Report to

Department of the Environment, Water, Heritage and the Arts

Climate Change and the Resource Recovery and Waste Sectors

April 2010

M M A

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1 INTRODUCTION

Greenhouse gas emissions from the waste sector arise from the breakdown of biodegradable waste disposed in landfills and from the release of gases during the treatment of waste water. Methane, a potent greenhouse gas, is released as a by-product of the breakdown of organic material by microbial action under anaerobic conditions in landfill and waste water treatment facilities.

In 2007, the waste sector emitted around 14.6 Mt CO_2e, a decrease of 22.5% from the 1990 level of 18.8 Mt CO_2e[1]. The decline was due to active policies to reduce the level of waste going to landfills and being recycled instead, and to the development of technologies that collect and combust methane released from landfills and waste water treatment plants. The diversion of waste from landfills has slowed the rate of growth of emissions of methane, whilst methane recovery results in less emissions going to the atmosphere.

Emissions from this sector contribute around 3% of total net emissions in Australia. Although only responsible for a minor portion of Australia's emissions, the sector provides the opportunity for low cost sources of abatement.

Around 76% of waste sector emissions come from methane released from solid waste in landfills. Most of the remainder comes from treatment of waste water, although there is a small amount from incineration.

MMA was commissioned by the Department of the Environment, Water, Heritage and the Arts (DEWHA) to undertake a study of emissions from landfills to answer:

- What quantity of emissions over what time scale will not be covered by the Carbon Pollution Reduction Scheme (CPRS) following the decision to exclude landfill legacy emissions?
- In addition to landfill legacy emissions, what quantity of other landfill emissions will not be covered by the proposed CPRS?
- What approaches (e.g. direct approaches including legislation, offsets, etc) could be taken over time to address the waste-related component of greenhouse gas emissions that will not be covered by the proposed CPRS?

In this report, there is a breakdown of the costs of abatement of greenhouse gases from waste sector activities as well as projections of emissions of greenhouse gases from the waste sector, concentrating solely on landfill emissions. Emissions of greenhouse gases from operating landfills including those that are not covered under the proposed CPRS (small scale landfills) and legacy emissions from waste disposed of at landfills in the past are covered. All monetary values in this report are in mid 2009 dollar terms. Monetary values are reported in Australian dollars.

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[1] Department of Climate Change (2009), *National Greenhouse Gas Inventory: Accounting for the Kyoto Target*, Canberra, May.

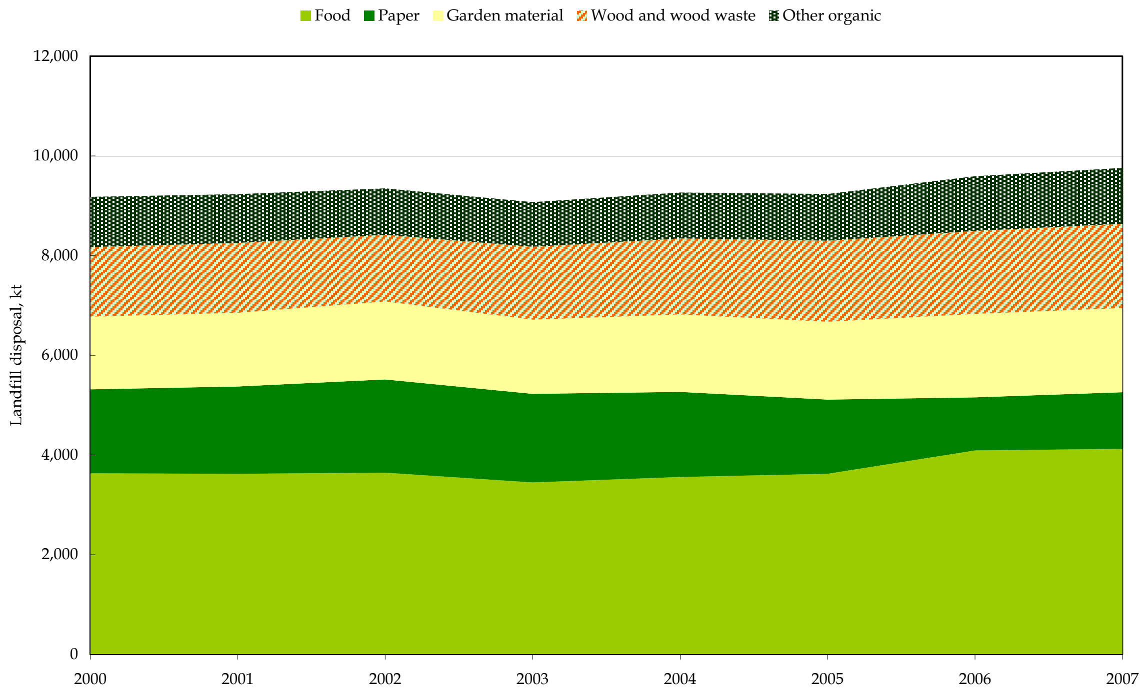
2 TRENDS IN WASTE EMISSIONS

The main greenhouse gas produced in landfills is methane, which is produced from the anaerobic decomposition by biological agents of organic material.

2.1 Trends in waste disposal

Despite numerous recycling and other programs to curb the generation of waste, waste material going to landfill has increased moderately since 1990. Disposal of putrescible waste has increased by around 1.2 Mt from 1990 to 2007, a growth rate of around 1% per annum. The growth in disposal occurs because of the impact of population and income growth, which has led to increased levels of waste generation despite increased levels of recycling.

Figure 2-1: Disposal of putrescible waste to landfills



Source: Department of Climate Change (2009), *National Inventory Report: 2007, Volume 2*, Canberra

As far as putrescibles are concerned, most of the growth has occurred in food material and wood waste. There has been a small decline in the amount of paper going to landfills.

2.2 Emission trends and methods for calculations

Emissions from solid waste disposal fell steadily over the period from 1990 to 2007 to reach 11.1 Mt CO_2e in 2007. Overall emissions fell by 25% over this period. Although landfill disposal has increased and methane emissions from the stock of putrescible waste in landfills have increased over time, a larger portion of the methane emissions is now being captured and either flared or used as an energy source.

The Australian Government has predicted that emissions from solid waste disposal will remain around 11 Mt CO_2e in 2020, assuming that current waste reduction and abatement measures remain in place[2]. The main measures reducing emissions include waste diversion policies (which accounts for 70% of the predicted contribution of measures to reduce emissions) and policies to encourage use of methane in landfills for power generation.

Emissions are calculated based on a range of formulae, rather than being actually monitored. Emissions are calculated by tracking waste disposal trends (as a function of activity levels) and using derived emission intensity factors to arrive at overall emissions by type of waste material.

2.3 Abatement opportunities

The major abatement activity from landfills is power generation. As at the end of 2009, there were 58 such generation facilities in Australia, with the capacity of around 165 MW. One-third of the capacity resides in NSW. Victoria and Western Australia also have large capacities.

Table 2-1: No of generators by State and capacity (2009)

State	Number of plants	Capacity, MW
NSW	14	61.1
ACT	3	4.4
Queensland	10	18.6
Victoria	11	33.6
South Australia	6	20.9
Tasmania	2	2.1
Western Australia	11	23.5
Northern Territory	1	1.1
Total	58	165.3

Source: MMA Renewable Energy Database.

The growth in landfill gas power generation has occurred largely over the last decade. This growth has come about due to a number of factors:

- Energy market reforms allowed landfill gas generators to earn better buy-back rates for the electricity generated.

[2] Department of Climate Change (2009), *Tracking to Kyoto and 2020: Australia's Greenhouse Gas Emission Trends 1990 to 2008-12 and 2020*, Canberra, August.

- Development of methane gas collection technologies and methods for extracting methane from landfills. This was aided by strategies of embedding infrastructure into landfills as they are being filled with waste.
- Government policies to demonstrate landfill gas generation technologies.
- Implementation of support measures. In particular, the Federal Mandatory Renewable Energy Target (MRET), the NSW Greenhouse Gas Abatement Scheme (GGAS) and Queensland Gas Electricity Certificate Scheme provided financial rewards for landfill gas generation. In the case of the NSW GGAS scheme, landfill gas generators could also earn revenue from converting methane into carbon dioxide.

Based on the available data, most new landfill gas operators connected to the National Electricity Market (NEM) are receiving support from the NSW GGAS. Given that prices for NGACs are capped currently at \$17/t CO_2e (increasing to \$20/t CO_2e), this provides a guide as to the type of cost that is required under an emission trading scheme to justify investment in landfill gas generators. However, higher permit prices will be required to increase the proportion of landfill sites using methane capture and generation technologies. Smaller landfills and rural landfills would require even higher prices due to the smaller scale of operation.

In more recent times, other options for abatement have been developed. The suite of abatement options include:

- Flaring of gas at landfill sites.
- Diversion of degradable material.
- Capturing methane from wastewater treatment to either flare or use as a fuel for industrial process heat or electricity generation.
- Waste to energy processes that involve the sorting and cleaning of waste steams to inert, recyclable and organic materials, with the latter used as a fuel source in pyrolysis or gasification facilities to raise steam and/or electricity. The energy produced is used in the sorting and cleaning process, with the excess exported to grid. Biochar may also be a by-product.

Most of these options are expensive and are only likely to be adopted either under an emission trading scheme which imposes a permit cost on landfill emissions or through direct government support for these technologies under waste reduction programs.

2.4 Policy responses

Waste policy continues to evolve from a focus on minimising harm to the environment through improper disposal of wastes, to diverting waste from landfills to be recycled or reused. As part of this, two principles have now been adopted by most State and Territory Governments, namely:

- The adoption of a 'hierarchy of waste' - where reducing consumption is preferable to waste re-use and recycling which in turn is preferable to waste disposal.
- The setting of targets for the amount of waste going to landfills.

A range of landfill levies, recycling and product stewardship programs have been adopted to reduce waste. Despite this, targets for the level of waste diverted from landfills have generally not been achieved. More recently, several State and Territory Governments have announced new waste reduction targets and overhauled waste management strategies. On 5 November 2009, Australian environment ministers agreed to a new national policy on waste and resource management that aims to reduce the generation of waste and contribute to the reduction of greenhouse gas emissions.

In addition, the proposed CPRS is a central policy for reducing emissions from a range of activities including waste disposal activities. Under the proposed CPRS, emissions from stationary energy, transport, industrial processes, waste, and fugitive emissions will be covered from the start of the Scheme.

The proposed CPRS has the following proposed provisions:

- Landfill facilities with direct emissions from prescribed waste exceeding 25 kt per annum will be liable under the proposed CPRS.
- Legacy emissions (those incurred from waste deposited before July 1 2011) will count towards determining inclusion (the 25 kt threshold target) but they will not incur a liability to surrender emissions units (that is, they will not be part of the national target).
- A threshold of 10 kt applies to small landfills within a prescribed distance to large liable landfills. This is to avoid waste being diverted from the liable landfill to a small nearby landfill.

It is possible that emission not covered under the proposed design (legacy and emissions from small landfills) may be part of offset arrangements or part of a complementary measure covering emissions from landfills. The Government did introduce amendments to provide for crediting of abatement from agricultural emissions and other sectors not covered by the CPRS (including legacy waste and emissions from landfill facilities which closed prior to 1 July 2008) that are counted towards Australia's international climate change obligations.

3 METHOD AND ASSUMPTIONS

MMA used a version of its model of resource flows, called WASTENOT, which models flows of resources from the consumption to dispersal into either recycling activities or to landfill. Externalities associated with the resource flows, including emissions of greenhouse gases from either recycling activities or land filling, are also calculated. For the purposes of this study, the model has been modified to include options to mitigate emissions of methane from landfills. Other sources of emissions from the waste sector such as incineration are not included as they contribute less than 0.3 Mt per annum of greenhouse gas emissions.

The model includes emissions from all activities from consumption to disposal or recycling. To maintain consistency with the sectoral definitions employed under the National Greenhouse Gas Inventory, the abatement costs derived only apply to emissions from landfills. The model covers emissions of greenhouse gases from all landfills including those not covered under the proposed CPRS and legacy emissions from waste disposed of in landfills in the past.

Treatment of emissions from downstream activities, for example increased transport activities from transporting recyclates material, were not included as part of the analysis.

Modelling of waste generation and disposal behaviour was based on data to 2006 plus recent data on waste disposal and recycling published by State government agencies. Projections of emissions were adjusted to take into account the additional historical data on emissions published in the 2007 National Greenhouse Gas Inventory[3].

3.1 Abatement options

The model considers the total emissions from solid waste and specifically covers the following mitigation options:

- Flaring of gas at landfill sites
- Diversion of degradable material
- Diversion of recyclable material
- Capturing methane from waste treatment to either flare or use as a fuel for industrial process heat or electricity generation.

Each option may be introduced to a chosen level of effectiveness and introduced over a chosen period to reflect constraints on the uptake rate of the options.

[3] Department of Climate Change (2009), *National Inventory Report: 2007, Volume 2*, Canberra.

Methane recovered is converted to CO_2 equivalents (CO_2e) and the costs of mitigation per tonne of CO_2e are determined for each year in which additional mitigation is introduced[4]. The net value added of recycled material is allocated as an offset to the mitigation cost.

Options for abatement considered in the model are shown in Table 3-1. Waste minimisation options were not considered directly in this analysis, as the adoption of these options are part of wider policy proposals managed by each State government. However, the impact of waste minimisation policies is reflected in the overall emissions potential from landfills.

Table 3-1: Abatement options in the waste and water treatment sectors

Mitigation Option	Sub-option	Description
Waste minimisation	Cleaner production	Less packaging, environmentally friendly products.
	Recycling	Recovery and re-use of material
Diversion from landfill	Composting 1	Organic waste composted in windrows. Residue used as soil conditioner
	Composting 2	Organic waste composted in vessels. Residue used as compost and biogas flared.
	Home composting	Each household composts all their food waste.
	Incineration	Burning of waste with energy recovered as heat and power.
	Other thermal processes	Pyrolysis, gasification.
	MBT	Greater separation and breakdown of waste.
	Anaerobic digestion 1	Degradation of organic material accelerated. Digestate into agricultural compost and biogas for power generation.
	Anaerobic digestion 2	Degradation of organic material accelerated with heat and power recovery.
Landfill management	Capping, design	Maximises microbial methane oxidation in the cover soils
Capture of landfill gas	Flaring	LFG captured and ignited
	Landfill gas (LFG) for direct combustion	LFG used as a fuel for industrial processes. Gas is piped directly to customers.
	LFG for electricity generation	Electricity generation using internal combustion engine.
Waste to energy	Fluidised beds	Fluidised bed combustion of refuse-derived fuel
	Cogeneration	Cogeneration in breweries, paper mills and sewerage plants.
	Incineration	Incineration of waste fuels in cement kilns and power plants

4 This conversion was undertaken assuming a Global Waming Potential for methane of 21.

3.2 Method

3.2.1 Model structure

The modelling framework is based on the manufacture, use and disposal cycles of major waste streams in Australia. For each of the three waste streams – municipal solid waste (MSW), commercial and industrial waste (C&I) and construction and demolition waste (C&D) - the flow of waste from creation to disposal is modelled for a number of waste types. For this study, the waste types considered were:

- Mixed paper and cardboard.
- Old newspaper.
- Timber.
- Garden organics.
- Food organics.
- Textiles.

In this study, the focus was only on organic waste streams and did not include hazardous or other waste streams.

The model determines the cost of the management of wastes and environmental loads emanating from wastes. The model has three components:

- Waste generation projections – for each waste type and waste stream, waste generation tonnages are projected based on exogenous variables such as population and Gross State Product (GSP) forecasts.
- Waste management optimisation – for each waste type and waste stream, a financial model is used to determine the waste management solution that maximises profits to collectors and handlers subject to regulatory constraints and other incentives to divert waste.
- Assessment – for each waste type and waste stream, the economic, social and environmental impacts of the waste management solution are calculated.

The purpose of the waste generation module is to calculate the waste generation in Australia by waste stream and for each waste type, based on exogenous input variables. For the purposes of this study, only the abatement options for waste disposed at landfills were considered in detail.

Stages of the modelling process include:

(1) For each of the three waste streams (MSW, C&I and C&D), projections were made as to the total waste generated. Waste generated for these three streams in each state were projected based on exogenous variables such as population and GSP forecasts. Municipal solid waste generated was projected using a model of household

expenditure and disposal patterns, where waste generated increases as function of population growth and income. C&I waste generated was projected as a function of GSP projections (using historical data to determine the relationship between waste generated and economic growth). C&D waste generated was related to building approval data, which in turn is related to projections of economic growth.

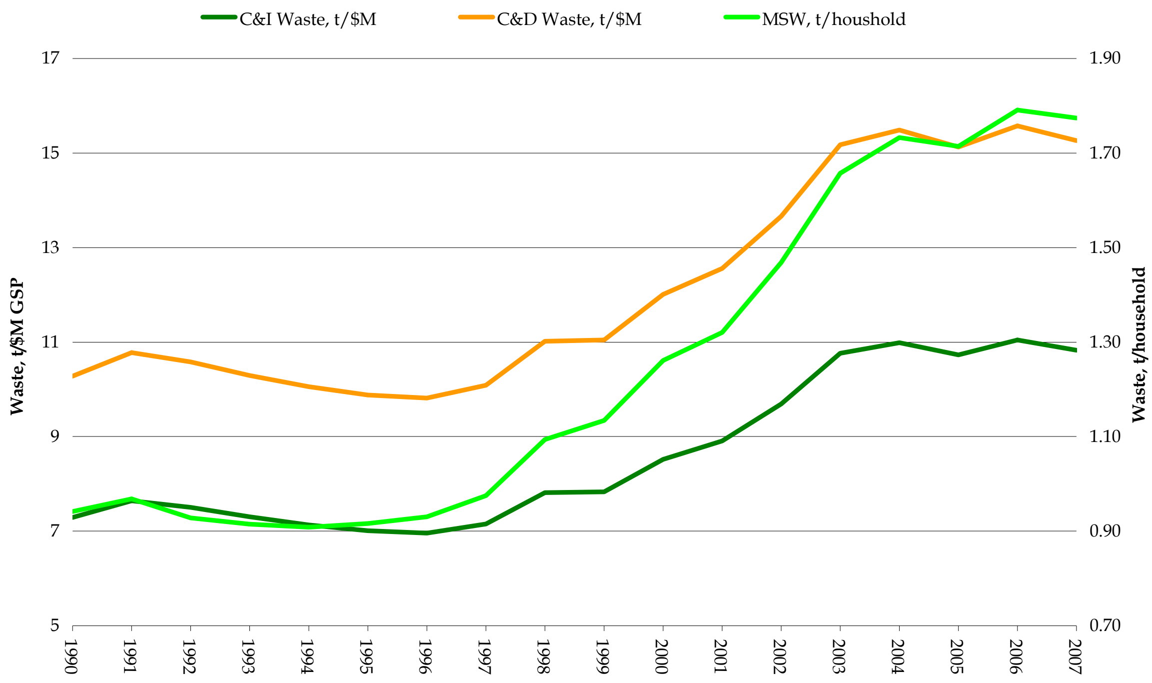
(2) A linear programming algorithm was used to determine the least cost means of disposing of waste generated, subject to regulatory constraints and other incentives to divert waste. Waste generated can be diverted to landfills, material sorting and recycling facilities (and over the long term to alternative waste treatment facilities). In this study the focus was on organic material including food waste, paper and textiles, garden and green waste and wood waste. The amount going to landfill in this model is affected by the cost of carbon on landfill emissions where these are faced by landfill operators (i.e. on the proportion of landfills liable under the proposed CPRS). The amount of organic waste going to landfill is affected by the availability and cost of other options to treat the waste (thus avoiding landfill emission costs).

(3) Part of the process in stage (2) involves determining the uptake of abatement options to mitigate emissions at landfills liable under a proposed CPRS (or in response to other policy measures such as the Renewable Energy Target and NSW Greenhouse Gas Abatement Scheme). The options modelled include flaring, capturing the methane to treat and sell as pipeline quality gas, and capturing the methane to use to generate electricity. Emissions can also be avoided by diverting the waste to waste to energy facilities that use the organic material to create steam and electricity (and potentially other useful by-products such as biochar). The model determined the long run marginal cost of each option per tonne of carbon abated, taking into account capital and operating costs of each option and deducting revenue from sale of useful products (electricity, Renewable Energy Certificates (RECs)).

(4) Emissions from landfills were calculated using the IPCC First Order Decay (FOD) model. Degradable organic carbon (DOC) stocks in landfill were estimated using historical waste data for Australia. The organic materials dumped at landfills for the projection were as determined in stages (1) to (3).

The rate of waste generated per million dollars of GSP is increasing over time but appears to have stabilised since 2003 (see Figure 3-1). It was assumed that a logistic model using GSP as an independent variable is appropriate for determining waste generation.

Figure 3-1: Waste generation rate by sources in Australia



Municipal waste stream

Waste generation from the municipal waste stream was assumed to be driven by household consumption. In the model, household consumption of goods and services is influenced by income growth, changes in consumer tastes and relative prices of consumer goods.

Household consumption of goods and services for each region was calculated as follows:

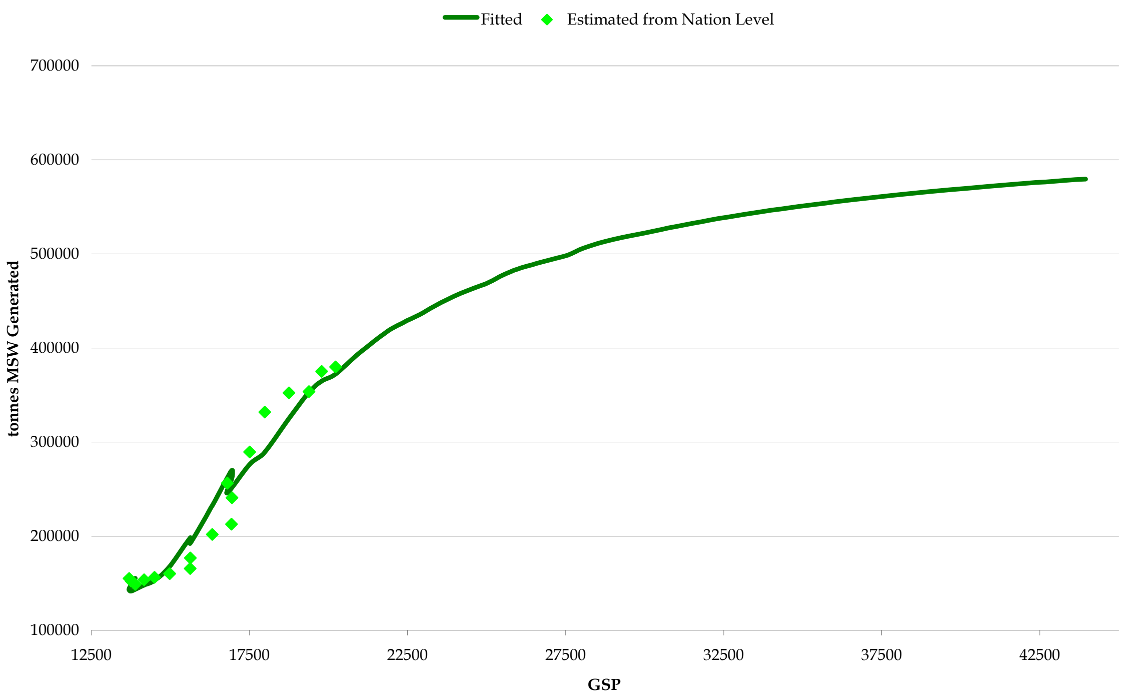
- The number of households in Australia was projected from population projections provided by ABS and trends in household formation (that is, number of people per house).
- Household income was projected by assuming income growth is in line with projected growth in GSP. Projections of GSP growth are obtained from published budget forecasts, with forecasts then extrapolated beyond the last year available.
- Income was allocated across goods and services using the proportion of expenditure available from the latest ABS household expenditure survey. From current waste and household spend data, the model determined what was spent on goods responsible for each waste category (that is, what proportion of household expenditure was likely to be on goods that produce waste).

- Waste generated by major waste types was calculated by multiplying expenditure on goods by historical data on tonnes of waste generated per dollar of consumption on each class of goods[5].
- Waste generated was assumed to be disposed of in either kerbside collection systems or recycling depots depending on the cost of each method including the opportunity cost of time (equal to average weekly earnings). Households were also assumed to have the option of diverting food scraps to composting for garden fertiliser. This will depend on the cost of in-house composting including the opportunity cost of time.

Data was gathered from the Australian Bureau of Statistics (ABS) and other sources relating to various household characteristics in Australia.

A logistic trend model was built using the estimated waste generation per household and GSP per household from the period 1990 to 2006. The MSW stream is projected on the basis of the projected number of households and income growth per household. Figure 3-2 shows the relationship between MSW and GSP. The projection of number of households was estimated using ABS data[6] and the number of households to 2050 was estimated by holding the persons per household constant after 2026 and using the population forecasts provide by the ABS.

Figure 3-2: MSW generation and GSP



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[5] Waste generation data was obtained from Hyder (2009), *Waste and Recycling in Australia*, report to DEWHA, October (and previous issues)

[6] Australian Bureau of Statistics (2006), Household and Family Projections 2001 to 2026, Catalogue No 3236.

Commercial and industrial waste stream

The amount of commercial and industrial waste produced was linked to the demand for manufactured goods and services. The higher the consumption of goods and services the higher the waste produced by the commercial and industrial sector.

Each of the major industry sectors in Australia was modelled as follows:

- Value of output (industry income in dollar terms) was projected from ABS reported historical values and industry sector growth forecasts[7].
- Tonnage of waste generated from manufacturing was determined from historical data on commercial and industrial waste generation by waste type.
- A waste factor was calculated as tonnage of waste per unit of industry income (t/$M/year).
- Future waste generation by industry and waste type was determined by applying the waste factors to the projected industry incomes.

The manufacturing sector is divided into the major industry classes based on 2 digit Australian Standard Industry Classification (ASIC) classifications.

According to data from a landfill survey[8], about 49% of commercial and industrial waste disposed of in landfills is generated from manufacturing activities. Assumptions on the major waste types generated plus information gleaned about which sectors generate the waste are provided in Table 3-2.

Table 3-2: Assumptions on waste generated from the manufacturing sector

Material	Manufacturing sectors responsible
Paper and cardboard	Across all manufacturing sector in proportion to value of output relative to total value of output from manufacturing
Timber	Assumed to come from the wood and paper products and other manufacturing sectors
Garden and food organics	90% from the food and beverage industries, 10% shared equally across all other manufacturing sectors
Textiles	From the textiles, clothing and footwear sectors

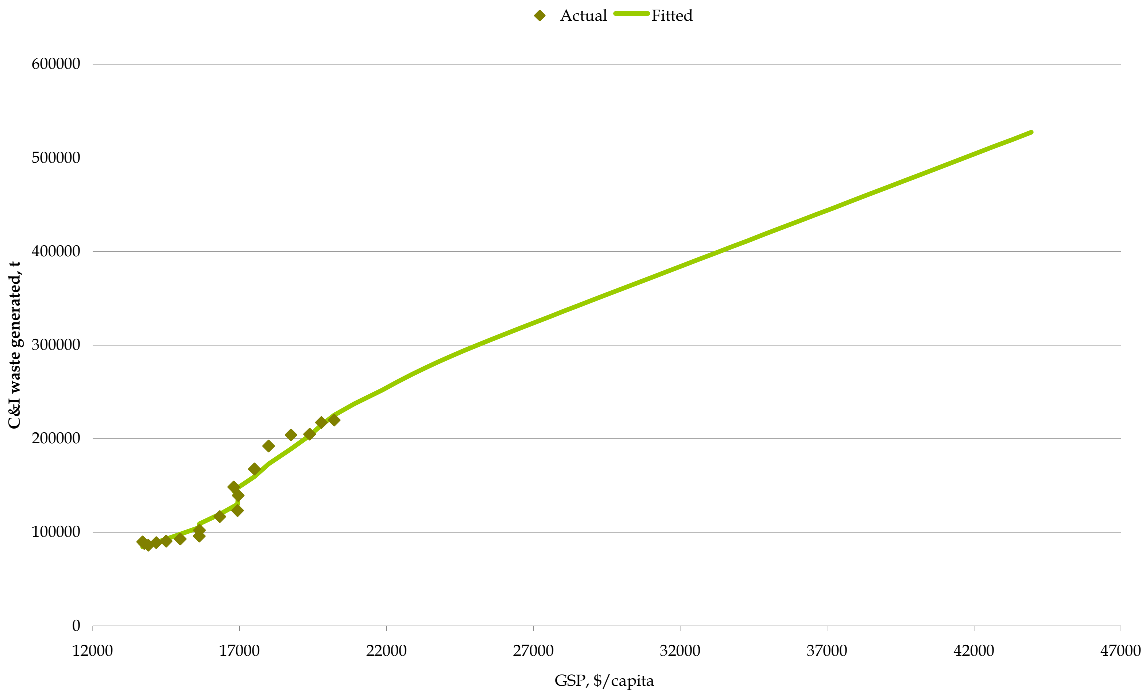
Source: MMA analysis based on information in Hyder (2009), *Waste and Recycling in Australia*, report to DEWHA, October (and previous issues); Waste Audit and Consultancy Services (2004), *Landfill Survey: Zero Waste SA*, June 2004, report to Zero Waste SA.

A logistic model relating C&I waste generation per million $ of GSP and the total waste generation by C&I stream was used to project waste generation in this sector. Figure 3-3 illustrates the waste generated from C&I stream as a function of GSP.

7 Sourced from BIS Shrapnel and Econtech.

8 Waste Audit and Consultancy Services (2004), *Landfill Survey: Zero Waste SA*, June 2004, report to Zero Waste SA.

Figure 3-3: C&I waste generation and GSP



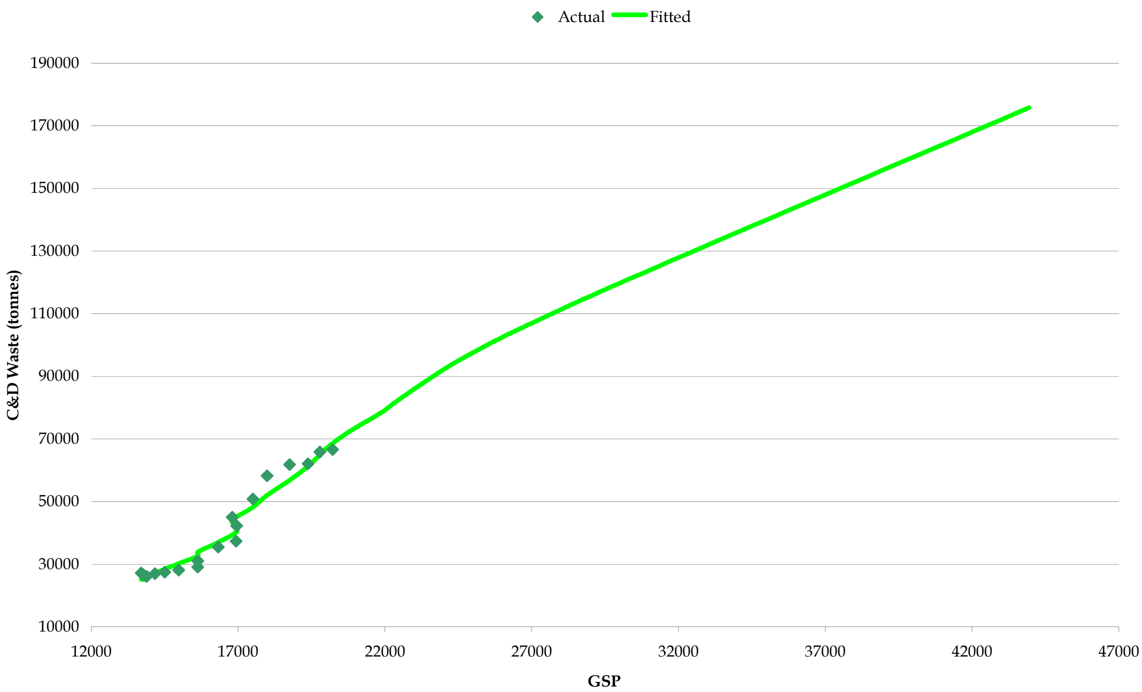
Construction and demolition waste stream

Construction and demolition waste was assumed to be generated from the service and household sectors. Some demolition material was also assumed to be generated from the manufacturing goods sector, although the data indicates that this sector generates only a small proportion of this waste. The level of waste generated was linked to building activity expenditure, which in turn was assumed to increase in line with GSP. The relationship between the building activity expenditure and GSP was developed from regression analysis of historical data.

Data was gathered from the ABS and other sources relating to the amount of construction and demolition waste and recycling in Australia for different waste categories. The future amount of waste generated by each waste category was assumed to be in line with the historical ratio of waste generation to total waste generation for each waste type.

Projection of C&D waste generation was done by building a logistic model of waste generated per million dollars of GSP. Figure 3-4 below presents the projection of total waste generated as GSP increases.

Figure 3-4: Projection of C&D waste generation as GSP increases



Waste management optimisation module

In the model, there were four choices for waste management:

- Reduce waste generation at source.
- Re-use or recycle waste.
- Dispose of waste at landfills.
- Dispose of waste illegally.

For each year of the study, the waste management optimisation model allocated collected waste from each waste stream to material recovery facilities, landfill, or source reduction on a profit maximising basis, subject to regulatory constraints and other incentives to divert waste. That is, the model determined the allocation of waste to various disposal/recycling activities based on what disposal method maximises profits to collectors and handlers. Waste management costs were assumed to be passed back to the waste generators – either directly in the case of C&D and C&I waste streams and indirectly through council rates (assumed to be on a rate per bin size) in the case of MSW - providing waste generators with incentives to minimise waste production.

The key inputs to the optimisation model were the annual waste generation tonnages, as determined by the waste generation projections module, and the financial costs and revenues of material recovery, source reduction and landfill disposal options.

For this study, current State and Territory Government policies were assumed to remain in place as they are currently structured (that is, landfill fees and subsidies to recycling remain as currently enforced). It was assumed that no new measures for recycling to meet stated goals for recycling are enacted.

The model determines recycling rates as part of the solution to minimise waste collection and treatment costs. Therefore, the recycling rate depends on the cost of recycling relative to other disposal methods and incentives provided or regulations enforced by Government to improve recycling rates. For example, the recycling rate for paper increases over time due to increase kerbside recycling in some of the minor states and full establishment of formal collection procedures from commercial enterprises.

3.2.2 Estimation of abatement cost

The marginal abatement cost was assumed to be the change in total cost that arises when the quantity produced changes by one unit. Mathematically, the marginal cost function is expressed as the derivative of the total cost function with respect to quantity. The marginal cost may change with volume, and so at each level of production, the marginal cost is the cost of the next unit produced. Thus, the marginal cost at each level of production includes any additional costs required to produce the next unit. At each level of production and time period being considered, marginal costs include all costs which vary with the level of production, and other costs are considered fixed costs.

Calculation of the long run marginal cost (LRMC) of abatement involved:

- All costs and benefits were estimated on a year-by-year basis over the project life
- Each year's net costs were then discounted to a reference year. This yields the net present value (NPV) of costs/benefits. The reference year is often the one preceding the one during which the first capital expenditure is to take place.
- Each year's level of abatement was estimated and then discounted to the same reference year, yielding the net present abatement quantity (NPAQ). The abatement is discounted because:
    - Abatement in a given future year does not have as much utility as current abatement and there is a risk that it will not materialise. Discounting all abatement to the reference year makes them comparable.
    - On a practical level, if the abatement is not discounted, the LRMC value is too low – so low that no investments would be justified if the emission permit price were similar.
- The long run marginal cost of each abatement option is then calculated as a ratio of NPV to NPAQ.

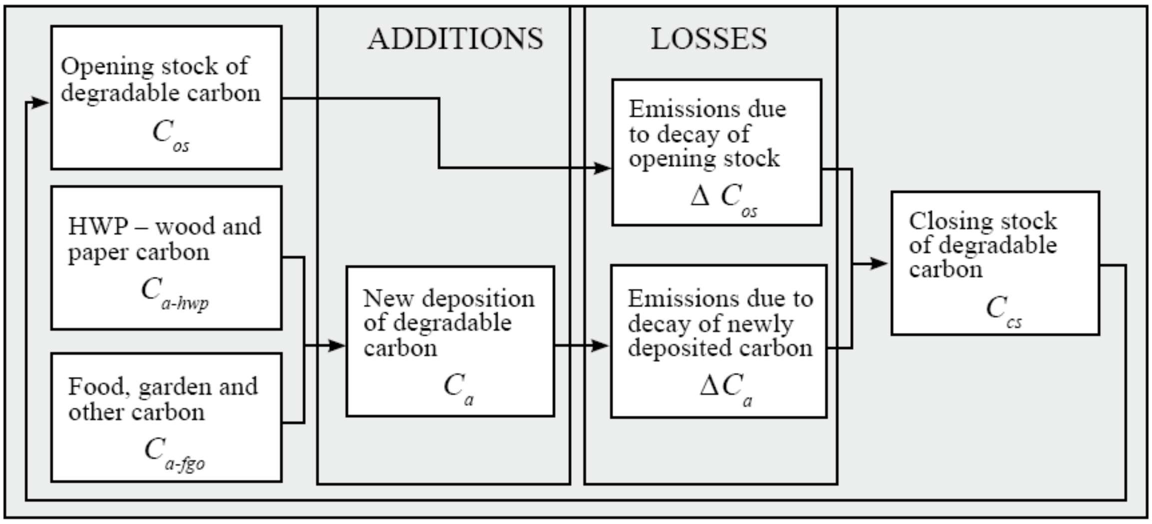
In the model, the LRMC in \$/t CO_2e was used to determine the carbon price that would be required to enable a new abatement option to proceed economically. The model stacks the new abatement options in each year from least cost to highest cost. The abatement costs calculated were over and above the options already in existence.

3.2.3 Calculation of emissions

Emissions from the waste-sector were projected using the IPCC First Order Decay (FOD) approach. Degradable organic carbon (DOC) stocks in landfill were estimated using historical waste data for Australia and the projection of total waste generation was done using statistical modelling.

Emissions from solid waste are predominantly from methane generated at the landfill sites[9], which is produced when degradable organic carbon found in the waste stream decays. The amount of methane generated each year depends on the amount and type of waste at the landfill accumulated over time as well as the type of landfill. The concept of the carbon stock approach is illustrated in Figure 3-5.

Figure 3-5: Carbon stock model flow chart



Source: Department of Climate Change.

To estimate emissions from solid waste first required the estimation of current DOC stock present in the landfill as well as yearly deposits of waste to landfill. A time series of waste deposited in the landfill sites since 1940 was estimated using the volumes of total waste generated in Australia[10]. Historic total waste generated at time t was estimated using historic population, per capita waste (PCW_t) and a ratio of per capita waste generated for 2006 for both Australia and the states.

The calculation is as follows:

$$Total\,Waste_t = State\,Population_t * PCW_t(National) * \frac{PCW\,State_{2006}}{National\,PCW_{2006}}$$

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[9] The modelling uses the Global Warming Potential of 21 for methane, the same as the NGGI. Changes to the GWP will change the emissions from the waste sector from those estimated in this study.

[10] Australian Greenhouse Office (2007), *National Greenhouse Inventory Report 2006*, Canberra

Total waste for each decade since the 1940's is shown in Table 3-3. Values for the intervening years were estimated by linear interpolation. These values were used in the First Order Decay model to estimate the degradable organic carbon.

Table 3-3: Total generation of waste and disposal to landfill, kt, Australia

Year	1940	1950	1960	1970	1980	1990	2000	2007
Generated	9,637	10,065	15,185	17,748	17,098	16,422	25,571	42,718
Disposed to landfill	9,637	10,065	15,185	17,748	17,098	16,408	19,560	21,341

Source: MMA estimates based on data provided by DCC (2009), *National Greenhouse Inventory Report 2007*, Canberra; Hyder (2009), *Waste and Recycling in Australia*, report to DEWHA, October (and previous issues); and state based government agencies.

3.3 Assumptions

3.3.1 General assumptions

General assumptions included:

- GSP/capita grows between 1.4% per annum to 1.8% per annum, reflecting a slighter lower rate than occurred historically due to the ageing of the population.
- Long term population growth rate of 1.3% per annum. This reflects historical trends but more recent data suggests a slightly higher growth rate may occur if recent immigration rates continue.
- Carbon prices increases from \$25/t CO_2e in 2012/13 to \$37/t CO_2e in 2019/20, \$55/t CO_2e in 2029/30 and \$120/t CO_2e in 2049/50.
- Renewable Energy Certificate prices that can be earnt by landfill gas generators under the Renewable Energy Target Scheme decrease from \$69/MWh in 2011 to \$12/MWh in 2030.

3.3.2 Cost of abatement

Assumptions underpinning the costs of abatement for each option are shown in Table 3-4. The abatement cost is the long run marginal cost of deploying each option. The long run marginal cost is the present value of the costs of each option (capital and operating costs) over its economic life divided by the present value of the level of emissions abated over its economic life. Revenue streams from sales of recycled material or fuel to the market was treated as a negative cost.

Table 3-4: Cost assumptions

Sub-option	Capital cost, $/t carbon	Operating cost, $/t carbon per annum	Reduction efficiency, % of CH_4 emissions
Composting 1	1,600	370	95%
Composting 2	1,891	324	95%
Home composting	18	73	70%
Other thermal processes	783	55	75%
MBT	1,600	481	93%
Anaerobic digestion 1	1,787	268	95%
Anaerobic digestion 2	2,161	499	100%
Capping, design	2,074	3	44%
Flaring	130	17	75%
LFG for energy 1[11]	177	12	75%
LFG for energy 2	732	39	75%
Fluidised beds	890	47	75%
Cogeneration	890	47	75%
Incineration	430	30	75%

Sources: MMA analysis based on US EPA (2006), *International Analysis of Methane and Nitrous Oxide Abatement Opportunities*, report to the Energy Modelling Forum, Working Group 21, Washington; IPCC Working Group III (2007), *Climate Change 2007: Mitigation of Climate Change*, Cambridge University Press; Warnken ISE (2007), *Management and Resource Recovery Activities in Australia*, report prepared for SITA Environmental Solutions; and Delhotal, et. al., (2007), "Mitigation of methane and nitrous oxide emissions from waste, energy and industry", *Energy Journal*.

Long run marginal costs were calculated using the following assumptions:

- Economic life of 15 years for each option.
- Eighteen month construction period, with interest during construction added to capital costs.
- Weighted average cost of capital of 10% in pre-tax real terms.

3.3.3 Emission calculations

The mix of MSW, C&I and C&D streams varies over time. The variation in the mix is large between years, largely due to variations in the population growth, GSP growth and increase in per capita waste generation. Since the mixture of waste by source is only available for 2006[12] these values were used for all periods. These are reported in Table 3-5 and Table 3-6. Since the proportions of wood and paper entering the landfill vary year by year using constant percentages of waste type will clearly introduce error to our estimates.

Table 3-7 lists all other model parameters.

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11 An average methane capture rate of 85% has been reported in AGO (2007), *Review of Methane Recovery and Flaring from Landfills*, 22nd October 2007. In this study, 75% has been assumed as more recent data suggest a lower rate.

12 AGO (2007), *Australian Methodology for The Estimation of Greenhouse Gas Emissions and Sinks 2006*, Canberra

Table 3-5: Waste stream percentages, Australia, 2006

Waste Stream	Proportion[13]
Municipal Solid Waste	28.4%
Commercial and Industrial	34.4%
Construction and Demolition	37.2%

Table 3-6: Waste mix percentage by stream and key model parameters

Waste Type	MSW	C&I	C&D	DOC	Half Life
Food	26.2%	8.0%	0.0%	15%	12
Paper and Textiles	26.2%	48.0%	3.0%	40%	17
Garden and Green	10.2%	4.0%	2.0%	20%	14
Wood	2.2%	12.0%	6.0%	43%	35
Other	35.2%	28.0%	89.0%	-	-
Total (%)	100.0%	100.0%	100.0%	-	-

Table 3-7: Other assumptions used in calculating landfill emissions

Parameter	Value
Fraction of Degradable Organic Carbon (DOC_f)	0.5
Fraction to CH_4 (F)	0.5
Oxidation Factor (Ox)	0.0
Landfill Methane Correction Factor (MCF)	0.9

The methane correction factor (MCF), which reflects the potential for methane generation at a landfill, varies from 0.4 to 1 depending on the type of landfill sites[14]. In this study, a constant MCF of 0.9 has been assumed for all years until 2020 and then 1 thereafter, based on the assumption that all the landfill sites will be well managed and the landfill sites that were closed in 1990's will be completely stabilized.

3.4 Abatement cost curves

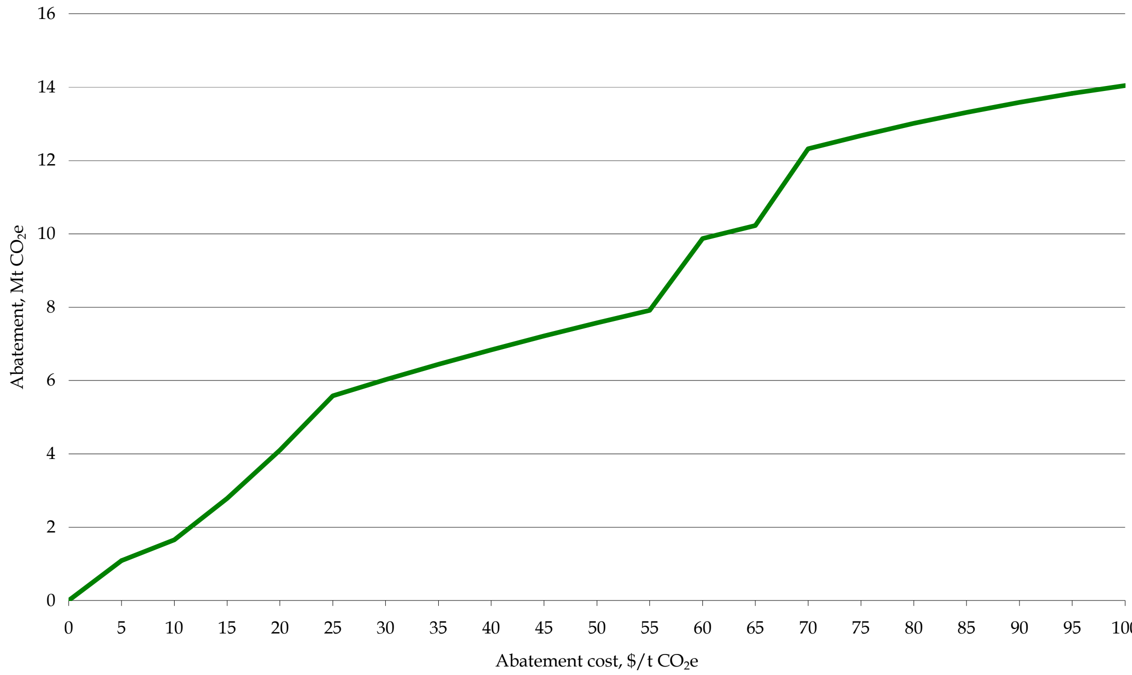
The cost curve for potential abatement from solid waste management in Australia is included in the following chart. Cost of abatement increases as more abatement is

[13] Hyder Consulting (2008), *Waste Recycling in Australia*, prepared for the Department of Environment Water, Heritage and the Arts, November.

[14] The methane generation potential varies with the quality of management of landfill and the physical structure of the landfill (depth, coverage, etc.)

required, reflecting the diseconomies of scale in gas collection as less favourable sites are processed. The data indicates that about 4 Mt of additional abatement[15] can occur for less than $20/t CO2e. Around 8 Mt of abatement can occur for less than $50/t CO_2e and around 14 Mt of abatement can occur for less than $100/t CO_2e.

Figure 3-6: Abatement level and cost for abatement activities at landfills



Note: This represents annual abatement additional to what already occurs. Abatement activity can be taken up under a range of support measures (such as the Renewable Energy Target Scheme) so the final carbon price required for adoption may be less than shown.

The abatement comes mainly from:

- Flaring. This is likely to be a low cost option, being adopted at major landfills as an initial option with low permit prices. The benefit to landfill operators is that they basically avoid paying for emissions of methane from the landfill. Flaring is also the major option for small landfill sites and for remote landfill sites.
- Capture to provide fuel. The potential for abatement from this source is limited by the quality of the gas collected and by the low availability of host industrial customers to use the gas.
- Capture to use in an electricity generator. This is the major source of abatement in the long term and provides landfill operators with an additional source of revenue. However, the cost of this option increases exponentially as smaller sites convert to this option and as gas collection gets more difficult (mainly from sites already closed).

15 Above abatement activity already occuring.

The model determines the level of uptake of abatement options based on costs of the abatement activity relative to permit price and other incentives for abatement (such as the Renewable Energy Target scheme, which provides an additional revenue stream for electricity generation based on landfill gas).

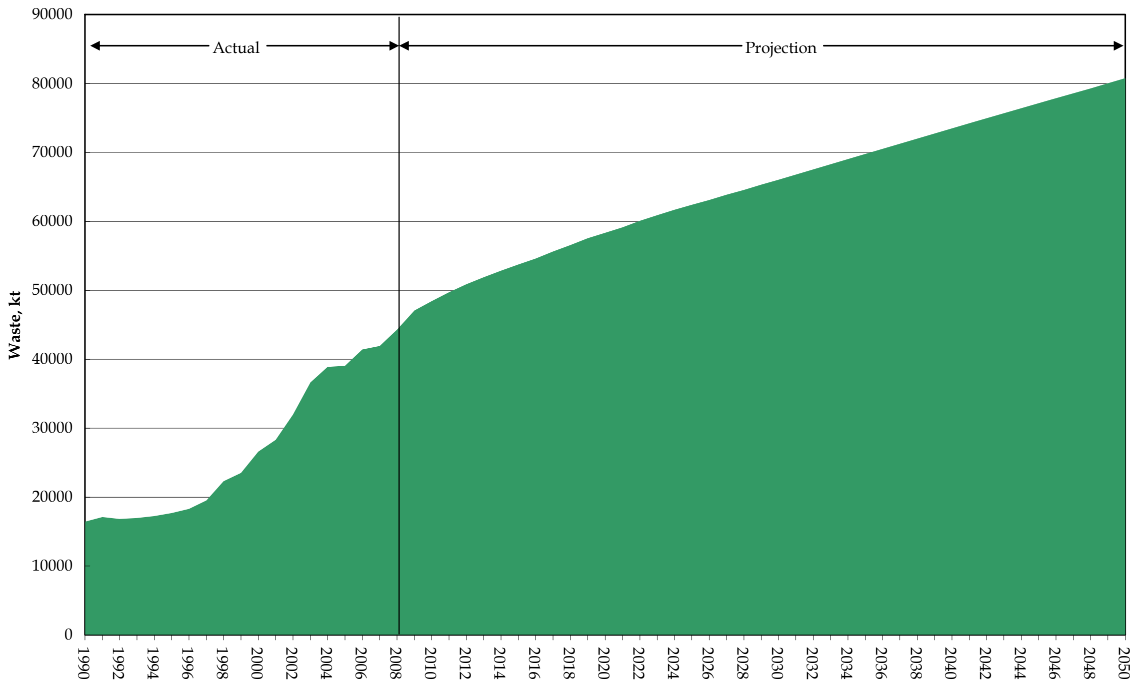
4 PROJECTIONS

4.1 Waste generation

Preliminary projections of waste generated are shown in Figure 4-1. Waste generated is projected to continue to increase as population and incomes continues to increase. The rate of increase falls over the projection period due to several factors including a declining income growth rate with the ageing of the population and a slowing of population growth rates.

Waste generated is projected to grow from an estimate 42 Mt in 2008 to reach around 80 Mt in 2050. Around 50 Mt is recycled into other materials and around 30 Mt is projected to be deposited in landfills. Organic material deposited to landfill increases from around 10 Mt in 2008 to 14 Mt in 2050. Most of the material is paper and textile products and food waste.

Figure 4-1: Waste generation in Australia



The model's projection of waste generation from organic material shows a growth rate in waste generation rates of around 2% per annum. This is lower than recent historical data and lower than some other projections[16]. The projection is lower in this study due to lower population and economic growth rates than recorded in recent times and decrease in waste generation rates as incomes grow (as a higher proportion of growing incomes is

[16] Personal communication with DEWHA.

spent on goods and services other than food and clothing with less embodied organic material).

Figure 4-2: Waste deposited into landfills and recycling facility

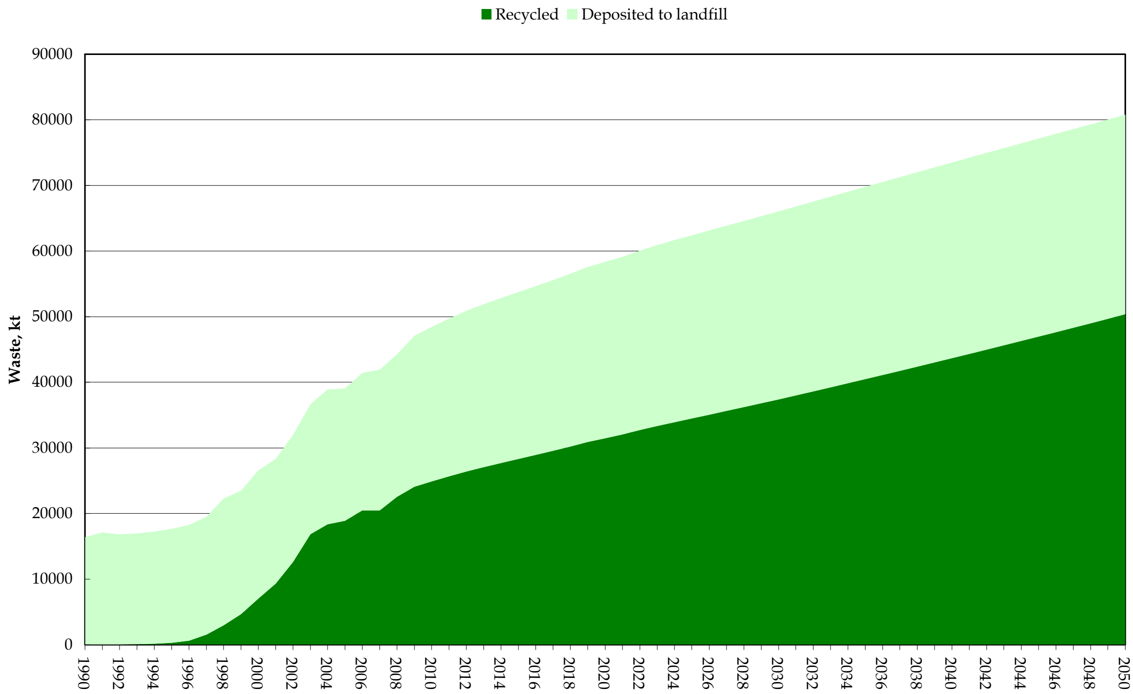


Figure 4-3: Organic material deposited to landfills

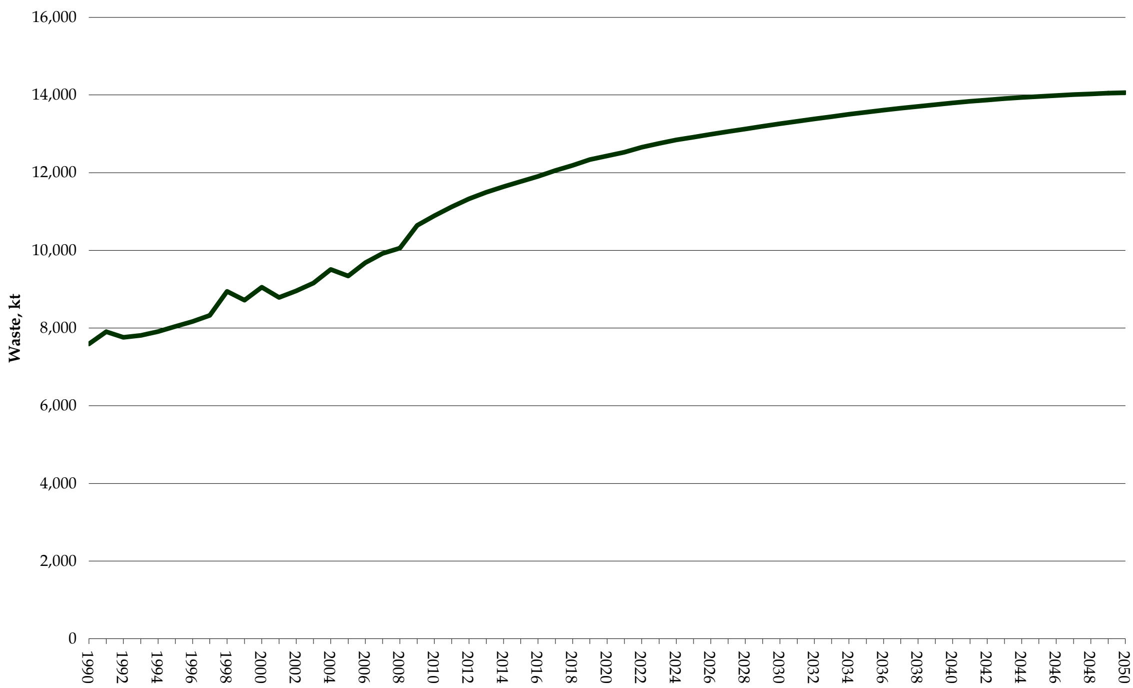
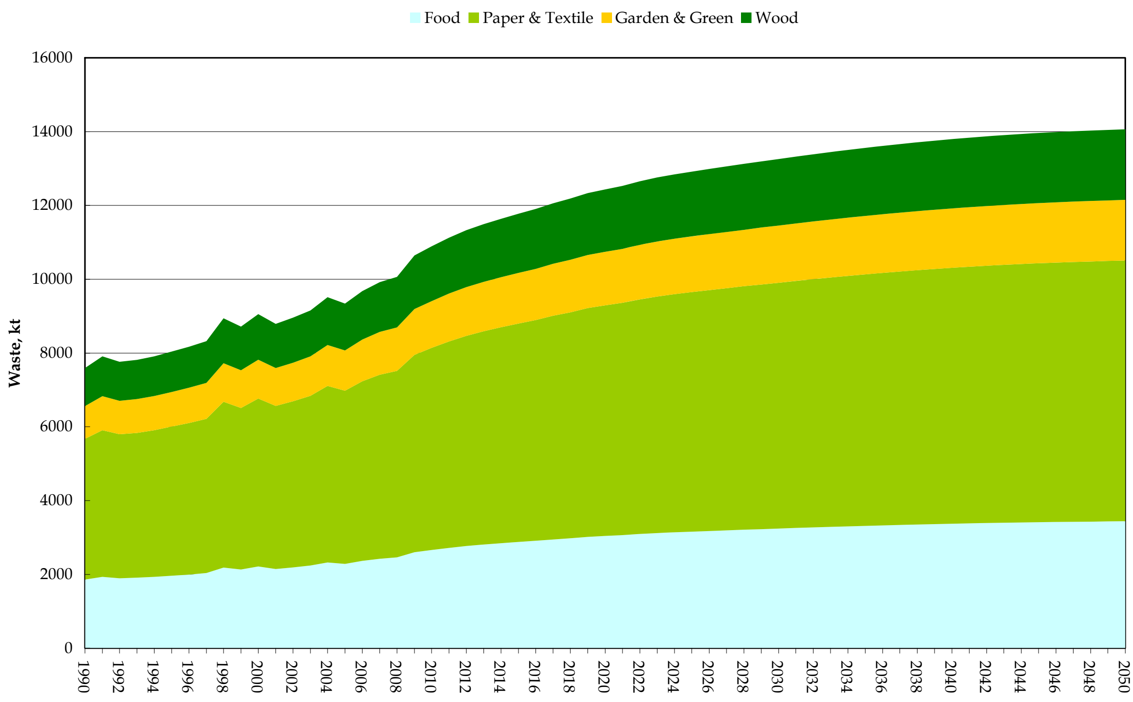


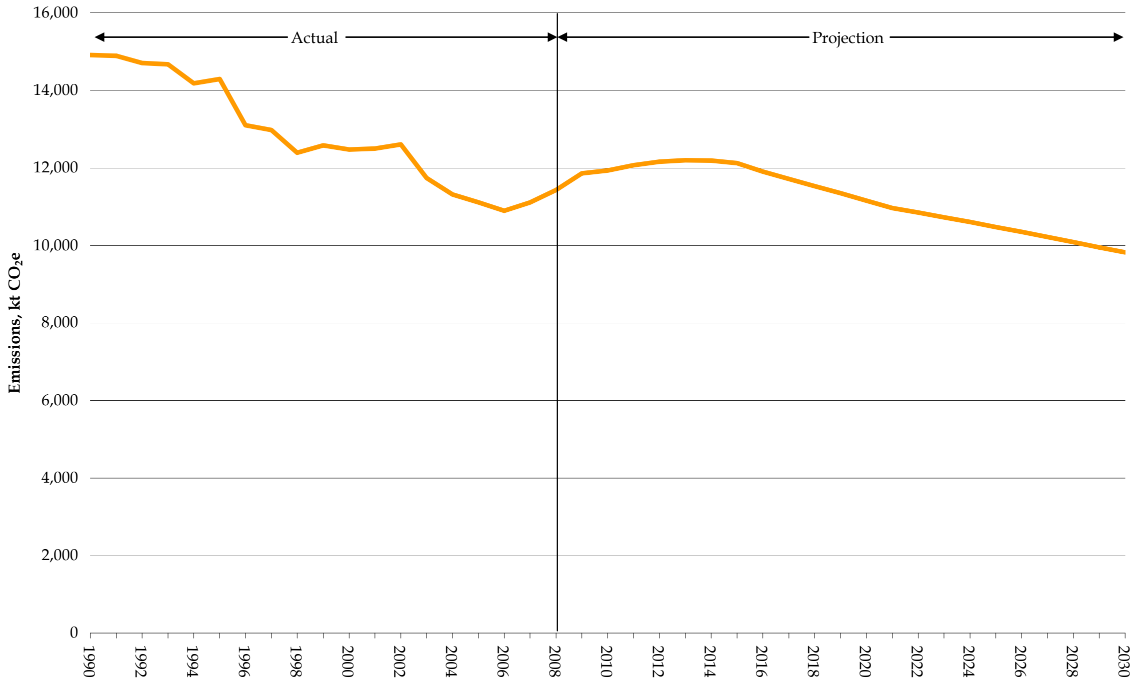
Figure 4-4: Organic material deposited by type of material



4.2 Emissions

Emissions from organic material deposited in landfills are projected to grow initially as a function of continuing deposits and the impact of legacy emissions. From 2015 onwards, emissions are projected to fall to be just under 10 Mt CO_2e in 2030.

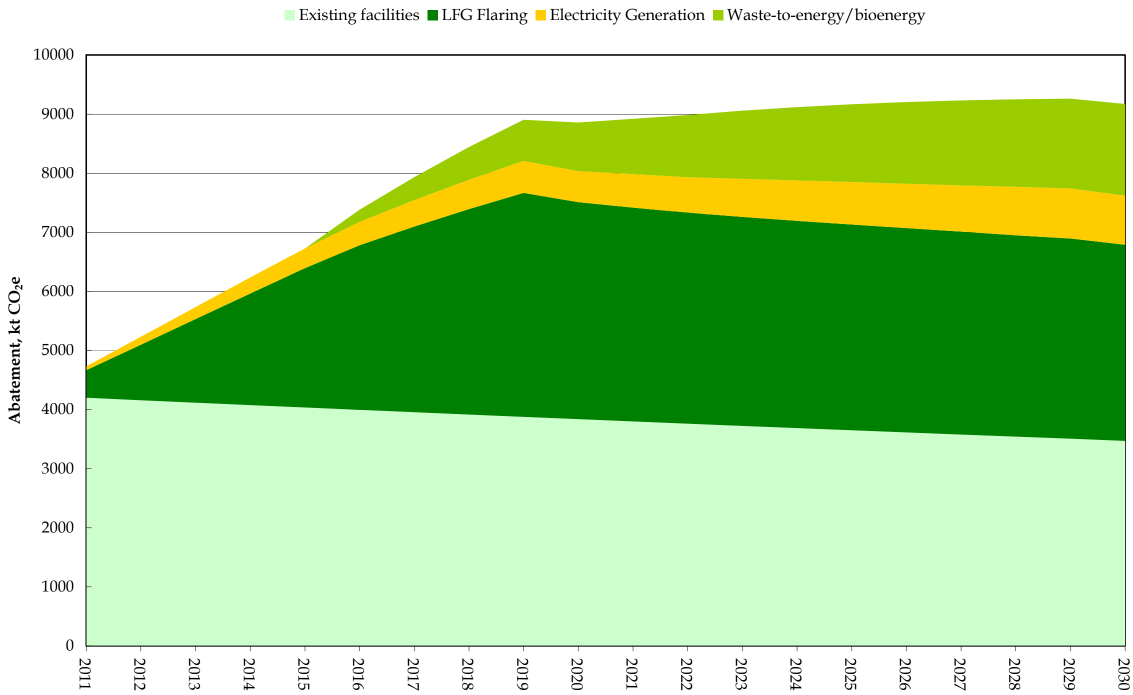
Figure 4-5: Emissions from landfills



The fall in emissions is due to falling legacy emissions as the stock of organic material deposited before 2011 depletes through degradation, and the implementation of additional abatement options at landfills. Around 9 Mt CO_2e of emissions are abated due to the adoption of abatement activities (that is, if the abatement activities had not occurred there would be an additional level of emissions of around 9 Mt CO_2e). Around 5.7 Mt CO_2e of the 9 Mt CO_2e comes from new abatement activity in part in response to the carbon prices likely under the proposed CPRS[17], [18].

Around 60% of the abatement comes from flaring and 40% either through additional electricity generation from landfill gas and advanced waste treatment options such as waste to energy facilities and pyrolysis processes to produce bio-energy products.

Figure 4-6: Abatement from landfills



The reason for landfill gas flaring being the main option until 2030 is the low cost of this option relative to other abatement alternatives especially at smaller land fills and the relatively low permit prices which are below the abatement costs for other options in the period to 2030[19]. The level of electricity generation from landfill gas and waste to energy options is expected to increase under the Renewable Energy Target Scheme, but not enough to cause these options to be the prime source of abatement. Even so the level of electricity generation from landfill gas is expected to nearly quadruple. Beyond 2030

[17] The net effect of the proposed CPRS on abatement is likely to be lower than this as some of the activities would have proceeded under other government programs in absence of the CPRS.

[18] On the other hand, some existing abatement activity may have ceased in absence of the proposed CPRS or other incentives.

[19] Data collected by the Waste Management Association of Australia (WMAA) indicate a large proportion of the large landfill sites already have flaring. The increase in flaring rates indicated by this analysis reflects increase disposal of waste in landfill (increasing the stock of biodegradable material), the extension of flaring activities to smaller sites and increased use of flaring at sites that already have some form of flaring.

higher electricity prices brought about by increasing carbon permit prices see the use of these options increase.

Table 4-1: Level of electricity generation form landfill gas and waste to energy facilities, GWh

	2006-07	2019-20
Australia	557	2,170
Queensland	22	353
NSW/ACT	314	543
Victoria	61	465
Tasmania	8	39
South Australia	28	98
Western Australia	117	667
Northern Territory	7	7

Source: MMA analysis

On a state level, the highest level of emissions occurs in the populous states of NSW, Victoria and Queensland. These states have the highest level of legacy emissions, whilst the smaller states have a high proportion of emissions from small landfills not covered by the proposed CPRS. The most populous states also have the highest level of abatement at the moment, but the level of abatement over time increases in other states as new landfill gas generation opportunities are concentrated in these other states.

Table 4-2: Emissions from landfill by State

	2006-07			2019-20		
	Emissions	Abated	% Abated	Emissions	Abated	% Abated
Australia	11,104	4,500	29%	11,152	8,859	44%
Queensland	2,503	178	7%	2,415	1,440	37%
NSW/ACT	4,497	2,537	36%	3,630	2,217	38%
Victoria	2,109	493	19%	2,753	1,897	41%
Tasmania	233	65	22%	238	157	40%
South Australia	594	226	28%	795	399	33%
Western Australia	1,094	945	46%	1,205	2,693	69%
Northern Territory	74	57	43%	117	57	33%

Source: MMA analysis and data from NGGI

4.3 Value of permits

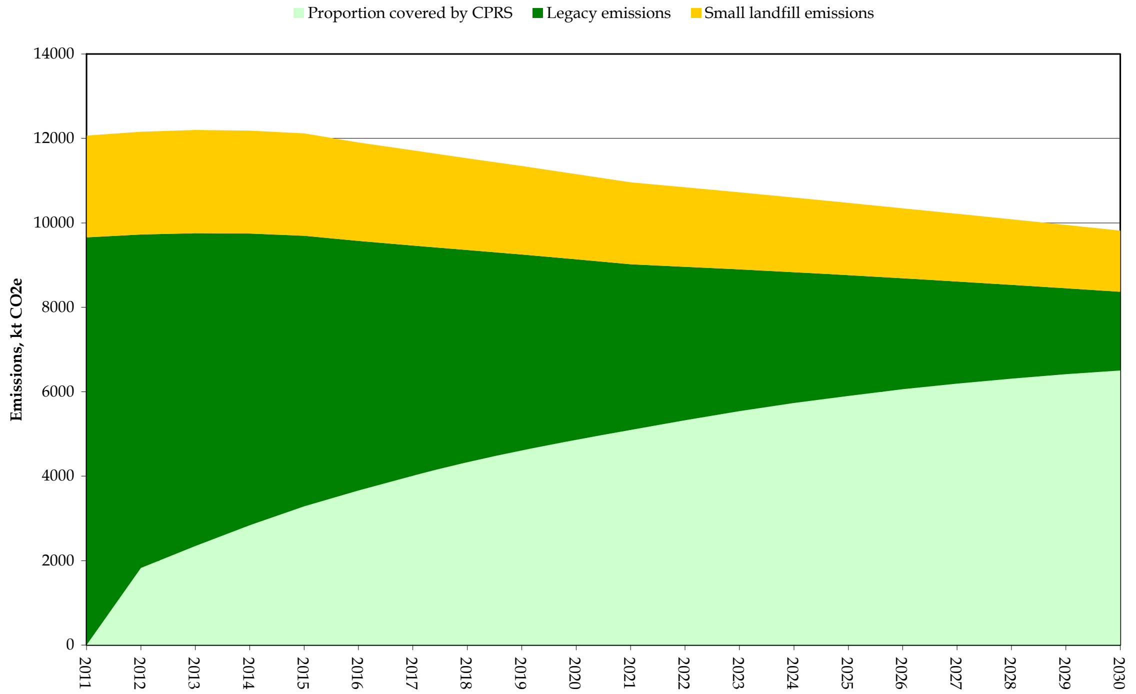
Under the proposed CPRS, not all emissions from landfills will be covered under the proposed emission trading scheme. Under the modelling assumptions, around 15% of emissions will be covered in 2012, increasing to around 66% in 2030. Legacy emissions at large landfills are projected to fall from around 65% of emissions in 2012 to 19% of emissions in 2030. Emissions from small landfills (with less than 25 kt CO_2e emissions) decrease from 20% of emissions in 2012 to around 15% in 2030.

If these emissions are covered under the emission trading scheme, the value of the permits are estimated to be around $1.4 billion (to 2020) to $2.4 billion (to 2030). Of this amount, around $0.3 billion to 2020 and $0.8 billion to 2030 come from small landfills, which are under the threshold amount for inclusion in the proposed CPRS.

Table 4-3: Net present value of the carbon impost from emissions not covered by the proposed CPRS, $ million

	to 2020	to 2030
Total	1,396	2,350
Legacy emissions	1,005	1,600
Small landfill emissions	391	750

Figure 4-7: Emissions by landfill category



5 IMPLICATIONS

5.1 Issues

There are number of issues in projecting emissions from landfills, which are discussed below.

First, emissions from landfills under the NGGI procedures are calculated using a range of formulas on the rate of degradation of biological material. These formulas are based on available evidence on the rate of decomposition, which are based on limited studies. The rate of decomposition varies upon the condition of the landfill and there is a risk that as more studies are undertaken there could be changes in the formulas used to calculate emissions or the assumptions used in the calculations. As an example, recent studies have indicated that the rate of biodegradation is slower than original estimates, which means that the legacy calculations may need to be changed. A change in the degradation rates used to calculate emissions would impact on estimates of historical emissions as well as the future level of emissions from organic material currently in landfills.

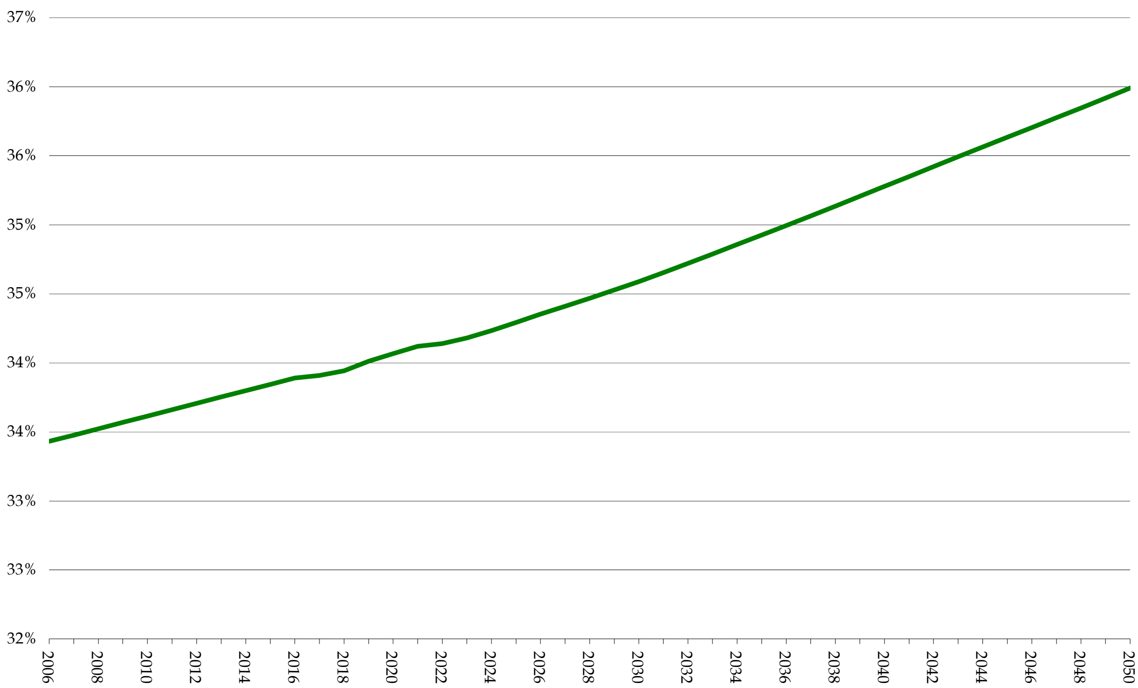
Second, the data on amount of material going to landfills is of low quality, often being incomplete and with data being inconsistent across state jurisdictions. In particular, the proportion of organic material is based on limited surveys of landfill operations, not on actual tonnages through some weighing procedure.

Third, the modelling assumed no additional effort to increase diversion or recycling rates. The proportion of organic material recycled estimated by the model shows only a small increase in recycling rates (see Figure 5-1). However, the State and Federal Governments may seek to adopt other policies to increase the amount of recycling. Additional actions to reduce the rate of material to landfills will alter the rate of emissions from landfills. A review of the intentions on State government agencies indicates there is an increasing emphasis on diverting food waste and other organic material to be recycled. On the other hand, the cost of increasing recycling or waste diversion rates will increase as the proportion of recycling increases, often in an exponential fashion. This cost increase may deter further action to encourage recycling.

Fourth, under a proposed CPRS, costs will increase even for the current recycling effort due to higher transport costs (as fuel prices increase due to the imposition of carbon liabilities) and higher energy costs for processing of the recycled material. As production of virgin material are likely to face similar cost increases, the increase in transport and energy costs from recycling in unlikely to materially impact on the demand for recycled material. In fact, there is even a small probability for some recycled material, there will be an increase in the demand for recycled material due to lower cost increases than occurs for the production of virgin material (e.g. for production of aluminium). This is likely to be less of an issue for organic waste material, with the exception for wood products.

For organic waste management, estimating future rates of recycling is further complicated because the Renewable Energy Target (RET) Scheme will drive investment in landfill gas generation and therefore provide incentives to dispose of putrescibles to landfill. On the other hand, incentives provided by the RET scheme could drive the development of alternative waste treatment technologies especially waste to energy technologies, leading to less material going to traditional landfills.

Figure 5-1: Implied recycling rates for organic material in Australia



Source: MMA analysis. Covers the proportion of waste generated diverted from landfills from food, paper and textiles, garden organics and wood wastes.

Fifth, there is an assumption in the analysis that waste management costs are passed back on to waste generators either directly or indirectly providing an incentive to minimize waste generation. This is reflected in the modelling by a parameter reflecting the elasticity of waste generated to price for landfill services. This is set at highly inelastic rate of -0.05, implying that for every 1% increase in waste generation costs, the level of waste generated falls by 0.05%. There is no reliable data on the level of response to waste management costs, and there is a high prospect that the response could be higher or lower than assumed. For municipal solid waste, there may be no response (or the response is expressed through illegal dumping) as the rates do not directly reflect the amount of waste generated. For C&I and C&D waste streams, the response could be greater as these sectors may be more price sensitive.

Finally, the level of methane capture rates for some of the abatement options is uncertain. For example, the analysis was based on the assumption that methane capture was around 75% for land fill gas flaring and electricity generation, which is less than some historical estimates and greater than others. The assumption was based on the assumption that flaring and generation equipment are well maintained and replaced once every 17 years (the average life of the equipment in Australia). However, it is possible that more accurate data could show lower conversion efficiencies for these options. Lower rates of conversion would reduce the effectiveness of these options and increase the abatement cost per unit of abatement. Less abatement would occur as a result.

5.2 Sensitivities

In this section, we explore the impact of changes to the key assumptions to provide insights into the implications of the uncertainties listed in Section 5.1.

A major uncertainty is the future rate of recycling. A sensitivity was performed with the rate of recycling constant at 2008 levels and the rate of recycling experiencing a 10% decrease from historical recycling rates by 2020. The analysis indicates that with constant or a slow decline in recycling rates, the level of emissions remains relatively steady to 2020. By 2020, emissions are higher by around 2 Mt CO_2e from the lower levels of recycling. More importantly, emissions with the lower rates of recycling are around 18% lower than 1990 (compared with 25% with a slight growth in recycling rates) and around 2% lower than 2000 levels (compared with 11% with a slight growth in recycling rates).

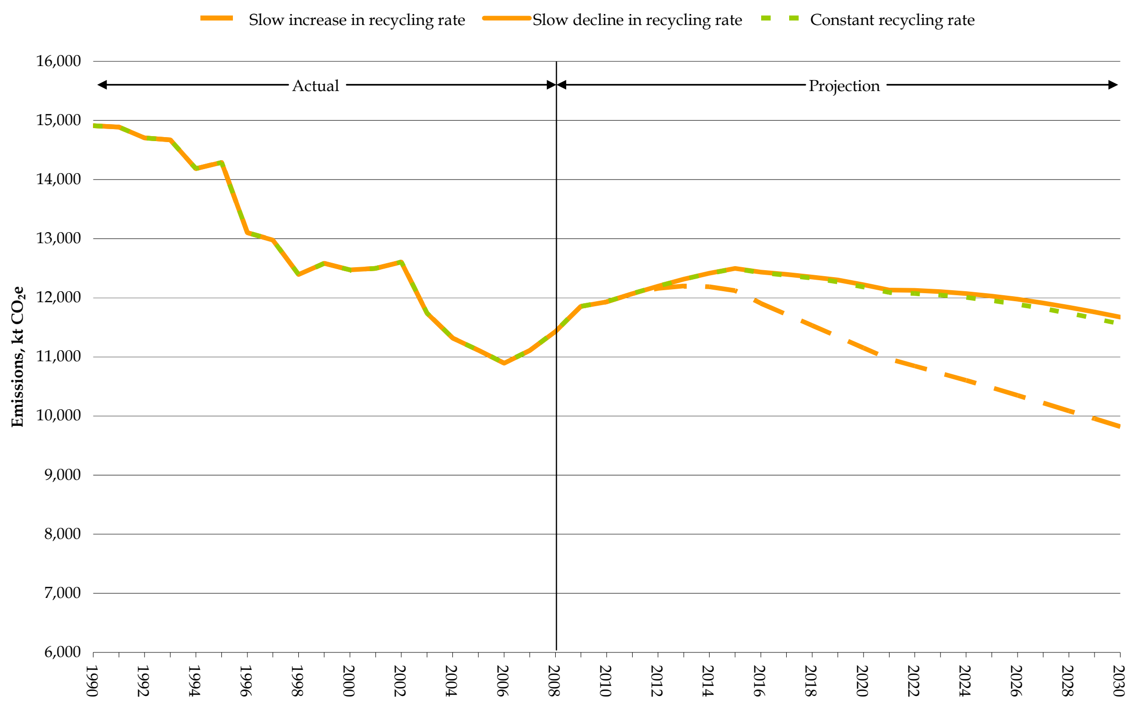
The impact of lower rates of recycling was limited by the slow degradation of organic material in landfills. Further, as more organic material enters landfills, this provides more opportunity for capture through flaring or landfill gas generation under current abatement measures.

This sensitivity analysis provides two insights. First, the level of recycling is an important determinant of the level of emissions and more effort may be required to adopt or encourage recycling efforts, especially where net social benefits can be demonstrated. Second, constant or falling recycling rates will mean that waste sector will not achieve its share of the national emission reductions under the proposed CPRS, implying the need to purchase more permits elsewhere.

Another major uncertainty is the waste generation rate. The estimates in this analysis indicate growth rates of around 2% per annum for waste generation. Other studies project waste generation rates of over 4% per annum.

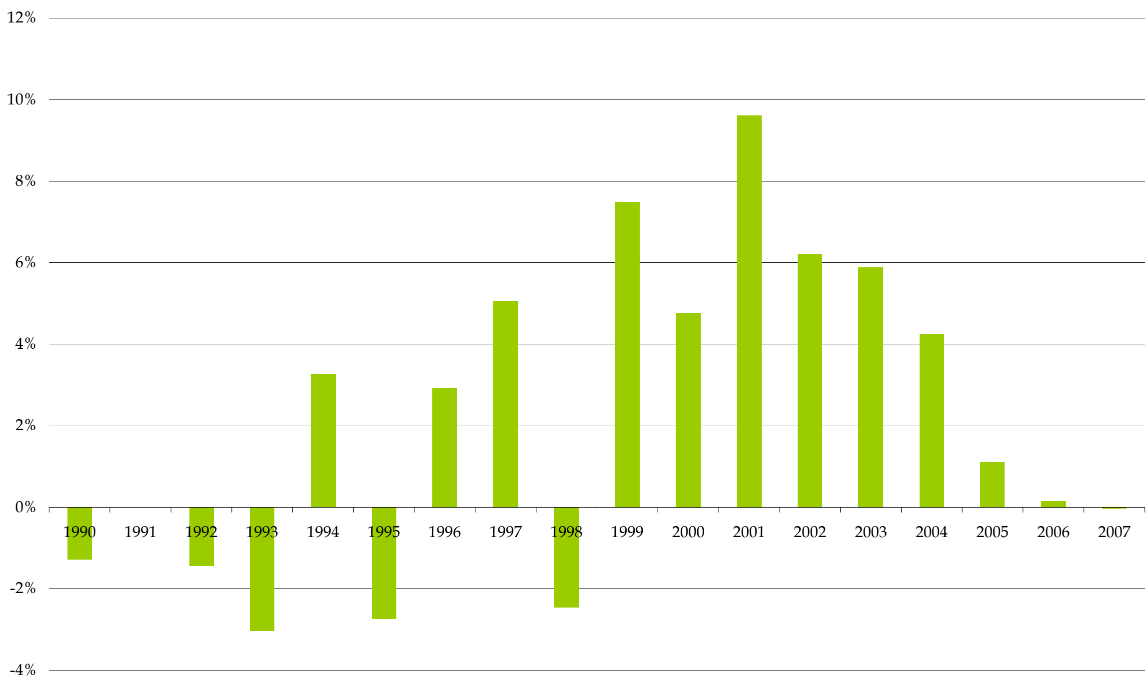
Estimates of waste generation have been obtained from bottom up analysis of waste collection data. This data indicate high generation rates in recent times. However, analysis of top down data indicates much lower waste generation rates. Using data on apparent consumption of food, material for clothing, and wood product sales at a domestic level obtained from ABARE and other sources indicates domestic consumption of organic material at much less than the estimated rates of historical waste generation. Based on apparent consumption data, and assuming growth rates in waste generation in line with growth in apparent domestic consumption would indicate an average growth rate of 2.2 per annum since 1990.

Figure 5-2: Sensitivity of emissions from landfills to different recycling rates



The lower rate from the top down data is not to suggest that the bottom data is incorrect. Rather it is to highlight the disparity and uncertainty in the growth rate estimates for waste generation.

Figure 5-3: Growth in apparent domestic consumption of organic material



Source: MMA analysis based on apparent domestic consumption data provided by ABARE, agricultural marketing boards, ABS, and annual reports of wood product and textile manufacturers.

Assuming a waste generation growth rate of 4% per annum would see generation of organic waste reach 15.4 million tonnes in 2020 compared with 12.4 million tonnes under the original assumptions. This would lead to emissions being around 2.7 Mt per annum higher in 2020.

Clearly, it will be important to obtain better data on waste generation and recycling rates as the overall level of emissions are highly sensitive to both variables. But the level of legacy emissions and emissions from small landfills excluded from the proposed CPRS is less sensitive to variations in these assumptions (see Table 5-1). Most of the variations occur at landfills covered by the proposed CPRS.

Figure 5-4: Sensitivity of emissions from landfills to waste generation rates

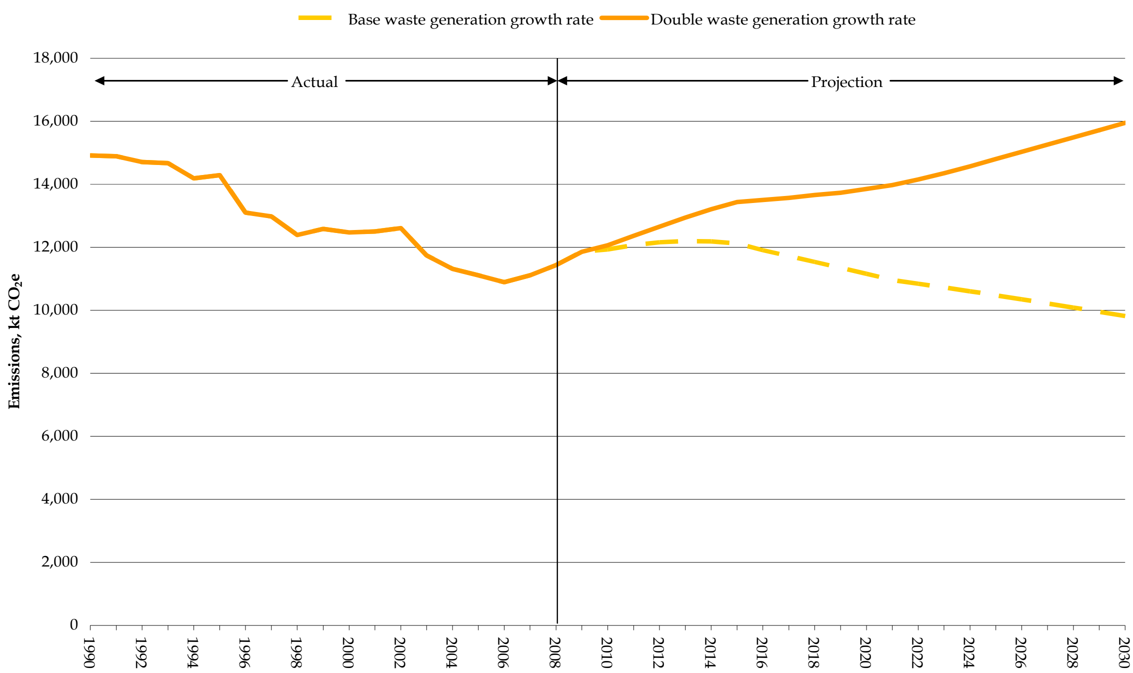


Table 5-1: Sensitivity of emissions to changes in waste generation and recycling rates by landfill category

	2020			2030		
	Covered by CPRS	Legacy	Small landfill	Covered by CPRS	Legacy	Small landfill
Emissions						
Base assumptions	4,863	4,273	2,016	6,503	1,865	1,450
Double waste generation rates	6,759	4,714	2,379	11,549	2,378	2,020
Constant recycling rate	5,653	4,384	2,147	8,072	1,900	1,580
Decline in recycling rate	5,613	4,452	2,153	8,089	1,987	1,597
Proportion of emissions						
Base assumptions	44%	38%	18%	66%	19%	15%
Double waste generation rates	49%	34%	17%	72%	15%	13%
Constant recycling rate	46%	36%	18%	70%	16%	14%
Decline in recycling rate	46%	36%	18%	69%	17%	14%

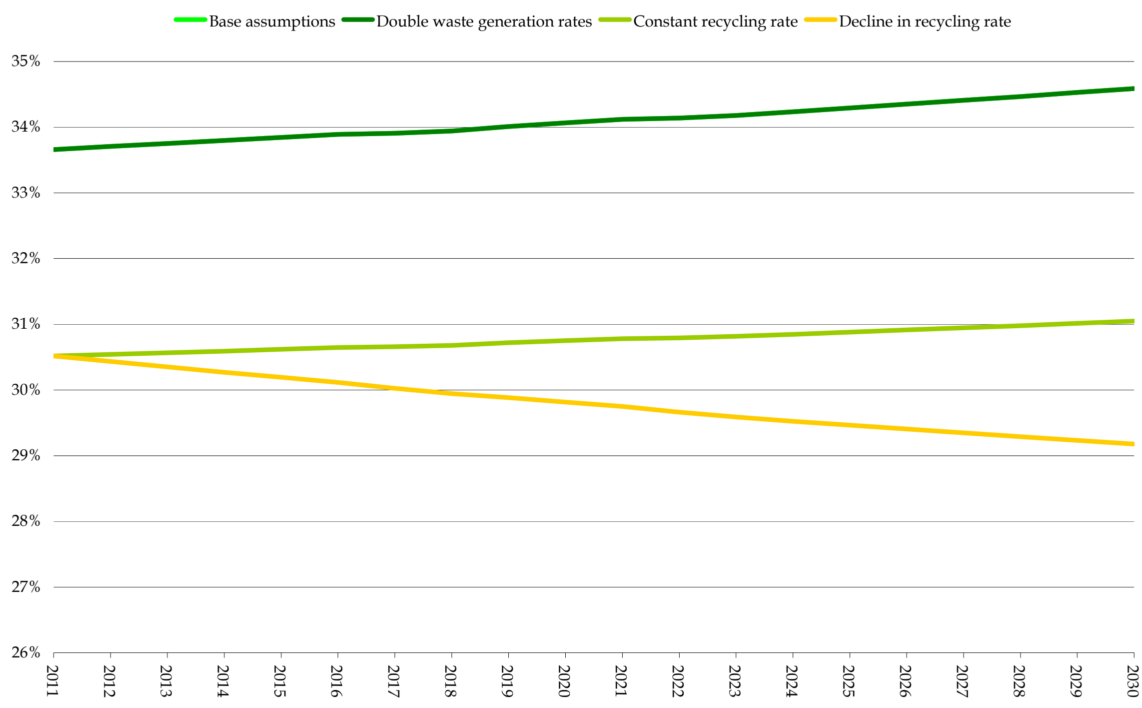
Source: MMA analysis

5.3 Policy implications

The proposed CPRS impacts on both the level of abatement activity at landfills and the level of waste diverted to recycling activities. The level of abatement activity is determined by incentives provided by the proposed CPRS through avoidance of costs at covered landfills (that is, through avoiding or reducing the need to purchase permits) and through improved revenue streams (for example, electricity generated earns higher prices as costs for electricity from other sources increases). The level of waste diverted to recycling will depend on the interplay between increased costs for recycling (due to higher energy prices), the increased value of recyclates (due to higher prices for virgin materials), and the higher cost for landfill due to need to purchase permits.

The level of recycling under base assumptions increases slightly. The increase in the recycling rate is more likely to be due to incentives and regulations that directly affect the recycling rates. The impact of the proposed CPRS is muted due to low proportion of energy costs in recycling activities and the modest increase in landfill costs due to the CPRS (particularly in the period before 2020). However, the impact of the proposed CPRS on recycling rates may be underestimated in this study as there was no consideration of the impact of the CPRS on virgin material prices. This factor is not likely to be material for food and garden organics but could be material for wood products.

Figure 5-5: Recycling rates



The level of abatement at covered landfills is obviously geared to the permit price under the proposed CPRS, which provides an incentive to reduce emissions at these sites. For legacy emissions and operating landfills not covered by the proposed CPRS, the range of options for abatement of emissions is limited. Typically, the cost of abatement at small sites is more expensive than for the larger covered sites. For legacy emissions, abatement is difficult because often abatement activity requires facilities to be installed at non-operating sections of landfills (e.g. to bury drainage pipes), which is typically more expensive than installing the same facilities as the operating landfill is being filled. The lifespan of the abatement options is also likely to be shorter at old (non-operating) landfills. The small size of those landfills not covered by the proposed CPRS will also mean higher per unit costs for abatement.

Table 5-2: Cost estimates for abatement options for small and large landfill facilities, $/t CO_2e

Option	2020	2030	2050
Flaring - large facilities	44.85	44.85	44.85
Electricity generation - large facilities	46.24	50.76	51.93
AWT facilities - large facilities	159.36	210.02	148.64
Flaring - small facilities	54.82	54.82	54.82
Electricity generation - small facilities	60.83	65.15	66.08
AWT facilities - small facilities	192.60	253.42	179.27

Source: MMA analysis. Estimates are median cost estimates. Costs in any state can vary according to gas production rates and electricity revenues.

The analysis indicates that the carbon price would need to be at least $50/t CO_2e for additional abatement to occur at small facilities and to mitigate legacy emissions under an offset program. Although future carbon prices are difficult to predict, the carbon prices predicted in the Australian Low Pollution Future Study would indicate that permit prices above $50/t CO_2e would not occur until after 2020. This is not to say that no additional abatement would occur at permit prices lower than this, but that the level of abatement is likely to be modest. As legacy emissions are likely to fall off after 2020, there is a possibility that an offset arrangement under the range of carbon prices predicted by most studies would lead to no abatement of these emissions.

The analysis did not examine directly the cost of alternative policy approaches to reduce emissions at landfills not covered by the proposed CPRS. However, the analysis provides some indication of the approaches that are likely to be more successful. The approaches would need to account for the higher cost of abatement opportunities and the limited lifespan of legacy emissions.

For legacy emissions, the main approach is to improve the economics of landfill gas generation facilities. Flaring is another option, but this could be limited as many of the legacy landfills may be located near new suburbs. The Renewable Energy Target Scheme provides incentives to use legacy landfill gas to generate electricity. The proposed CPRS provides indirect incentives as the revenue earnt on electricity sales from landfill gas generators increase as permit prices increase. Thus, to get a higher level of abatement would require indirect approaches, such as the removal of market impediments to small scale or embedded generation under the current rules and regulations governing electricity markets. Identifying market impediments to small scale landfill generation requires further study.

A number of approaches are available for avoiding emissions at small scale facilities. Two approaches are likely to be most prospective. First, improving waste management and recycling arrangement by amalgamating waste collection infrastructure at fewer but large sites. Second, assist in the development of alternative waste treatment methods (e.g. waste to energy facilities, AWT facilities that produce energy, biochar and other useful by-products). These facilities could be located at the more centralised collection facilities, improving the economies of scale and reducing the cost of abatement.