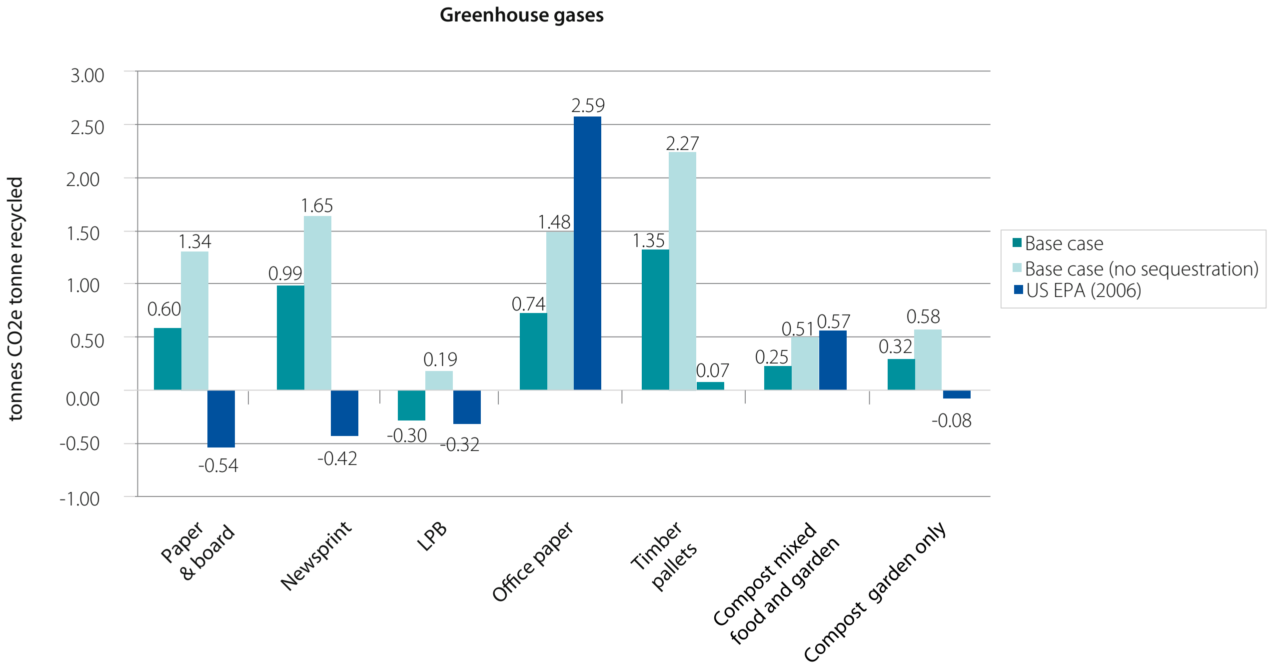
A core assumption underpinning greenhouse gas results for organic materials is the treatment of organic waste in landfill. The net benefit of recycling or composting organic waste is partially determined by the avoided impacts associated with sending organic waste to landfill (Section 5.2). This means that the net benefits of recycling will be increased if landfill processes are highly greenhouse intensive, and will be reduced if landfill processes generate few greenhouse emissions or if landfills actually absorb organic carbon.

In this study a baseline assumption has been made that carbon in organic material that is deposited in landfill, and not degraded, is sequestered in the landfill. This assumption is consistent with Department of Climate Change (2007), however may not be universally acknowledged. To test this assumption, a sensitivity study was undertaken on two alternative landfill scenarios:

> Base case (no sequestration): Landfill generates greenhouse gases as described by Department of Climate Change (2007), however carbon is not permanently sequestered and is released as biogenic CO_2.
>
> US EPA (2006): Rather than using Department of Climate Change assumptions for emissions from landfill, assumptions are used from the widely acknowledged study Solid Waste Management and Greenhouse Gases – *A Life Cycle Assessment of Emissions and Sinks* (US EPA 2006) . This study assumes a portion of carbon is sequestered.

Results of the sensitivity study are shown in Figure 13 below.

Figure 13. Sensitivity of organic materials to changes in landfill assumptions



Results show the clear increase in the net benefits of recycling, from a greenhouse gases emission perspective, if carbon is not assumed to be sequestered in landfill (base case – no sequestration). This is because landfill impacts are significantly increased under this scenario, increasing the net benefit of recycling, which avoids landfill.

The US EPA data is shown to reduce the net benefits of recycling certain materials, and increases benefits associated with others. This is due to more detailed carbon content information used in the study, and the specific nature of carbon storage and methane generation data, which is based on empirical studies. This is in contrast to the Department of Climate Change approach which applies a relatively standardised approach to determining emissions, with fewer material categories.

In general the sensitivity analysis suggests that recycling is universally beneficial if the assumption is made that biogenic carbon cannot be stored in landfill. If, however, there is a belief that some carbon can be stored, the Department of Climate Change data and the US EPA data give a sense of the range of possible outcomes.

9 Comparison

Other studies

Greenhouse gases emission results achieved in this study were compared to two similar LCA studies of recycling processes:

> Grant, T. and K. James (2005). *Life Cycle Impact Data for Resource Recovery from Commercial and Industrial and Construction and Demolition Waste in Victoria. Melbourne, Centre for Design, RMIT University.*
>
> Grant, T., K. James, et al. (2001). *Stage 2 Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria. Melbourne, EcoRecycle Victoria.*

The results of the comparison are shown in Table 5. In general, most results were consistent with the comparative studies, however there were some exceptions, which have been noted. In some cases, reasons for variation could not be explained.

Table 5. Results compared to other studies (greenhouse gases)

Greenhouse Gases (tonnes CO2e)							
#	Material (source shown bracketed)	Memo: Prior calculator	This study	Grant & James (2005)	Grant et. al. (2001)	Variation*%	Reasons for variation greater than +/-50%
1a	Aluminium cans (kerb)	15.20	15.85		14.90	6%	
	Aluminium cans (C&I, C&D)		17.72	17.49		1%	
1b	Aluminium scrap (C&I, C&D)		17.72				
2	Copper (C&I, C&D)		3.43	3.40		1%	
3a	Packaging steel (kerb)	0.80	0.40	1.49	1.07	-69%	The steel production model has evolved since the study of Grant & James (2005), reducing significantly the impact of virgin iron production, thereby reducing the benefit of the avoided steel production.
3b	Steel (C&I, C&D)		0.44	1.67		-74%	The steel production model has evolved since the study of Grant & James (2005), reducing significantly the impact of virgin iron production, thereby reducing the benefit of the avoided steel production.
4	Asphalt (C&I, C&D)		0.03	0.02		87%	The quantity of bitumen avoided when recycling has slightly changed compared with thr Grant & James (2005) study, which probably explains the results difference.
5	Brick (C&I, C&D)		0.02	0.01		117%	The difference of results with the study of Grant & James (2005) seems mainly due to a difference in the impacts of transport.
6	Concrete (C&I, C&D)		0.02	0.03		-18%	
7	Plasterboard(C&I, C&D)		0.03	0.05		-40%	
8	Cardboard/paper packaging (kerb)	0.40	0.60		1.32	-54%	The difference is mainly due to a difference in the quantity of avoided material and differences in the landfill model employed.
	Cardboard/paper packaging (C&I, C&D)		0.63	0.30		107%	The main difference with the study of Grant et. al. (2001) is mainly due to the updated version of the landfill model.
9	Newsprint/ magazines (kerb)		0.99		1.46	-32%	

#	Material (source shown bracketed)	Memo: Prior calculator	This study	Grant & James (2005)	Grant et. al. (2001)	Variation*%	Reasons for variation greater than +/-50%
	Newsprint/ magazines (C&I, C&D)		1.04	0.46		125%	The main difference with the study of Grant et. al. (2001) is mainly due to the differences in the landfill model, and more recent data for newsprint reprocessing.
10	Liquidpaperboard (kerb)	0.20	-0.30	0.64	0.35	-160%	The two previous studies assumed two different possibilities for LPB recycling. During this study, the possibility of recycling in Shoalhaven has been removed. The process used at Visy is now the only one taken into account. Furthermore, the landfill process has ben updated.
11	Office paper (kerb)		0.74				
	Office paper (C&I, C&D)		0.67				
12	Timber pallets/packaging (C&I, C&D)		1.35	0.50		170%	The amount of wood avoided by the reprocessing of pallets is significantly higher than for Grant & James (2005).
13	Food & garden organics (kerbs)		0.25	0.52		-52%	The composting model has been almost entirely reworked, which makes any assumption on the reasons of the results change very difficult.
14	Garden organics (kerb)		0.32	0.52		-38%	
15	Glass containers (kerb)	0.40	0.56		0.35	60%	It was not possible to determine a reason as why the material impacts differed
	Glass containers (C&I, C&D)		0.62	0.60		5%	
16	Sheet/laminated glass (C&I,C&D)		0.02	0.03		-12%	
17	PET #1 (kerb)	1.50	0.95		0.95	0%	
	PET #1 (C&I,C&D)		1.18	1.04		14%	
18	HDPE #2 (kerb)	0.50	0.84		0.59	42%	
	HDPE #2 (C&I,C&D)		1.08	1.05		3%	
19	PVC #3 (kerb)		1.38		1.70	-19%	
	PVC #3 (C&I,C&D)		1.95	1.88		4%	
20	Mixed plastics #7 (kerb)		1.53		0.95	61%	It was not possible to determine a reason as why the material impacts differed
	Mixed plastics #7 (C&I,C&D)		1.59	1.37		16%	
21	Rubber tyres (C&I,C&D)		1.07	1.19		-10%	

*Where two reference values exist, variation is based on average of reference values.
Variance greater than +50% and less than -50% highlighted.

10 Conclusions

Conclusion

The aim of this study was to provide a transparent and objective evaluation of the environmental benefits and impacts of recycling waste materials from residential, (C&I) and (C&D) sources in NSW. In addressing this aim, LCA has been employed to determine the net environmental impacts associated with recycling 21 material types from both kerbside and C&I and C&D sources. Results have been achieved for each of the 21 materials considered, with the general conclusion being that recycling generates environmental benefits.

In general, metals recycling provided the highest benefits per tonne, and concrete, brick and asphalt provided the lowest benefits per tonne. Although benefits for dense wastes such as brick and asphalt were low, these waste materials are generated in large quantities, making the state-wide potential savings for these materials significant. For example, over 1.7 million tonnes of waste concrete was recycled in 2006–2007 which is nearly 155 times the amount of aluminium over the same period (NSW DECCW 2009).

Outcomes for composting and recycling of organic wastes, in general, provided positive outcomes across most indicators. From a greenhouse gases perspective, these outcomes were found to vary depending on assumptions made with respect to the degradation of waste in landfill and the storage of carbon in landfill.

Overall, although challenges were encountered with respect to data collection, the results achieved are believed to be suitable for use in the Benefits of Recycling Calculator. Scope exists to further improve the quality of results achieved.

Limitations

The report and data collected in developing the report are not intended to be used for comparative analysis between materials or between different recycling processes. Such a study would require more interpretation, different allocation approaches and different data quality criteria.

This report has embraced the principals of ISO 14040, where feasible. It is intended to provide guidelines at a policy level to assist councils within NSW when contemplating the benefits of increasing the recycling of specific materials. Data collection for the materials recovery was complicated because for many materials there were difficulties in obtaining the necessary information from companies in a compressed timeframe. Although much of the data used have been reported previously in other LCA reports, the majority of data are derived from the region surrounding Melbourne and adjusted to suit the Sydney application. Also, some of the data are 6–7 years old and would greatly benefit from being updated from both sources, specifically NSW.

Notwithstanding the data challenges encountered, it is believed that overall similarities of the NSW application to analysis already undertaken made it possible to develop reasonable estimates for all the 21 materials considered.

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