A Review of Subsidy and Carbon Price Approaches to Greenhouse Gas Emission Reduction

THE CLIMATE INSTITUTE

SH43458 | 14 August 2013

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SKM

A Review of Subsidy and Carbon Price Approaches to Emission Reduction

Document title:	SH43458 Emission Reduction Fund Policy Review
Version:	10
Date:	14 August 2013
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File name:	C:\Users\wgerardi\Documents\TCI Carbon Policy\SH43458 Report V10.docx

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1. Introduction

The Climate Institute requested SKM MMA and Centre of Policy Studies (CoPS) to undertake an assessment of alternative policy options to achieve a given carbon emission target in Australia. The focus of the study was to compare outcomes under a suite of subsidy based policies to the outcomes under an emission trading scheme. The outcomes of the study are presented in this report.

There are several market based approaches that could be used to achieve a carbon emission target. Which approach is more or less effective in achieving the target will depend on any restriction placed on the measure, the ability of each approach to manage the uncertainties on the cost and future scale of abating carbon emissions, the long term behavioural signals provided and the relative impacts on the broader economy.

In principle, a subsidy scheme, such as the proposed Emission Reduction Fund (ERF), could achieve the same level of abatement at a similar cost to an emission trading scheme provided the sectoral coverage was the same and the eligible abatement options were the same. Any difference in effectiveness and cost may be due to other factors such as a limit on the budget available to be spent through the subsidy scheme and differences in sectoral coverage. Whether projects receiving funding under the subsidy scheme will proceed or go under either before they are built or after a few years of operation, as has happened under other subsidy scheme, is also important to the effectiveness of the scheme.

SKM MMA used a marginal abatement cost approach to assess the options chosen under the subsidy fund. The approach was used to assess a range of emissions abatement opportunities in a range of sectors covering energy, transport, agriculture and land use change, industrial processes, fugitive emissions, and waste. The approach involved the assessment of the cost and potential emission abatement of the eligible options. The assumption was that the lowest cost combination of options is selected under the fund to meet the abatement cap up to any budget or other declared constraints. Only options that are additional (i.e. would not have proceeded in absence of the fund or carbon abatement incentive) were considered.

The estimated level of abatement by options and their cost are input into CoPS's Monash Multi Regional Forecasting Model (MMRF)to determine broader economic impacts.

This report outlines the assumptions and method used and discusses the result of the modelling. Limitations and uncertainties in the approach are also outlined. The focus of the analysis was on potential impacts – there is no discussion on which approach is more efficient.

2. Policy Settings

The ERF is a form of subsidy scheme. Under the ERF, tenders will be held to support emission abatement options up to the budget targets. The approach is to pick those options that minimise the cost of meeting a specified target set at the Kyoto Protocol Second Commitment Period QELRO of 99.5% below 1990 on average for the 2013 to 2020 period.

Five policy scenarios were requested to be evaluated. The parameters of the scenarios are:

- *Reference case*: Current policy environment with a carbon pricing mechanism as currently designed securing reduction in emissions (using the agreed targets under the Kyoto Protocol as target for covered sectors). The modelling was completed before the recent announcement of a move to emission trading on 1 July 2014. The price assumed for 2014 is higher than the projected market price of around \$6/t CO_2e. Whilst this will impact on the results for 2014/15, there would be minimal impacts in subsequent years
- *Base policy case*: Carbon price mechanism and associated revenue transfers repealed on 1 July 2014 and replaced by an Emission Reduction Fund with funding capped. Baselines (based around historical emission intensities), penalty for emissions above baselines, and new entrant baselines assumptions apply. Other initiatives such as the Carbon Farming Initiative and the Renewable Energy Target (RET) remain unchanged.
- *Case 1*: As with base policy scenario but large scale RET reduced to match a real 20% by 2020 and a 25% by 2025.
- *Case 2*: As with base policy scenario but baselines set as are absolute, not on an emission intensity basis.
- *Case 3*: As with base policy scenario but liable entities can purchase international and domestic units to avoid penalty and/or purchase units from liable parties who have emissions below their baselines.
- *Case 4*: As with base case but RET set at 30% of total generation by 2020 and 50% by 2030.

The time frame for the modelling is 2015 to 2050. The modelling is conducted over a long period because investments in long lived low emission assets are determined by the long term outlook on costs and revenues.

The level and timing related to Emission Reduction Funding will also be important, with funding is only committed to 2020. Assumptions on budget availability after 2020 are illustrative and so the focus of the discussion of results is on the impacts before 2020.

2.1 Policy parameters

2.1.1 Reference case

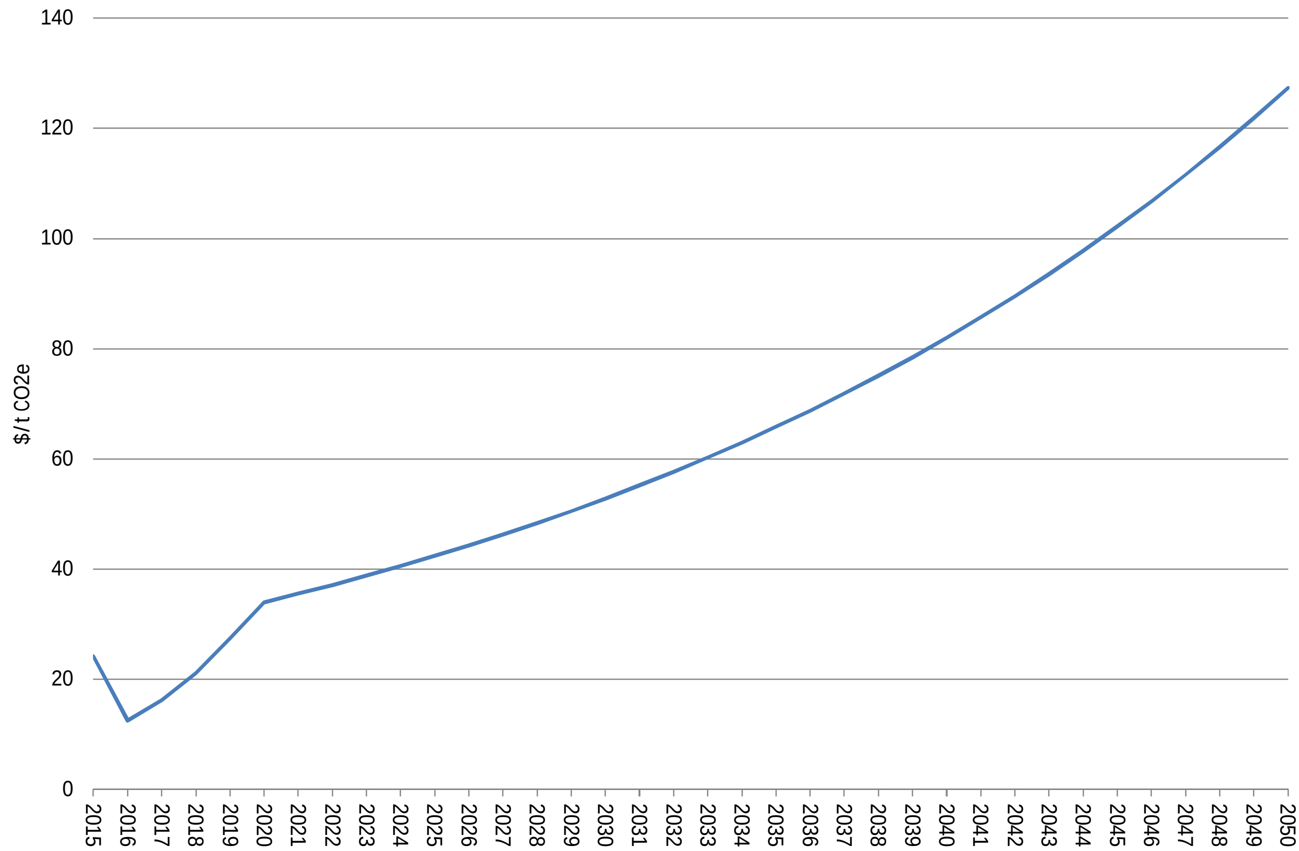
The key element of the reference case is the carbon price. Forecast of carbon price are shown in Figure 1. The price remains around \$24/t during the fixed price period and then drops to \$13/t in the first year of emission trading escalating 7.5% per annum to reach about \$34/t in 2020, and then increasing by 4.5 per cent per annum in real terms. This projection reflects recent Treasury projections of the carbon price and is representative of mid-point forecast based on current analyst expectations.

Market prices are inherently uncertain. The underlying assumption is that for an emission trading scheme to be effective in reducing emissions to meet long term targets, the carbon price will eventually reflect the long run marginal cost of abatement options.

The targets in the modelling will follow the provisional targets set in the Australian Government's submission to the UNFCC for the negotiation behind the second commitment period under the Kyoto Protocol. The proposed commitment (the Quantified Emission Limitation or Reduction Objective (QELRO)) is for an emission budget from 2013 to 2020 of 4,626 Mt over 8 years. This is equivalent to an annual average target of 99.5% of 1990 levels over the eight year period.

As the modelling goes out to 2050 a budget over this period is required. We have assumed that the target trajectory will decline gradually to the legislated target of 80% reduction on 2000 levels by 2050. This translates to a national emissions target of 117.4 million tonnes in 2050.

Figure 1: Carbon price assumptions



Other features of the scheme remained as planned including:

- Inclusion of the stationary energy, industrial processing, waste (new waste emissions), and fugitive emissions. Road transport emissions are excluded initially, but heavy road emissions were assumed to be to be included after 2016. Legacy waste (pre 2012) emissions were assumed to be excluded from the target but can be used as an offset.
- Agriculture and land use change remain excluded but can participate indirectly by contributing offsets under the Carbon Farming Initiative.
- Threshold is around 25,000 tonnes. Small gas users (and from 2016 road users) are captured indirectly as their liabilities are captured at the retail point.
- Compensation arrangements to remain in place (for households, EITE, and industry adjustment assistance). EITE is wound back from July 2020 onwards and then abandoned from 2026 onwards as other major emitting countries participate in international trading. Industry assistance is assumed to continue until 2026.
- LRET and SRES schemes remain in place as currently configured, with multiplier on small-scale PV remaining at 1.
- National Energy Savings Initiative not implemented. State energy efficiency schemes remain as planned.
- CEFC to continue funding at $2.5 billion per annum as low cost loan targeting novel or newly commercialised renewable and low emission technologies. ARENA to continue funding at the level set in the recent budget. Funding (for ARENA) beyond the forward estimates is not assumed to proceed.

2.1.2 Base policy case

In the base policy case, the carbon price is repealed in mid-2014. This will be replaced by an Emission Reduction Fund. The ERF is designed to reward emission reduction through a producer grant type system. Elements of the ERF for modelling purposes are:

- Target is the same as the reference case of a target meeting Australia's second commitment period Kyoto Protocol QELRO. This target is predicted to be on average of 578 Mt CO2e per annum over the period 2013 to 2020.[1]

- The funding comes out of the Federal Budget. There is a cap on funding set at $300 million in 2014/15, $500 million in 2015/16 and $750 million in 2016/17, $1.0 billion in 2017/18[2] and $1.2 billion in 2018/19 and in 2019/20. Budgets after this period have not been set but it is assumed that funding will increase by 5% per annum thereafter.

- Table 1: Funding allocations under the ERF Policy

Year	Budgeted amount, $ million	Cumulative spend, $ million
2014-15	300	300
2015-16	500	800
2016-17	750	1,550
2017-18	1,000	2,550

- The abatement will be procured through a reverse auction process. For modelling purposes we will assume that this is the same as a tender process, with the following assumptions:
  - The grants apply to actual abatement as they occur (i.e. not deemed upfront[3]) and set on pay as bid rates. The payment period was set over the specified period and designed to achieve a zero or positive payback in that time. Funding will be spread over 5 to 10 years, to ensure long term performance and set at a level to meet sectoral payback periods. Annual funding was limited to the budget constraints listed above.
  - Sectors covered included all sectors covered by the current CEF program plus legacy waste, transport users and land use change (including forestry), and legitimate soil carbon options.
  - The amount of abatement for each project was determined as the net change in abatement compared to conventional versions of the technology. It was assumed that the intent was to achieve additional abatement over and above what would have occurred under business as usual conditions. It was assumed there will be a rigorous process to determine that abatement will be additional, and this takes time to evaluate. Administrative cost of this process was assumed to be $2/t and $3/t abated in line with costs incurred under the GGAP and NSW ESS programs. This cost will be met by the ERF fund and will be covered as part of the bid price. It was assumed that approval would take one year so that any option selected would be installed in the normal installation period plus one year.
  - The program would cover energy efficiency programs and would support energy efficiency options not already part of another Federal or State Government program. It was assumed that the scheme would encourage aggregators who bid in one bid a program of installations over several premises for one type of activity, with the aggregation costs (for undertaking the transaction) recovered through their bid. Funding was allowed to cover energy efficient investments with paybacks greater than 2 years.

[1] Source: Australian Government (2012), *Submission under the Kyoto Protocol: Quantified Emission Limitation or Reduction Objective (QELRO)*, November

[2] Source: G. Hunt (2012), "A plan for a cleaner environment and real solutions for all Australians", speech to the Alliance to Save Energy workshop on *Summer Study on Energy Efficiency and Decentralised Energy*

[3] This assumption was applied to all options except energy efficiency options where some deeming upfront was allowed.

- Abatement options that are currently developed or advanced in development (that is, in early commercialisation phase of development) were considered in the modelling. Advanced renewable generation options that would not be expected to be installed under the LRET scheme or SRES would be eligible as long as they are near commercialisation.
- Compliance cost of medium to large scale projects was set equivalent to one full time employee at the mid management level working for one year. This cost will be set for all options and will be recovered through the grants received (i.e.; the grants required will be sufficient to cover both the additional capital and operating costs but also the transaction costs)
- The reverse auction process is assumed to cover the cost of abatement that could not be covered by normal commercial transactions (i.e. the net incremental cost of adopting the option) plus compliance costs.

- The historical baseline for each sector set at the historic emission intensity for the industry averaged over a period of three years. The process was as follows:
  - NGERS data was used to derive baselines for entities that are registered under the scheme – baselines for these entities will be set at the historical average for the three years to and including 2010-11. Where 3 year averages are not available the latest year data was used (see Table 2).
  - AGGI data was then used to derive industry averages for the remaining sectors.
  - Based on growth projections and emission intensity projection by industry class in the Monash Multi-Regional Forecasting (MMRF) model, the penalty paid in regard to the historical baseline was determined: projected emission above historical baseline for industry sector will pay the penalty
  - For the emission intensity option, baselines were set using value add as the numerator.
  - For new entrants, emission intensities will be set at the top Australian rate for each sector[4].
- It was assumed that the historical baselines will be increased for business expansions and new entrants as long as they adopt best practise in regards to emission intensity technology. The penalty acts as a shadow price in investment decisions to expand or for new entrants to enter. Firms have the choice either of paying the penalty when expanding or investing in low emission technology. The choice will depend on what is the least cost. Firms can avoid paying the penalty (on emissions above baselines) if it is lower cost to invest in new technology. Thus, the penalty acts as a shadow cost in the investment decision. The penalty for emitting above baselines will be set at $15/t in 2014/15 increasing to $20/t in 2020, escalating by 6.5% per annum in nominal terms (and about 4.0 % in real terms) thereafter.
- The Carbon Farming Initiative continues and to be expanded to include land based sequestration options (including the 25 year option, with the emission abatement discounted by one-quarter to reflect the disparity of this period with the assumed 100 year cycle for emissions in the atmosphere). In effect the mechanisms for setting offsets under the CFI were extended to all sectors under the ERF. Information published by DCCEE for projects funded under the adjustment scheme was used as a guide to potential abatement or emission levels.
  - Administrative and compliance costs were set at a fixed rate to reflect that there are economies to scale for these costs. For example, the administration cost would be high if the program includes soil carbon initiative because of small size of grants.
- CEFC to be scrapped. ARENA to be kept as planned. ARENA budget restricted to $3 billion as per current budget plan. Projects funded under ARENA cannot receive additional funding under the ERF program.
- SRES and LRET to remain as planned, except in the sensitivity cases.

To the extent that ERF and other coalition policies to reduce carbon emissions do not achieve the target, there is the option of closing the deficit by sourcing international credits. A post modelling exercise was undertaken to calculate the cost of purchasing sufficient

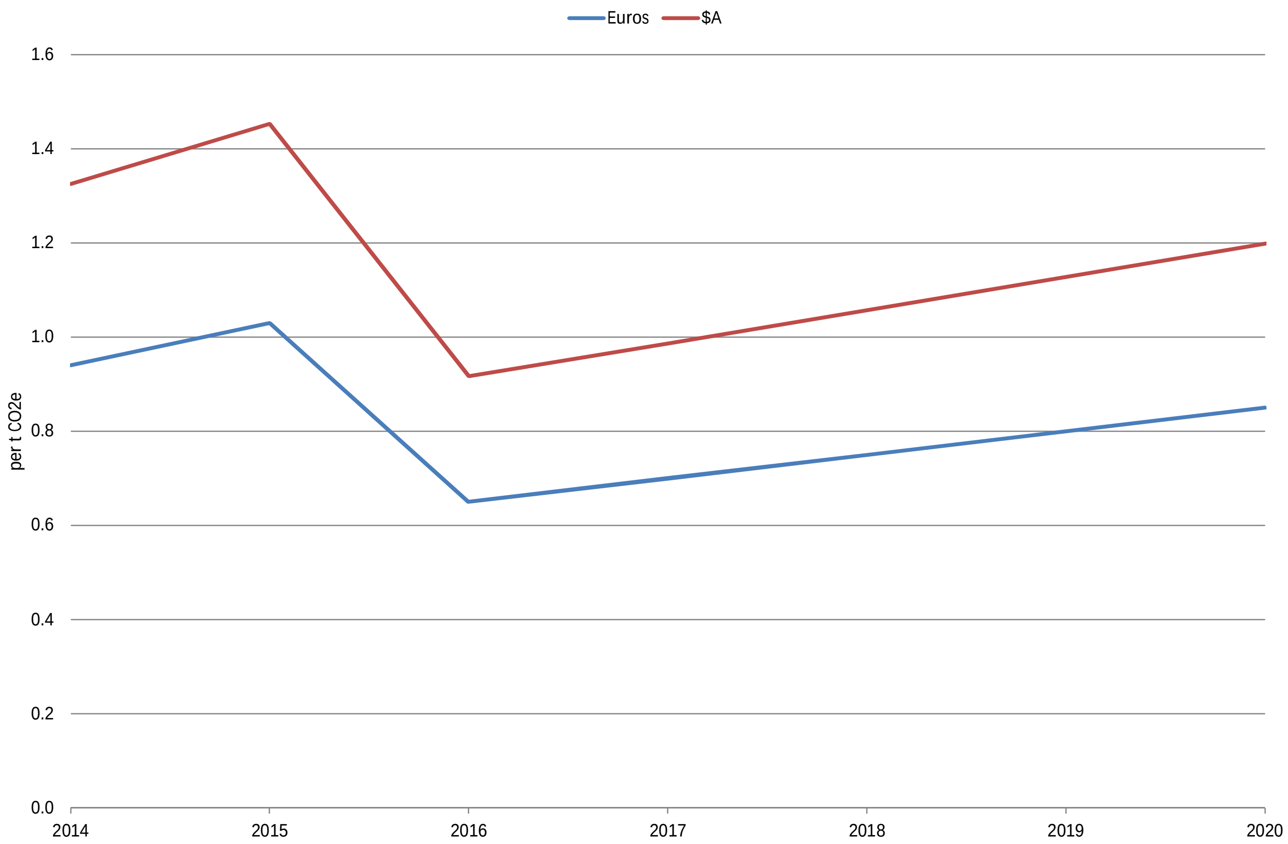
[4] In the modelling, this was set at most efficient emission intensity rate using NGERS data for each industry sector. This data covers around 81% of emissions from activities other than land use and private road transport.

certificates to bridge the deficit between both the 5 and an equivalent 25 per cent emission reduction target. The projected price for Certified Emission Reduction units (CERs) to calculate the amount needed is shown in Figure 2. We undertook a sensitivity around the price of undertaking action, ranging from the CER price to the shadow price of undertaking additional abatement, using the typical abatement costs to determine this shadow price.

Table 2: Initial baseline assumptions by economic sector, t CO_2e per annum

Category	Average	Maximum	Minimum
Accommodation, hotels and cafes	16,961	34,210	2,646
Alumina	2,448,817	3,150,509	1,918,824
Aluminium	3,144,198	8,100,358	320,712
Business services	74,118	576,288	1,763
Cement	1,866,154	2,814,132	214,152
Chemicals	709,505	2,042,187	9,364
Coal mining	976,479	4,945,918	105,223
Communication services	35,941	87,336	108
Construction services	316,525	730,542	79,355
Dwelling services	20,345	20,345	20,345
Electricity generation	6,377,509	23,077,947	18,622
Electricity supply	251,129	2,598,626	457
Financial services	11,216	24,811	6,832
Forestry	38,218	72,701	3,735
Iron and steel	1,921,743	7,527,149	121,724
Iron ore mining	3,111,812	8,673,986	122,055
Meat and meat products	112,504	208,841	51,562
Motor vehicle and parts	42,228	69,131	27,887
Non-ferrous ore mining	252,075	3,290,715	8,592
Non-metal construction products	514,626	2,411,909	28,856
Oil mining	204,572	347,252	61,892
Other food, beverages, tobacco	69,463	310,536	9,936
Other manufacturing	130,783	441,503	11,475
Other mining	72,714	178,961	19,435
Other non-ferrous metals	452,158	1,483,545	20,442
Other services	4,457	4,457	4,457
Paper products	274,009	521,981	21,795
Petroleum and coal products	1,867,790	2,388,137	1,421,797
Public services	80,488	931,637	1,061
Trade services	49,439	349,455	380
Wood products	83,296	83,296	83,296
Air transport	774,964	4,452,612	4,058
Business services	74,118	576,288	1,763

Figure 2: Projected CER prices



Sources: Reuters, 3 June 2013

3. Methodology and Assumptions

3.1 Approach

A two stage approach was undertaken to evaluate of the benefits and costs of both policies:

- Using marginal abatement cost analysis to inform the level of uptake of abatement options under both policies. The analysis provided information on the low cost options for abatement likely to be taken up in each policy scenario, and the level and cost of that abatement.
- Data on costs of abatement options were input into the MMRF model to determine broader economic impacts.

3.1.1 Modelling of Direct Action

The coalition proposes a number of measures apart from the ERF. Our approach to modelling the the subsidy scheme is as follows:

- Set as the baseline a no carbon price emissions trajectory. Use the Kyoto Average as the target range of emissions for the period 2013 to 2020. Determine from this, the amount of (cumulative) abatement required.
- Work out the abatement achieved by a number of non ERF programs. Essentially standard assumptions were used to work out abatement that occurs under each program up to the budget constraints as follows:

Program	Annual payment, 2014/15 to 2017/18, $m
One million solar roofs	100
Clean energy hubs	15
Solar towns and schools	25
Geothermal and tidal towns	12.5
Urban forests and green corridors	12.5

- Use the marginal abatement cost analysis to determine remaining abatement under the ERF as constrained by budget outlined in Table 1.
- For the remaining gap (if any) to the national target, undertake a spreadsheet calculation of the cost of purchasing the gaps from the international CER scheme or from domestic emission reduction in Australia. This was done for the target range of 5% to 25% reduction.

3.2 Emission abatement options

3.2.1 Assumptions

Abatement options considered in the analysis included:

- Energy efficiency options.
- Renewable energy options (beyond those deployed under the RET scheme and covering all stationary energy sectors).
- Efficiency improvements at existing generators and more efficient new conventional generation options.
- Alternative waste treatment technologies such as waste-to-energy options, and alternative landfill gas methane treatments (flaring, and fuel in electricity generation).
- Mine gas mitigation options (treatment of pre-mine drainage, ventilation air methane and waste mine gas).
- Options to reduce methane releases in gas pipelines.
- Alternative transport options (electric vehicles, alternative fuels, fuel cell).
- Options to improve industrial processes in major emitting industries (cement, aluminium, steel and iron, lime) including alternative materials (e.g. alternative cementitious material) and processing technologies.
- Soil carbon restoration options.

- Carbon capture and sequestration options.

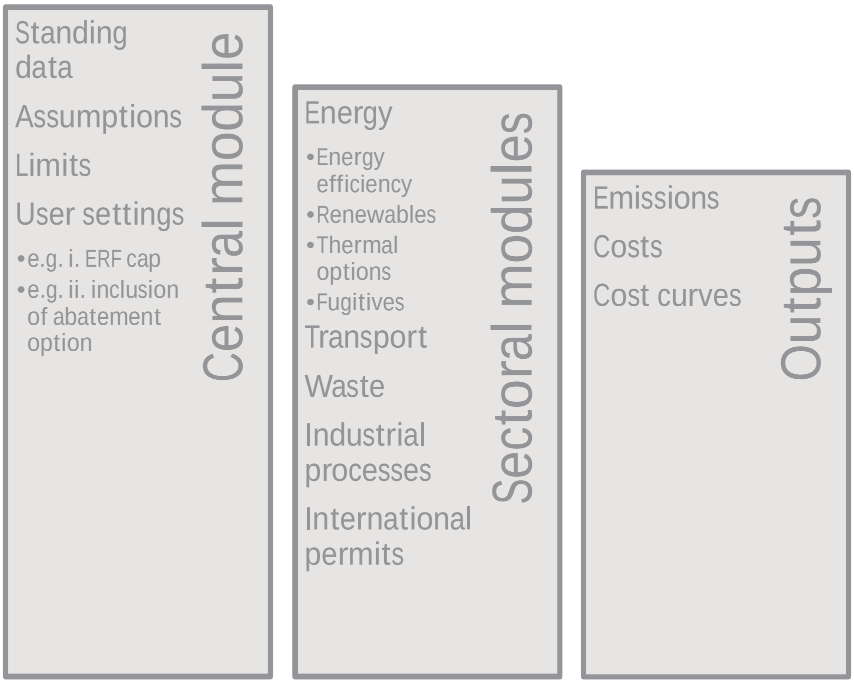
Greater details around the assumptions surrounding each of these options are provided in Appendix A.

The analysis of abatement costs was based around a range of spreadsheet models that estimates the abatement and abatement costs by activity. A visual description of the model structure is provided below in Figure 3.

Small scale options were included under the assumption that aggregation is allowed. The aggregation option was modelled as a reduced transaction cost to comply with the ERF funding.

Average abatement costs are calculated as the present value of costs over the life of the options, divided by the present value of abatement over the life of the option.

Figure 3: Analytical structure for a given sector



3.2.2 Data collection

A range of data sources have been considered in formulating both the business as usual projections and the mitigation impacts and costs of the options. National data is used, supplemented by international data where it has been more recent, comprehensive, or where relevant local data has not been available. More detail on what data has been used is given in the sectoral descriptions below.

Data sources include:

- The National Greenhouse Gas Inventory, Methodology, and Projections.
- The IPCC Fourth Assessment Report 2007.
- Potential for GHG Abatement from Waste Management and Resource Recovery Activities in Australia (e.g. Warniken ISE (2007)).
- SKM MMA's database of renewable energy costs.
- The National Framework for Energy Efficiency reports.
- IEA Documents.
- US DOE Documents.
- World Watch Institute reports.
- Industry data and information.
- The Australian Bureau of Statistics.

- Annual Reports and Sustainability Reports.

3.3 General assumptions

Base macroeconomic assumptions are outlined in the following Table. They will be applied to all policy cases.

Table 3: Macroeconomic policy assumptions

	2014	2015	2016	2017	2018	2019	2020
Real private consumption	2.80	2.79	2.70	2.66	2.56	2.48	2.44
Real investment	1.92	2.05	2.02	1.94	1.90	1.85	1.94
Real government consumption (state)	3.00	2.90	2.80	2.75	2.75	2.75	2.75
Real government consumption (federal)	2.50	2.50	2.50	2.50	2.50	2.50	2.50
International export volumes	4.92	4.62	4.45	4.21	4.09	3.97	3.91
International import volumes	2.35	2.39	2.33	2.26	2.21	2.16	2.20
Real GDP	3.00	2.97	2.88	2.80	2.73	2.68	2.66
Employment (hours)	1.49	1.48	1.47	1.47	1.46	1.45	1.44
Employment (persons)	1.49	1.48	1.47	1.47	1.46	1.45	1.44
Capital stock	3.44	3.30	3.19	3.10	3.01	2.92	2.85
Real wage rate	1.73	1.52	1.44	1.17	1.16	1.09	1.04
National terms of trade	-1.48	-1.48	-1.48	-1.48	-1.48	-1.48	-1.48
Devaluation of the real exchange rate	1.57	1.58	1.54	1.72	1.70	1.68	1.66

Source: CoPS

Another key assumption was the amount of additional taxation or cutbacks in other Government programs required to fund the ERF. The assumption was that the budget expended on the ERF will be covered by cutbacks in other Government programs, reflected in a lower level of transfers from the Government to the household sector. This also includes the dismantling of the CPM related expenditures (e.g. EITE assistance) except the tax assistance to households under the CPM was not unwound.

3.4 Pre-action emission levels

Baseline emission projections were derived for a scenario without carbon abatement action but other technology support policies remaining in place.

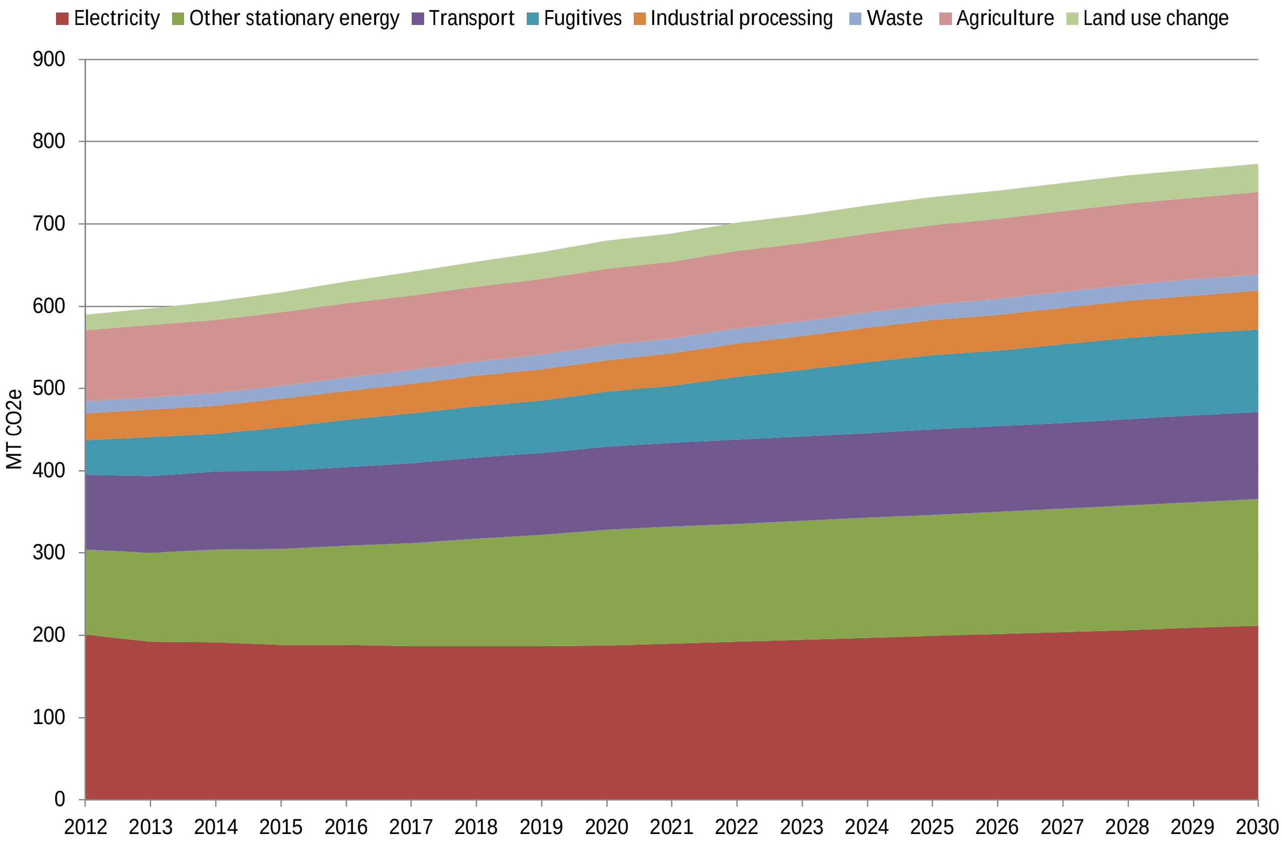
The steps adopted to derive this projection were as follows:

- The projections in the electricity sector were derived using SKM's electricity market models as the primary source. The projection was developed assuming that only lowest cost new entry enters the system, and was designed to meet demand within existing reliability guidelines. Carbon prices were removed. Renewable generation was determined by SKM MMA's Renewable Energy Market Model Australia (REMMA) under reduced wholesale price conditions.
- Direct combustion emissions were estimated from DCCEE without measures projections[5].
- The transport sector consists of road, rail, air, and sea transport emissions creation. The projections in the baseline case were derived using the SKM MMA transport market model. The projection was developed assuming technology limits applied in each year and projected fuel prices.
- For the fugitive emission sector, baseline emissions projections were derived from SKM projections of coal, LNG, gas and oil production. The projections assumed steady growth in coal mining (32% increase from 2013 to 2020), a doubling of gas production (from 2012 to 2020) due to increased production and exports of LNG, and a 40% reduction to 2020 in production and distribution of petroleum fuels due to the closure of three refineries.
- For all other activities, resent DCCEE estimates of emissions without a carbon price were used.

[5] http://www.climatechange.gov.au/~/media/government/aep/AEP-20121106-Summary.pdf and accompanying documents

The projections of baseline emissions are shown in the following chart. The projections indicate flat emissions growth for the electricity sector due to low rates of growth in electricity demand and uptake of renewable energy under the RET scheme. Emissions are projected to grow for all other activities on the back of continuing economic and population growth, with the fugitives, direct combustion and transport activities projected to have the most rapid growth rates. Overall, without action to curb carbon emissions, emissions are projected to increase from 590 Mt CO_2e in 2012 to 680 Mt CO_2e in 2020.

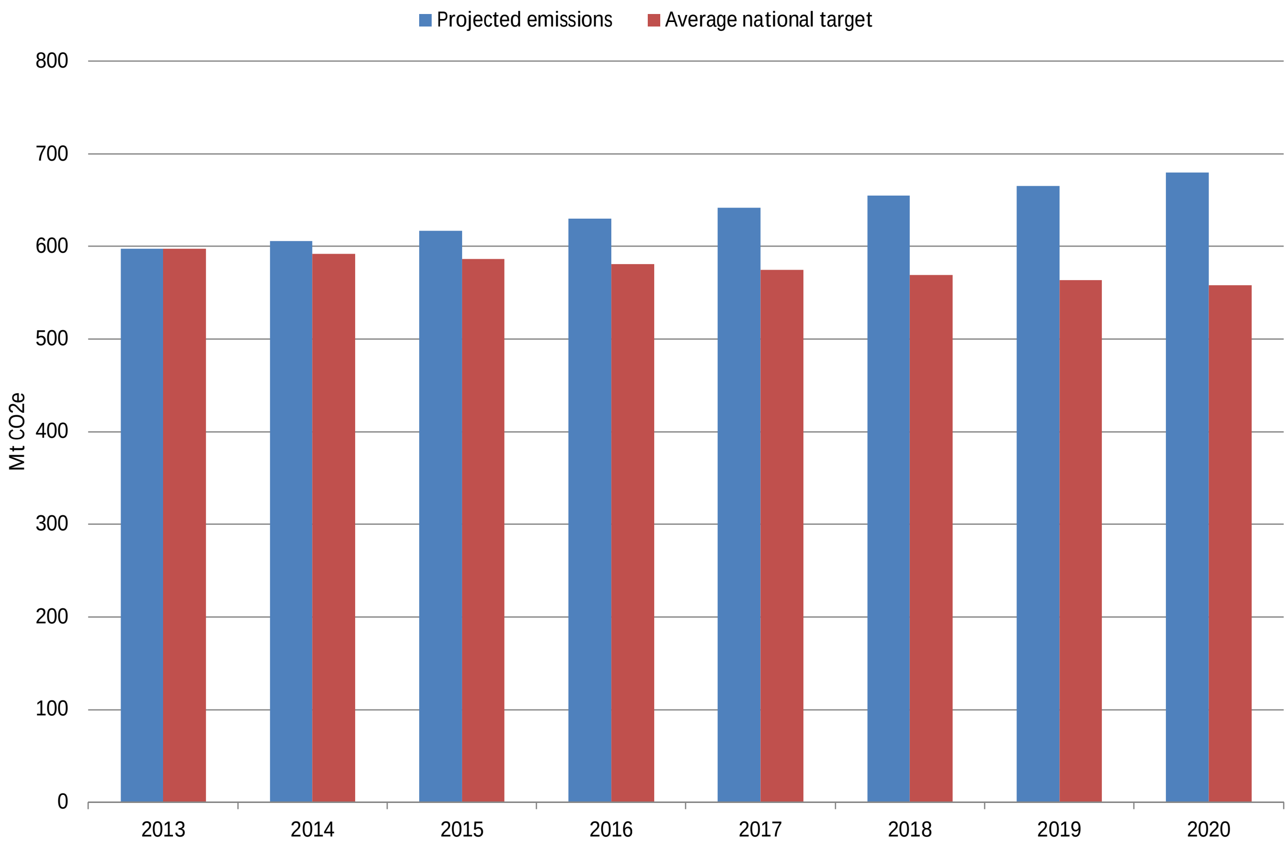
Figure 4: Baseline (without policy measures) emission projections



Source: SKM analysis

The baseline projection has emissions significantly higher than the targets agreed to by the Federal Government. In the period from 2013 to 2020, the cumulative gap in emissions to the target is projected to be 373 Mt CO_2e. The annual gap grows to around 120 Mt CO_2e in 2020.

Figure 5: Baseline emission projection compared to emission target.



3.5 Issues affecting all sectors

The abatement cost analysis is a heuristic approach that provides an indication of what could happen in a world that is much as we see it right now. SKM MMA did not attempt to model any second round effects of climate change or the prospective emissions abatement initiatives.

Where an interaction exists (i.e. when adoption of one abatement option affects use either positively or negatively of another abatement option) some effort was made to identify and approximately evaluate the effects.

4. Abatement and Abatement Costs

This section reports on the findings of the abatement that occurs under each policy scenario. The emphasis is on the level of abatement, where this abatement activity is likely to occur, and the cost of the abatement. The cost refers to the net cost to the economy in terms of additional incremental capital, fuel and operating costs.

4.1 Emissions and abatement

Projected emissions under the various policy scenarios are shown in Figure 6. Under all policy scenarios, emissions in Australia are projected to continue to grow albeit at a slower pace. Under the reference case (with carbon pricing) emission are projected to increase to 613 Mt CO_2e. The cumulative gap to the national target is some 184 Mt CO_2e, which is assumed to be bridged under the carbon pricing scheme through international purchases of permits.

Cumulative abatement from 2015 to 2020 under the reference case (carbon pricing) is projected to be around 263 Mt CO_2e, compared to a level of abatement of around 180 Mt CO_2e under the base policy case (subsidy scheme). The difference in abatement is due to a number of factors namely:

- The impact of carbon pricing on creating behavioural change. In the analysis of abatement options, uptake of options in some sectors is affected by future returns and costs avoided from uptake of the abatement option.
- Projected reductions in energy demand brought about by higher end-use prices for energy brought about by carbon pricing.
- Reduced level of renewable energy generation under RET in base policy case as insufficient revenues are earnt from electricity and certificate sales given the current LGC shortfall charge.
- The budget constraint applying in the base policy case.
- Higher costs of abatement in the base policy case due to the transaction costs of preparing and evaluating bids and the shorter payment times to recover costs.

Two factors ameliorate some of these impacts. There is a higher level of energy efficiency predicted for the base policy case as the value of the savings to energy consumers is more apparent[6]. Secondly, mitigation of legacy landfill gas through electricity generation or flaring can be more easily adopted under the base policy case.

Abatement under the base policy case is severely restricted by the budget available for the ERF fund. Furthermore, a number of tweaks to policy may result in higher levels of abatement. For example, revising upward the shortfall charge applying to liabilities under the RET Scheme may see more renewable energy generation under base policy case.

Alternate base policy cases lead to more or less abatement (see Figure 8). Higher and lower renewable energy targets lead to higher or lower abatement. This finding for the high RET target is based on the assumption that the shortfall charge is increased to achieve the higher target. Over the long term, the achievement of this higher level of generation requires high level penetration of solar generation and/or other sources of new renewable generation such as geothermal and ocean technologies. The higher RET target could also lead to higher consumer prices for electricity, which could lead to some reduction in demand further reducing emissions. This latter effect was not modelled.

Alternative methods of setting baselines have little impact on emissions (see Figure 9). In the base policy case, the setting of baselines on historical rates has little impact because of the assumption in the broader macroeconomic modelling that there is continuous autonomous improvement in production efficiency (e.g. autonomous improvements in energy efficiency) for most activities meaning that historical baselines are never breached. Setting of absolute baselines (based on historical absolute emissions) may lead to emission reductions but only if adjustments to the historical baselines are made according to best practise production techniques. In the modelling of the absolute baseline case, it was assumed this was reflected in certain technologies not being adopted due to their relatively high emission intensity. For example, it was assumed that there would be no new coal-fired generation plant. The impact of this on emission production is relatively minor in the period to 2020 due to there being no need for new thermal plant during this period.

Setting declining baselines does lead to some small reduction in emissions over the longer term, but little abatement to 2020. The reason for this is the assumption that liable entities can purchase international permits on the offset market to cover for any emissions

[6] Energy efficiency options were the only options in the modelling assumed to be paid under a deemed arrangement, where payments for ongoing abatement are rewarded upfront.

above baselines. The low cost of the offset permits means that it is often lower cost to purchase these offsets than embark on emission abatement activities.

Figure 6: Projected emissions under policy scenarios

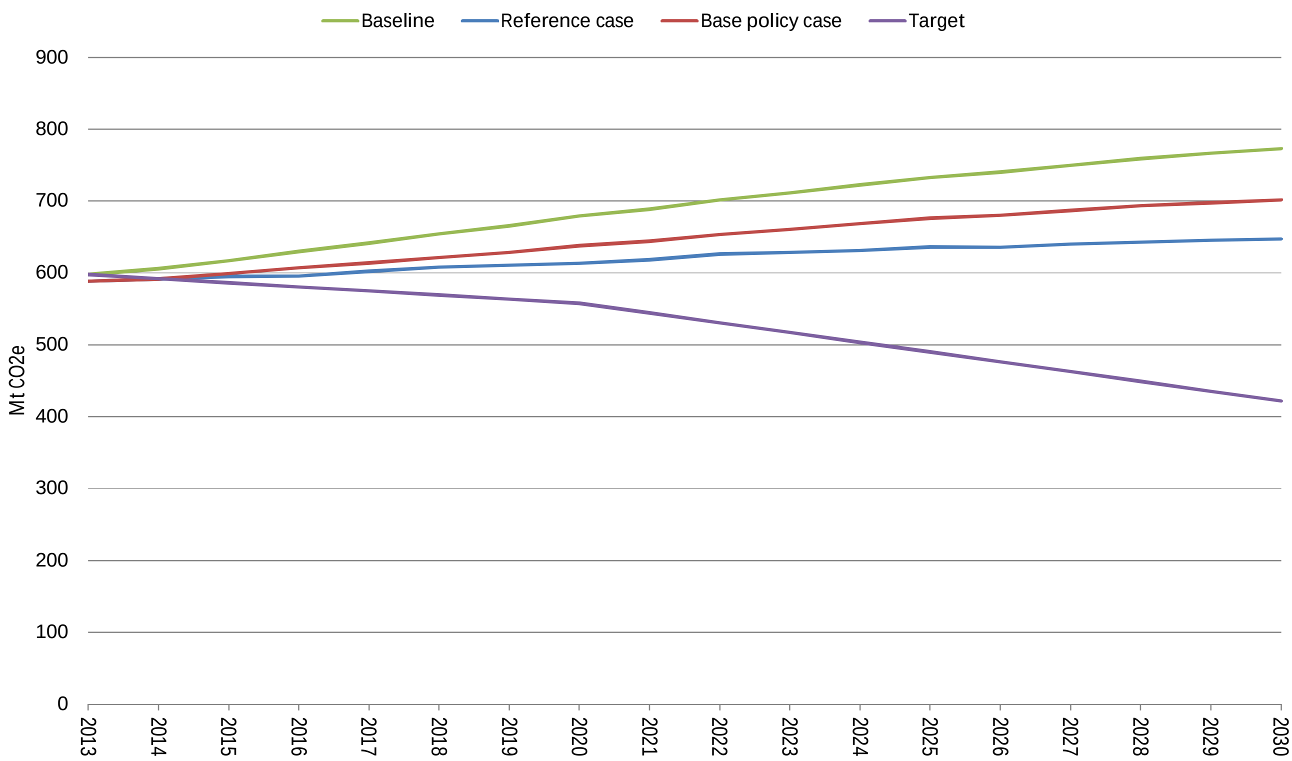


Figure 7: Abatement under policy scenarios

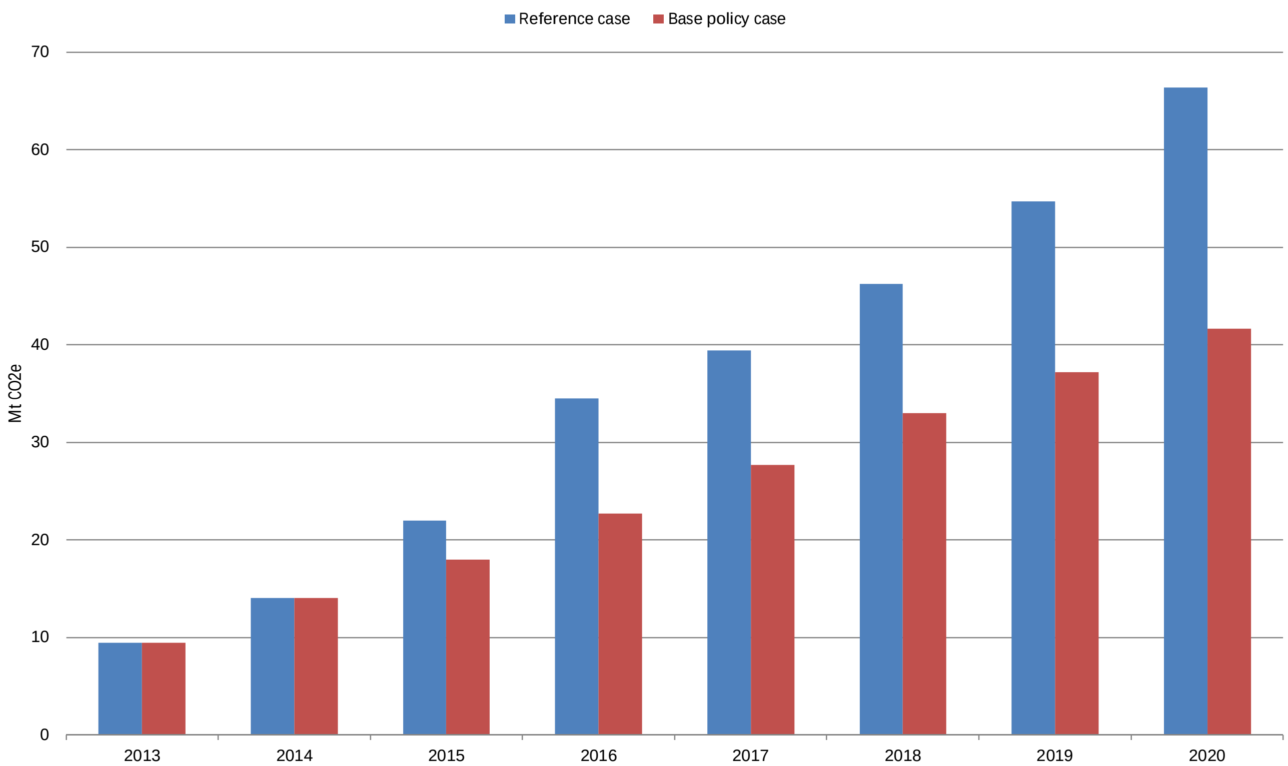


Figure 8: Abatement under alternative RET targets under the base policy case

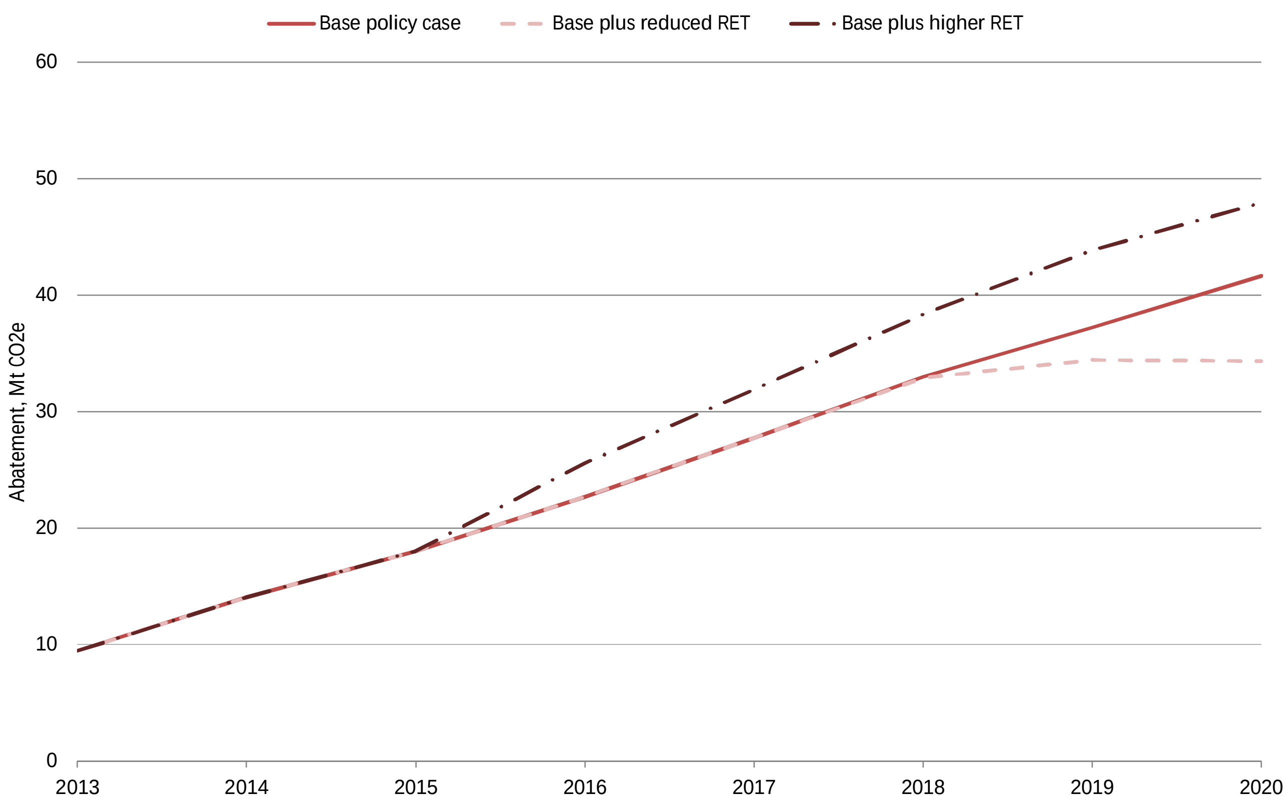
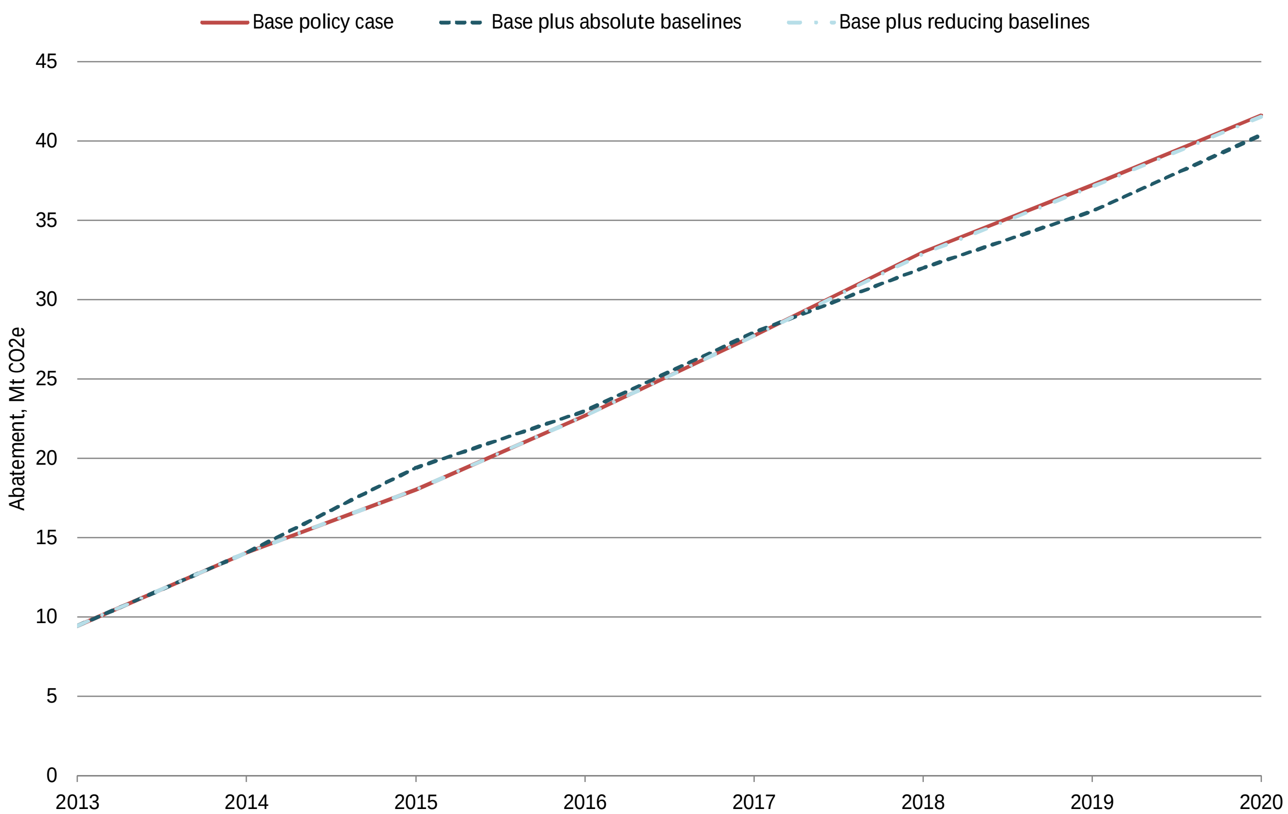


Figure 9: Abatement under alternative baseline assumption under the base policy case



4.2 Abatement activities

Abatement by activity under each of the policy scenarios is shown in Table 4. Abatement is spread across all activities, with the largest contributions coming from the stationary energy sectors. Contribution from the transport sector is relatively small compared to the total emissions from this activity. Contributions from other sectors are modest due to the relative cost of abatement in those sectors.

Table 4: Cumulative abatement by activity sector, 2013 to 2020, Mt CO_2e

Activity	Ref	BPC	PC -1	PC -2	PC -3	PC -4
Electricity	74	37	27	35	37	63
Other stationary energy	83	40	40	40	40	40
Transport	12	2	2	2	2	2
Fugitives	35	35	35	35	35	35
Industrial processing	34	12	12	12	12	12
Waste	29	36	36	36	36	36
Agriculture	12	34	34	34	34	34
Land use change	8	8	8	8	8	8
Total	287	204	194	202	203	229

Note: Agriculture sector includes contribution from restoration of soil carbon. Source: SKM analysis

By activity, the abatement is due to:

- For the electricity sector, the abatement in the reference case comes from reduced electricity demand, and retirement of some coal fired generating units (in the face of ever increasing carbon emission costs). There is some fuel switching from changes in the dispatch order, particularly in non-NEM grids, towards 2020 and onwards when carbon prices reach $30/t or more. High gas prices limit the amount of fuel switching that occurs. Excess of generating capacity also means there is a limited amount of new low emission generation (other than that encouraged by the RET scheme) entering the market. For the base policy cases, abatement mainly arises from adoption of energy efficiency options.
- For other stationary energy, the abatement occurs from adopting more efficient energy use practises. In the base policy cases, the level of abatement could be significantly higher in this sector if the budget constraint was relaxed.
- Abatement is minimal in the transport sector and comes mainly from more fuel efficient heavy vehicle use.
- A modest level of abatement occurs in the fugitives sector. The abatement mainly arises through flaring of methane at production facilities or coal mines and gas processing facilities, which is a relatively low cost form of abatement. There is also some capture of mine methane for electricity generation. Further abatement is limited by the cost of new alternative generation technologies and the increasing cost of capturing and collecting ever more quantities of methane at coal mines and gas pipes. The abatement is similar under the different policy scenarios.
- Abatement in the industrial processing sector is mainly limited to the replacement of cementitious material by other substitutes such as fly ash and blast furnace slag. The level of abatement is limited as the availability of technologies or processes that do not require the release of carbon dioxide is limited with some technologies assumed not likely to be available until well after 2020 (e.g. carbon anodes) and assumptions on the limit to substitution with alternative material inputs. These are relatively high costs forms of abatement.
- For the waste sector, abatement comes from the flaring of landfill methane emissions. Abatement was higher for base policy cases due to it being easier to account for legacy emissions as abatement.
- For the agriculture sector, abatement mainly comes from improved soil management practises. For the reference case, abatement was obtained from projections from the DCCEE[7]. It was assumed that abatement was greater in the base policy cases due to the expansion of options around soil carbon restoration as eligible abatement measures[8].

[7] See http://www.climatechange.gov.au/~/media/government/aep/AEP-20121106-Summary.pdf and http://www.climatechange.gov.au/~/media/government/aep/AEP-20121022-Agriculture.pdf.

4.3 Abatement costs

The costs of abatement are outlined in Table 5. The costs refer to the incremental costs from undertaking abatement activity. They do not include costs from second round effects (through changes in relative prices of inputs), which are captured in the macroeconomic modelling. Nor do they include purchasing of international permits.

Table 5: Economic cost of abatement, $M, mid 2013 dollars

Scenario	To 2020	2020 to 2030
Reference case	6,456	35,869
Base policy	5,829	15,848
Base case with lower RET	6,001	16,597
Base case with absolute baselines	5,498	15,038
Base case with declining emission intensity baselines	5,568	15,247
Base case with higher RET target	5,885	54,691

Source: SKM analysis

Costs are highest for the reference case due to the higher level of abatement activity. The costs of the base policy cases would be lower except for the implementation of some relatively costly (with relatively low abatement potential) support measures such as the solar roof program. The costs vary across the subsidy based policy cases due to the cost of varying levels of renewable energy uptake.

[8] This can be seen as a conservative assumption. Estimates from soil carbon abatement were assumed to be the mid-point of estimates provided by the DCCEE. Source: DCCEE (2012), Analysis of Coalition Climate Change Policy Proposal, Canberra

5. Broader Economic Impacts

Broader macroeconomic impacts are outlined in Table 6. Gross Domestic Product (GDP), Gross National Product (GNP) and employment impacts are all generally small out to 2020, but become more significantly affected from 2020 onwards, particularly for the reference (emission trading) case. Under all scenarios, the economy continues to grow strongly, albeit at a slightly slower rate.

GDP is generally smaller in all cases due to the costs incurred from abating emissions – there is generally a direct correlation between the costs of abatement and GDP impact, with higher abatement costs leading to greater reduction in GDP. Rising input costs (as a result of the carbon price) also impact on GDP.

GNP impacts are similar to the GDP impacts for the subsidy based policy cases. For the reference (carbon pricing) case, GNP impacts are greater than the GDP impacts reflecting the need to spend national income to purchase permits overseas. The GNP impact is also slightly greater for base policy case 3, where there is a sliding emission intensity baseline that creates emission liabilities met by the purchase of low cost permits on global markets.

Private consumption is affected by the carbon pricing mechanism, as is real investment. Private consumption falls because a greater proportion of national income is diverted to abatement activities.

Table 6: Macroeconomic impacts, % change from no carbon policy baseline

Variable	Ref case	Base policy	Policy case 1	Policy case 2	Policy case 3	Policy case 4
To 2020						
GDP	-0.36	-0.08	-0.08	-0.08	-0.08	-0.09
GNP	-0.43	-0.08	-0.08	-0.08	-0.08	-0.09
Consumption	-0.21	-0.13	-0.13	-0.12	-0.13	-0.14
Investment	-1.15	-0.04	-0.04	-0.05	-0.04	-0.04
Employment	-0.09	-0.02	-0.02	-0.01	-0.02	-0.02
To 2030						
GDP	-0.85	-0.12	-0.12	-0.14	-0.12	-0.61
GNP	-1.42	-0.12	-0.12	-0.14	-0.14	-0.60
Consumption	-1.52	-0.19	-0.19	-0.24	-0.22	-1.06
Investment	-2.23	-0.04	-0.04	-0.02	-0.05	-0.13
Employment	-0.13	-0.01	-0.01	-0.01	-0.01	-0.10

Source: CoPS

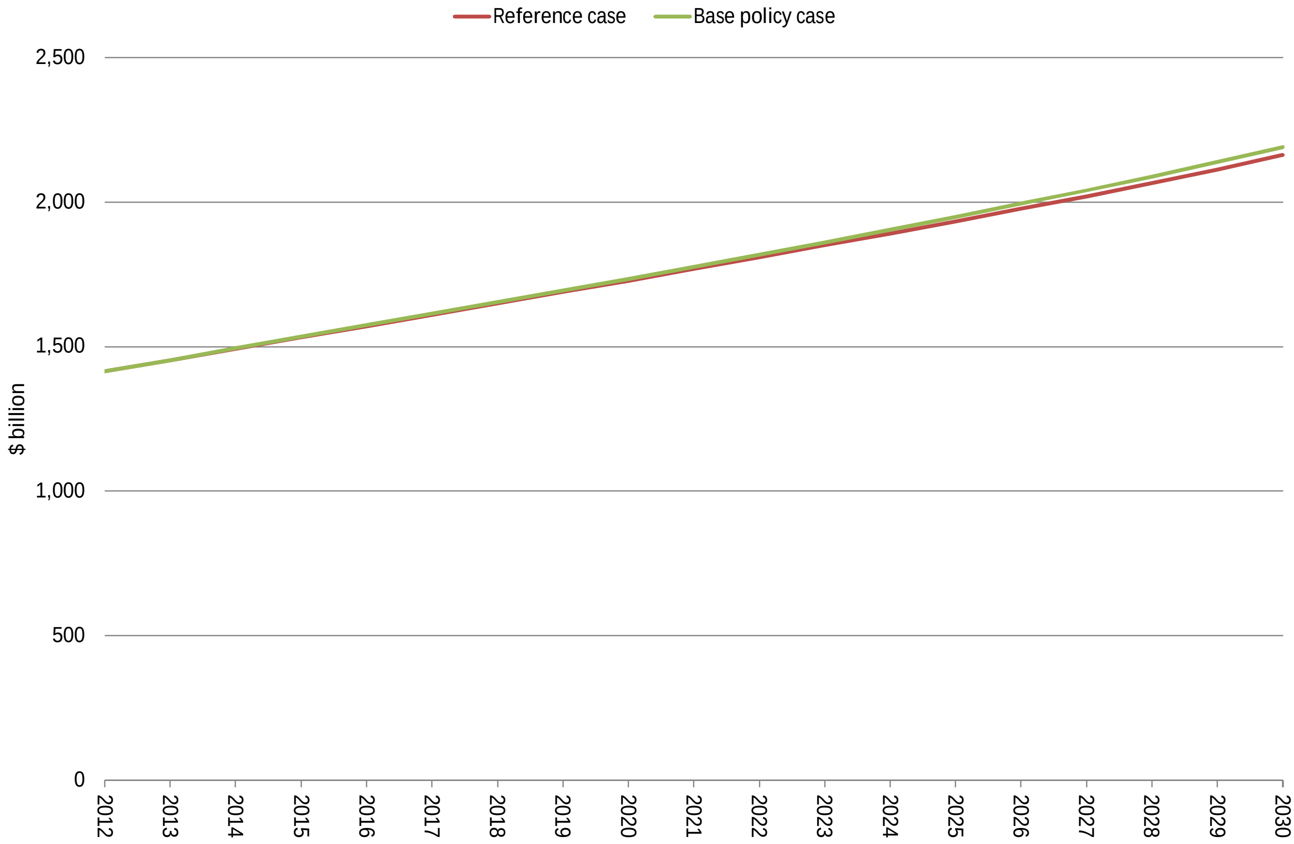
Without considering the social and economic costs of carbon emissions, the results indicate smaller impacts from the subsidy based policy cases. This result arises because:

- There are lower levels of abatement in the policy cases, with the gap in abatement increasing over time.
- The assumptions that international permits are purchased to make up the shortfall in abatement relative to the target in the reference policy case.
- The effects of increasing energy prices affecting economic activity.
- The impact of lower returns to capital in the traded goods sector and the resulting lower rate of growth of some industries.

These results should be interpreted with care. First, there is a direct correlation between the level of abatement and impacts on national income so that any difference in impact basically arises from different levels of abatement activity under each policy. The difference should be compared in relation to the level of abatement committed to be met by the Australian Government. If the social and economic costs of climate change per tonne of emission where included the results may be different.

Second, although the levels of national income, investment and private consumption are lower compared with a no carbon policy baseline, all major macroeconomic indicators continue to rise albeit at a slightly less rapid pace (see, for example, the predicted growth in gross national product in Figure 10).

Figure 10: Growth in GNP under different carbon policy cases



6. Limitations and Uncertainties

The analysis attempted to determine the relative impacts of emission trading and subsidy based approaches to reducing greenhouse gas emissions. The analytical approach provides indicative impacts for a set level of assumptions on key variables such as economic growth rates, technology costs and abatement potential. The approach used also relies on simplified assumptions on the response of economic participants to the incentives provided by either policy.

In particular:

- Investment in some low abatement technologies are assessed in terms of their long terms returns and costs, which are affectively known with some certainty. Thus, the timing of investment in abatement will be determined by assumptions of carbon prices and budgets available over the long term. In reality, investors would have varying expectations on future values of some key components of their investments and so may defer investments until better information is available. This is partly handled in the analysis by the use of a higher internal rate of return required to determine investment returns or short payback periods.
- Carbon price trajectory used in the reference case is based on one projection of future carbon prices. Future carbon prices may differ from those used depending on the degree of international action to curb emissions. Different carbon price trajectories would lead to different impacts under both policies, but particularly the reference case.
- Economic outlook for Australia (and globally) in the medium term is somewhat uncertain. Differing levels of economic growth may lead to slightly different economic impacts from each policy. The level of emissions will also be affected, particularly if energy demand remains subdued.

Appendix A. Assumptions on Abatement Options

A.1 Stationary energy sector

Sources of stationary energy emissions include electricity generation and use of combustion fuels to power appliances or equipment in businesses and homes.

Energy use projections (excluding electricity use) will be based on the most recent BREE projections. Electricity projections will be based on median projections published by AEMO, IMO and NTUT.

Broadly the abatement options considered are:

- Energy efficiency –. The modelling will assume that a subsidy scheme (ERF fund) would focus funding on the lowest cost activities that is already not covered by other energy efficiency programs. Under carbon pricing, uptake will be determined by electricity price levels. Under subsidy funding in the base policy scenario, funding will be applied on a capped basis, and the uptake determined to achieve this cap subject to availability constraints.
- Renewable energy policy (LRET) – the removal of a carbon price will reduce energy prices and consequently reduce the attractiveness of renewable energy to potential investors unless the LGC price or ERF is able to adequately compensate for the wholesale price reduction. An ERF is unlikely to be applied to this sector when renewables policy already exists. However there may be further renewable options untouched by the existing RET especially for other stationary energy activities.
- Renewable energy policy (SRET) – as before a missing carbon price element in the wholesale price could reduce investment in small scale renewables. An ERF is unlikely to be applied to this sector when renewables policy already exists. The Direct Action policy does include a planned 'one million roofs' program for PV.

A hierarchy approach was used so that energy efficiency, renewable energy, cogeneration and other low emission forms of generation all displace fossil fuel generated electricity from the base case. Fossil fuel generation options act on the remaining generation requirements.

Energy end use reductions or fuel switching are calculated in each sub-sector, and transferred back energy sector module as changes in either energy use per end use sector, or as a change in electricity consumption.

Emissions from energy production are calculated as per the NGI emissions methodology:

Emissions (tonnes) = Emission Factor (tonnes/GJ) x Fuel use (GJ).

The Department of Climate Change *Methods and Calculations Workbook* fuel specific emission factors are used and remain constant over the study period.

In the case of emission reductions resulting from reduced electricity consumption, a hierarchy is applied so that the introduction of additional renewable generation or energy efficiency measures which reduce electricity consumption are assumed to displace electricity generated from fossil fuels. In other words, any renewable generation in the base case is assumed to remain, and is not displaced by either energy efficiency or additional renewable generation.

The equation above is used to determine an average emission intensity of displaced electricity generated in units of Gg/GWh, which is effectively the business as usual fossil fuel emissions intensity for a given year. This electricity emission intensity is used to calculate emissions reduction from reductions in electricity use as follows:

Emissions Reduction (Gg) = Emission Factor (Gg/GWh) x Electricity Reduction (GWh)

A.1.1 Energy efficiency (including co-generation)

SKM utilises our National Energy Efficiency Model (NEEM) to derive estimates of electricity and gas energy efficiency savings projections under the various scenarios. The model includes more than 1000 energy saving activities, covering the residential, SME, large commercial and industrial sectors respectively[9]. This model estimates uptake of energy-efficient activities based on the relevant costs and regional characteristics specific to each activity. The NEEM derives a cost-curve for energy-efficient activities by mapping the potential amount of energy saving for each energy-efficient activity in ascending order of the net long-run marginal costs of the activities. To ensure the cost-curve represents a realistic estimate of the activities that could be taken up, several assumptions are applied to limit

[9] Detailed assumptions for these activities are outlined in the report by SKM MMA (2013), *Assessment of Economic Benefits from a National Energy Savings Initiative*, report to the DCCEE, March.

adoption of different activities. The energy savings and costs of each of these activities are limited by available market penetration and maximum rates of adoption. The NEEM also limits adoption by accounting for product adoption life cycles that impact on consumer investment decisions.

The NEEM:

- Determines the market size for each energy-efficient activity
- Captures the way in which consumers make investment decisions about energy efficiency by using payback thresholds as a proxy for consumer decision making
- Captures consumer heterogeneity when estimating the adoption of energy-efficient activities
- Captures other market factors that constrain the take-up of energy-efficient activities
- Enables uptake of the lowest cost activities first where dependencies exist.

The NEEM estimates adoption of energy-efficient activities using a combined economic and statistical approach. The model considers:

- Energy prices (including wholesale, network, white certificate and REC prices)
- Incremental capital costs of each energy-efficient activity
- Any discount on incremental capital costs resulting from other policies
- Any discount or impost on energy costs resulting from other government policies (e.g. carbon impost or cost of RECs)
- Expected energy savings from each activity
- The size and distribution of energy use over each regional market
- Lifetimes and expected replacement rates of appliances
- Upper limits or thresholds on adoption
- Assumptions regarding specific market barriers
- Theoretical market uptake curves mapping technology adoption from the level of early adoption to market saturation

The first step in estimating energy savings is to determine the natural market size available to each energy-efficient activity. The natural rate of stock turnover – estimated from the product lifetime[10] or otherwise appropriate value[11] - is used to determine the market size in any given year for each activity. The market size calculation considers increasing household numbers over time by applying stock-turnover ratios to projections of household numbers and site numbers. For the hot water replacement activities, the model can be limited to the replacement market only, excluding the market based on new homes.

Over several decades, published research in these fields has illustrated that consumers tend to heavily discount future gains or losses from energy-efficient technologies and inflate present gains or losses.[12] The discount rates implied by consumers in their energy-related decision-making tend to be substantially higher than those applied for other investment decisions.[13] The NEEM incorporates consumer decision-making into its modelling approach by specifying "payback thresholds" for each category of energy consumer.

The level of adoption of each energy-efficient activity is determined as a function of its technical payback period. It is assumed that activities with technical payback periods at or below the consumer's payback threshold would be adopted, i.e. the proportion of the market for which the activity was cost-effective (in terms of payback) is the proportion of the market assumed to adopt the activity. Since the technical payback period of a given activity will vary with consumers' annual energy consumption and the price of that energy, this method allows the heterogeneity of energy consumers within each sector to be considered explicitly. IPART survey data[14] has been reviewed to determine reasonable approximations to the spread of the distribution used relative to average values. This approach considers that energy consumers with the greatest benefit (i.e. high energy users) are more likely to adopt energy-efficient activities before consumers with lower benefit (i.e. low-energy users).

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10 The product lifetime dictated the natural time at which an appliance may be replaced. For example the market size for an appliance that lasts 10 years would be approximately 10% of all existing homes that own that appliance plus 100% of all new homes. If only 90% of all homes own a given appliance, then the market size estimate would be reduced to 90% x 10% = 9% of all existing homes plus 90% of all new homes.

11 In the case of insulation, which typically has a long product lifetime, a value of 25 years was assumed based on the average age of homes

12 Comprehensive overviews of how consumer behaviour can affect energy-related decision-making are found in Lutzenhiser (1993), Jaffe & Stavins (1994), Brown (2001), Wilson & Dowlatabi (2007) and Allcott & Mullainathan (2010).

13 Discount rates measure an individual's willingness to exchange present consumption for future consumption. See comprehensive reviews by Train (1985) and Neij et al (2009) concerning discount rates in energy-related decision-making.

14 "Residential energy and water use in Sydney, the Blue Mountains and Illawarra, Report from the 2010 household survey", http://www.ipart.nsw.gov.au/files/Report%20-%202010%20HH%20survey%20report%20FINAL%20website%20-%20APD.PDF

Technical payback periods are calculated for each energy-efficient activity. Inputs to the payback calculation include[15]:

- The average percentage energy savings for the respective energy end-use (before rebound effects).
- Retail energy prices (including adjustments for carbon, Renewable Energy Certificate (REC) and white certificate schemes in relevant scenarios).
- The average marginal cost of an energy-efficient activity relative to an alternative baseline activity (i.e. not the cost of installing an energy-efficient activity, but the difference in cost incurred relative to a baseline).
- The life of the option.

The model outputs realised energy savings and emissions savings. The model also estimates:

- Number of energy-efficient units adopted
- Incremental capital expenditures resulting from activity uptake
- Value of energy savings
- Value of the rebound effect.

Under the subsidy policy scenarios, simulations will be performed to replicate uptake at different shadow costs. Interpolation will be used to estimate emissions reductions achieved that meet a given ERF cap in the presence of other measures..

A.1.2 Renewable energy

The renewable energy sub-sector comprises generating technologies that derive their power from renewable resources and therefore have zero net carbon dioxide emissions. The energy sources included are:

- Wind generation.
- Hydrogen production from wind generation.
- Solar including small scale photovoltaic, large scale photovoltaic and solar thermal.
- Bio-energy:
  - Agricultural residue fuelled generation.
  - Forest and sawmill waste fuelled generation.
  - Sewage methane as a fuel for generation.
  - Wet wastes from industry to generate methane for electricity generation.
- Hydro electricity.
- Geothermal.
- Ocean power.

The uptake of renewable energy sources induces emissions reductions through the reductions in fossil fuel generation or by delaying the requirement for new fossil fuel power stations. This results in the renewable and fossil fuelled electricity sectors being interconnected, with any increase in renewable generation resulting in a commensurate reduction in fossil fuel generation.

SKM MMA's Renewable Energy Market Model Australia (REMMA) was used for the purpose of setting the mix of large scale renewable energy in place under the RET.

To determine the mix of small scale renewable energy, SKM MMA's distributed generation model was used.

The analysis of renewable energy generation potential was based on SKM MMA's internal database of existing, committed, and proposed renewable generation projects. These data have been collected over many years and include published and derived data on the capital and operating costs, capacity, fuel costs, location and capacity factors.

Each type of renewable generation has been assigned limits to the absolute quantity of the generation that may be installed. Individual limits are assigned for the period to 2020 and the period from 2020 to 2050. The limits are based on either:

- Resource availability.
- Economic constraints.

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[15] The payback period calculation does not include other gains that may occur from the adoption of an activity. Examples of other gains include positive publicity, reduced water use, reduced operating and maintenance costs / increased productivity, reduced waste requiring disposal and reduced emissions. The payback period is calculated by evaluating the ratio of capital cost to annual savings in dollars.

- Social issues.
- A combination of more the one of the above.

The total quantity of renewable generation that may be introduced into the electricity market is used in the model to reduce the quantity of fossil fuel generation. This total therefore has a hard limit of 100% of electricity consumption after allowing for energy efficiency reductions. The assumptions for the additional (above that adopted by the RET) renewable options that could be added under a subsidy based policy, are shown in Table 7.

Table 7: Renewable energy assumption

		Small-scale or remote wind	Solar PV	Solar Thermal	Agricultural residues	Forest & sawmill wastes	Hydro	Geothermal	Wave
Capex 2012	$/kW	3,500	3,800	6,500	6,000	4,770	2,200	6,000	8,000
Capex decline	Real %	1.0%	1.0%	1.0%	1.0%	1.0%	0.0%	1.5%	2.0%
Capex decline post 2020	Real %	0.5%	1.0%	1.0%	1.0%	1.0%	0.0%	1.0%	2.0%
Operating cost	$/MWh	10	10	10	15	15	3	12	0
Fuel cost	$/MWh	0	0	0	45	40	0	3	10
Ancillary service costs	$/MWh	10	5	5	0	0	0	5	0
Transmission connection costs	$/kW	200	200	200	200	200	200	300	300
Investment timing									
3 years before	%			30%				30%	
2 years before	%	50%	50%	40%	50%	50%	50%	30%	50%
1 year before	%	50%	50%	30%	50%	50%	50%	40%	50%
Life	Years	25	20	20	20	20	25	25	25

A.1.3 Carbon capture and sequestration

Carbon capture and storage (CCS) involves capturing the CO_2 generated, liquefying it and pumping it into geological storage. There is potential for CO_2 storage in formations throughout Australia, particularly in depleted oil and gas fields, and a trial is currently being undertaken in Victoria to assess a formation for the ability to collect and pump CO_2 into it and the assess the ability to contain the CO_2 for long periods. The CO_2CRC Otway Project is the country's first demonstration of the deep geological storage or geo-sequestration of CO_2. It is generally assumed that in new plant carbon capture would occur prior to combustion in association with coal gasification to generate a hydrogen fuel and a CO_2 rich waste stream that would be collected and stored.

Given the uncertainty surrounding the technology we have limited the uptake of CCS to 0% of total generation by 2020 and subsequently allowed it to be installed for up to 50% of electricity generation by 2050. In the period up to 2030 only relatively small scale demonstration plants are likely to be installed.

The key parameters utilised in the assessment of carbon capture and storage at power stations are outlined in Table 8.

Table 8: Parameters for carbon capture and storage[16]

Parameter	Value
Limit on uptake 2020 (% of generation)	0%
Limit on uptake 2050 (% of generation)	50%
Earliest Introduction date[17]	2030
Efficiency of capture	85%
Efficiency of storage	90%
Capital Cost ($/kW)	$8,700
Operating Cost ($/tonne CO_2e)	$75
Capex Deflator (%/year)	1%

The calculation of the emission reductions and costs is driven by the input of the percentage of generation that is required to utilise CCS in each period. The reductions in emissions are calculated using the pre-capture emissions, the efficiency of capture, the efficiency of storage, and the level of uptake in each year.

A.1.4 Improving efficiency of existing generation

The efficiency of existing electricity generating plant may be improved incrementally over time resulting in higher electricity output, and lower emission production compared to the electricity output.

The maximum improvements that could be achieved are assumed to be 2% in the period to 2030 and 5% in the period to 2050. Improvements in generator efficiency occur gradually over time as most generation technologies are mature and efficiency gains become more difficult as the efficiency approaches the theoretical maximum.

The costs of achieving these improvements are highly uncertain but are likely to be in vicinity of $50 million for each percentage improvement in efficiency. The physical options that may be utilised to achieve these performance improvements generally include high capital cost modifications that need to be installed during major plant shutdowns and may include installing modified turbine blades, boiler modifications, or burner modifications.

A.2 Fugitive emissions

Fugitive fuel emissions result from the leakage or escape of greenhouse gases from the fuel cycle, they may occur during extraction, refining, transmission, storage, distribution and retail. Emissions from coal production are dominant in this category, presently around 70% of all fugitive emissions. The remaining emissions are from LNG processing, natural gas and oil production and transport.

The analysis has considered the following types of mitigation options for fugitive fuel emissions:

- Capture of coal seam methane for use in electricity generation;
- Capture of coal seam methane for flaring;
- Upgrading the natural gas distribution network to prevent leaks;
- Collecting vented CO_2 from gas production for re-injection into the gas reservoir.

A.3 Transport emissions

There are potentially a very large number of emissions abatement measures applicable to the transport sector, ranging from efficiency improvements, behavioural change measures (e.g. greater access to and use of public transport) and technological change such as

16 SKM generation technology database and analysis

17 Some demonstration plant exists already and these will not be subject to the earliest date limitations

adoption of new technologies such as electric vehicles and fuel cells. SKM MMA restricted the options evaluated to road transport technology change activities to:

- Substitution of existing road vehicle technologies to less emissions intensive vehicle technologies including electric vehicles and fuel cells
- Substitution of fuel to less emission intensive sources (i.e. bio-fuels and LNG in large vehicles such as buses and trucks)

The primary costs considered include the change in the cost of alternative fuels and the incremental[18] purchase price cost (vehicle replacements only) or cost of retrofit (vehicle conversions only). SKM MMA has assumed that maintenance costs will be the same under all technologies. Costs of refuelling stations are not specifically allowed for in the modelling.

A.3.1 Fuel costs

Prices of liquid fossil fuels were projected forward assuming a similar rate of price increase as EIA crude oil projections. Prices of LNG and LPG were projected forward assuming a similar rate of increase to liquid fuels. Electricity price increases follow projections from the electricity market analysis.

A.3.2 Vehicle replacement or upgrade costs

The incremental cost of alternative and/or more efficient vehicle technologies was determined through reviewing FCAI data and published reports from CSIRO. SKM MMA assumed incremental technology costs as shown in Table 9. Incremental costs associated with diesel technology and LPG retrofits were assumed to be constant in real terms over the projection time frame. However, it is assumed that the costs associated with hybrid electric and electric vehicles reduce over time by 1% per annum.

Table 9: Estimates of current incremental technology cost

Alternative technology	Incremental cost ($/vehicle)
Electric	17,000
Hybrid electric	15,000
LPG retrofit	3,000
Diesel	2,500

A.3.3 Vehicle efficiency

New vehicles have become more efficient over time, with recorded values for different vehicle categories over the last two years provided in Table 10. A trend line was applied to project efficiency forward to 2050, subject to long term baselines at which vehicle efficiency are considered to be unlikely to go below.

A.3.4 Limits

Limits have been set on the application of each measure according to either SKM MMA's expertise or to external sources. These are built into the model and in many cases have a material effect on the abatement which is possible. For example, it is not possible to switch more than 100% of petrol consumption to more environmentally friendly alternatives.

[18] The incremental cost is defined as the cost of the new technology less the cost of the standard technology (in this case an internal combustion engine fuelled by petrol).

Table 10: Recent new vehicle efficiency estimates by vehicle type (L/100 km)

Vehicle size	2011	2012	Long-term baseline
Light	6.55	6.38	5.00
Small	7.63	7.37	5.50
Medium	8.06	7.54	6.00
Large	10.43	10.04	8.00
Upper Large	12.07	10.82	8.50
Sports	8.49	7.72	6.50
People movers	10.47	10.22	8.00
SUV small	8.53	8.19	6.50
SUV medium	9.57	8.92	8.00
SUV large	10.43	10.17	8.00
SUV upper large	12.50	12.37	8.50

Source: "Carbon Dioxide Emissions from New Australian Vehicles 2012", March 2013, National Transport Commission

A.4 Industrial processes emissions

Greenhouse gas emissions from industrial processes are classified as those that arise directly from production processes involving the use of carbonates such as limestone and dolomite, the use of carbon as a reductant, chemical industry processes and the production of synthetic gases. They relate to emissions from processes other than combustion of fuels and arise from chemical reactions involved in manufacturing processes.

Industrial Process emissions arise from the following industry types:

- Aluminium smelting;
- Cement production;
- Nitric acid production;
- Steel and iron production;
- Lime production;
- Use of carbon reductants during the production of ferro-alloys;
- Halocarbons and SF6 from air-conditioning and refrigeration, and foam-blowing;

While the synthetic gas component is currently relatively small, it is expected to be the fastest growing component because of increasing use of air-conditioning and refrigeration. Emissions factors are shown in Table 11.

Table 11: Calculated greenhouse gas emissions factors for industrial processes, tonnes CO2e/tonne produced

Industry	Emissions Factor	Notes
Cement	0.534	To be applied to clinker production only
Aluminium	1.76	Based on Rio Tinto Sustainability statement
Ferro-alloys	1.218	0.45 tonnes coking coal required for each tonne of ferro-manganese or silica-manganese produced[19], 34.2 GJ/tonne of refinery coke, and 91.06 kg CO_2-e/GJ refinery coke (NGI Methods and Factors workbook).
Lime	0.675	Sourced from NGI Methods and Factors workbook (November 2008)

19 "The Market and cost environments for bulk ferroalloys", Andrew Jones
Resource-Net, BP15, 1050 Brussels 5, Belgium; andrew@resource-net.com, Feb-07

Table 12: Industrial process emission abatement options

Aluminium Smelting	Computer controls and point feeders can provide extra process control and reduce energy and process emissions.
	Emissions associated with oxidation of carbon anodes can be substantially reduced with use of inert anodes, which were assumed to be not developed until 2025.
Cement	Alternative raw feed for clinker production include fly ash, slag and gypsum. Substituting a portion of raw feed in this way displaces lime and clinker and can reduce calcination emissions. The Australian cement industry already substitutes around 5% but this could occur up to 25%.
	Cement is typically composed of 95% clinker and 5% gypsum. Displacement of clinker requirements to other substitutes can reduce energy requirements and process related emissions further still. Fly ash and slag can also be used as a substitute.
	Carbon Capture is a potential though uncertain new technology that could be available after 2020. It has potential to capture and store up to 85% of emissions.
Iron and steel	Carbon reductant replacements. Not available until after 2030

A.4.1 Approach

A bottom-up approach is to be adopted with a database of the aluminium smelters, cement kilns and integrated steelworks constructed. Historical emission and production statistics were sourced from:

- the Australian Greenhouse Office,
- the Australian Aluminium Council (AAC),
- the Cement Industry Federation (CIF)
- company annual, environmental and sustainability reports, community statements and general media releases.

Production statistics are available for the metals and minerals industries, but unavailable for the chemical industry. SKM MMA has sourced projections of metals and minerals industries production levels for use in the analysis for 2020 and 2030. Projections beyond this time will be made on the basis of GDP. Currently emission abatement measures only cover the metals and minerals sectors. Production indices to 2030 were obtained from the Centre of Policy Studies' projections, and assumed capacity increases were distributed across the states. Abatement technology costs and assumptions were based largely on IPCC[20] and IEA reports.

The three industries were analysed independently, with the mitigation opportunities of each considered in aggregate.

A.4.2 Cement production

Direct emissions from the cement industry arise from the manufacture of clinker, in which raw materials such as limestone and chalk containing calcium carbonate ($CaCO_3$) undergo a calcination processes at high temperatures to form lime (CaO) and carbon dioxide:

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2.$$

The input raw feed generally also contains magnesium carbonate ($MgCO_3$) that oxidises in the kiln to form magnesium oxide (MgO) and carbon dioxide.

The lime is then combined with silicon based materials such as sand and clay to form clinker. After cooling, the clinker is ground and then blended, often with other additives such as slag, fly ash, and gypsum, to form cement. As the CO_2 emissions are directly related to the relative CaO and MgO content of clinker, NGGI utilises these shares to estimate the total process emissions from cement production. This accounting framework is maintained for this study.

[20] IPCC Working Group III Report, *Mitigation of climate change*, http://www.ipcc.ch/ipccreports/ar4-wg3.htm

As emissions are aligned with the volume of clinker produced, abatement can be achieved only through either changing the clinker chemistry, or capturing the outlet flue gases of the kilns. To achieve the former, substitute materials can be added to the kiln or cement, displacing lime and clinker respectively, thereby directly reducing calcination emissions. The most common raw material substitutes are fly ash, slag and gypsum, all of which are readily obtainable, with the cost varying in each state. For each kilogram substituted, around 0.67 kg of lime is displaced, with a third replacing inert ingredients such as sand. The full emission abatement potential is specific to the exact composition of the pre-calcined substitutes, with the calcium oxide and magnesium oxide content varying between 3.2% to 43% and 1.6% to 8% respectively as shown in Table 13. Current substitution rates are around 1.5% with the total replacement limited to world's best practise estimates of 25%[21]. As detailed data regarding the exact current substitution rates for individual kilns was unavailable, the substitution rates were considered to be equal across all plants.

Table 13: Chemical composition of clinker and kiln feed substitutes

Material	CaO content	MgO content
Clinker	66%	1.5%
Fly ash	5%	1.5%
Slag	43%	7.8%
Gypsum	3.2%	2.6%

Cement has traditionally been of the Portland variety, containing 95% clinker and 5% gypsum. However, blended cements or substitute cementitous materials (SCMs) have comprised up to 20% of the market, and can lead to abatement through reduced clinker production. Blended cements can contain up to 40% of slag, fly ash, gypsum and other pozzolanic materials. Blast furnace slag is the most common of these and has to be of a finer quality than that added to the clinker kiln. Currently, blast furnace slag is sent directly from the Port Kembla and Whyalla steel works to granulating plants where it is processed before blending with the clinker. It is estimated that the capacity for granulated blast furnace slag is around 900 kt without further investment[22]. Capital costs for new granulating capacity were taken to be $1.3 million annualised over 20 years for a 250 kt capacity[23].

As the structural properties of cement are altered with the substitutes, it is assumed that Portland cement will still comprise at least half of the domestic market. Nonetheless, the combination of raw material and clinker substitution can lead to abatement of around 1.4 Mt CO_2-e per annum at negative or low abatement costs.

The magnitude of abatement was estimated from the deviation of emissions from those under business as usual. Baseline emissions were calculated from current substitution rates and a stable ratio of Portland to blended cement. Emissions under a carbon price were derived from the displacement of CaO and MgO in clinker under the NGGI framework mentioned above.

The cost structure of abatement is sensitive to the quantity and composition of the substitutes, and varies across the states. For example, Queensland, New South Wales and Tasmania have a readily available source of quality fly ash, while the remaining states are more reliant on imports. Prices for fly ash and slag were obtained from CIF reports, with the former varying from $5-30/t and the latter $30/t, both inclusive of transport costs. Gypsum prices were estimated to be $0.46/t and limestone was valued at the current import price of $15.31/t (ABARE). Overall operating costs were derived for each kiln from the production cost statistics published by the CIF[24].

While associated transport and labour costs increase with the increase in additives, lower limestone use and energy savings occur through reduced clinker production. The energy savings were calculated based on fuel and electricity efficiencies obtained from CIF[25], and were estimated to be 4.40 GJ/t clinker and 120.47 kWh/t clinker respectively in 2010. These intensities were assumed to exhibit an improvement across the projected period due to the uptake of energy efficiency measures.

Abatement opportunities also arise from post-combustion carbon capture technologies, although this is unlikely to be viable without long term carbon reduction policy in place. The high emission intensity of the calcination process means that the concentration of carbon

21 ACF, Cementing the Future, 2005 and 2007 Update on technology pathway

22 CIF sustainability reports

23 http://www.bluescopesteel.com/go/html-page/from-slag-to-cement

24 http://www.cement.org.au/publications/docs/2005%20-%202006%20Fast%20Facts%20Final.pdf

25 CIF, 2007 Review of the technology pathway for the cement industry 2005-2030

dioxide in the off-gas from the kilns is typically twice that of power plants. This provides an attractive prospect of using chemical absorbents to capture the CO_2. The carbon capture and storage options are limited to post-combustion capture as it is more likely to avoid process re-designs that would be necessary for oxyfuel pre-combustion capture for example. It is suggested in the literature that the infrastructure could be similar to that of an IGCC power plant with capture installed[26]. Given the differences in the economies of scale of cement kilns and power plants, it is assumed that this technology could be available to the smaller cement kilns from 2020.

Investment costs are estimated to be of order \$200 t/CO_2 [27], with annual operating costs comprising of increased labour and maintenance, increase in energy costs to capture and compress the CO_2, and transport and storage costs. The latter cost was assumed to be of the range \$60-70 /t CO_2 depending on the locality. This value is much higher than the associated costs for power plants and was adopted to reflect the larger burden on the kilns of the necessary infrastructure. This constitutes the largest component of the cost, and assuming an 85% capture rate, specific abatement costs for CCS in the cement industry are approximately \$65-78 /t CO_2 in 2030.

A.4.3 Aluminium production

Aluminium is produced by the Hall-Hèroult electrolysis of alumina in a series of carbon-lined steel pots. The alumina undergoes a chemical reaction with high purity carbon anodes, with the oxidation of these anodes releasing carbon dioxide. Secondary processes may also occur, with a fraction of the CO_2 reducing to CO, however, it is assumed in NGGI reporting that CO_2 constitutes all of the gas produced during the carbon oxidisation. Emissions associated with the on-site manufacture of the anodes are not categorised in aluminium production and so are ignored here. The accepted value of carbon anode consumption is 0.413 kg/t Aluminium.

Aluminium production is also a source of the perfluorocarbons (PFCs) CF_4 and C_2F_6 which respectively have global warming potentials 6,500 and 9,200 times that of carbon dioxide. PFCs result as by-products from what is referred to as anode effects. Anode effects occur when the concentration of alumina in the pot drops below a critical level, preventing the process chemical reactions involving alumina from occurring. Instead, carbon from the anodes combine with the fluorine in the cryolite bath to form the PFCs. Additionally, during these events, the voltage across the cells rapidly increases, reducing the overall efficiency of aluminium production.

The total emissions released depend intrinsically on the frequency and duration of anode effects, with these dependent both on technological and operational parameters. Mitigation options include better computer systems, alumina point feeders and personnel training, all of which serve to improve the control process. In the past few years, many of the smelters have begun installing these systems which, coupled with improvements in manual operation, has led to a reduction in the PFC emission intensity.

Given that many of the potlines are already operating at close to optimum levels, the technical feasibility of achieving further reductions in PFC emissions is questionable. However, it is assumed that from 2010 control software will evolve and all smelter capacity can undergo further minor refinements in control algorithms, with the abatement potential limited to 16% of their 2011 baseline. The installation of point feeders, and advances in their technology was restricted to those potlines that have not been recently upgraded. These were discerned from recent company annual reports, and are listed in Error! Reference source not found. along with the associated retrofit capital costs annualised over a 15 year period. It was assumed that these major retrofits would follow the implementation of the minor retrofit, with the reduction efficiency of these upgrades around 25%.

Table 14: Retrofit assumptions for Aluminium smelters

Smelter	Capacity (Mt)	Minor retrofit	Major retrofit	Capital cost – minor (\$M/yr)	Capital cost – major (\$M/yr)
Pt Henry					
Potline 1	0.07	Yes	No	\$0.27	N/A
Potlines 2 & 3	0.12	Yes	Yes	\$0.44	\$0.37
Portland					
Potline 1	0.23	Yes	No	\$0.88	N/A
Potline 2	0.12	Yes	Yes	\$0.48	\$0.4

[26] IEA, Prospects for carbon capture and storage, 2006
[27] IPCC Working Group III Fourth Assessment Report

Bell bay					
Potlines 1 & 2	0.12	Yes	No	$0.46	N/A
Potline 3	0.06	Yes	Yes	$0.23	$0.19
Tomago	0.53	Yes	Yes	$2.03	$1.7
Boyne Island					
Potline 1	0.18	Yes	No	$0.7	N/A
Potlines 2 & 3	0.36	Yes	Yes	$1.39	$1.17

The capital and operating cost of retrofitting smelters with point feeders and computer systems is specific to cell technology. Under the retrofits, basic operating costs increase by 1-3% per annum due to an increase in maintenance and labour. Additionally there are cost savings associated with the reduction of anode effects resulting from increases in overall productivity and energy efficiency. The sharp increase in the voltage across the cell during anode events results in a larger electricity consumption. It is estimated that minimising these events can lead to energy savings of up to 6%, again this value dependent on the individual cell technology[28]. With these estimates, non-zero abatement requires carbon prices above $22 /t CO_2.

Elimination of the emissions associated with the oxidisation of the carbon anodes can only be achieved by changing the chemical process of aluminium production. Currently there is a large impetus to design a commercially viable inert anode that could replace carbon. In doing so, both carbon and PFC emissions would be eliminated. Research has focussed on the use of ceramics, cermets and metals, with cermets appearing to be more favourable.

If successful, inert anodes could be retrofitted into existing cells without altering the alumina feeding infrastructure. Capital costs are estimated to be $120/t Al and are inclusive of the retrofit and new anode manufacturing equipment[29]. The lifetime of the inert anodes is much greater than their carbon counterparts, with the latter needing weekly replacements. Thus, the benefits of the inert technology are a reduction in anode manufacture and the associated energy costs. It is estimated that, due to the decrease in production requirements, material costs of the two anode technologies are comparable.

Additional predicted benefits include a more stable cell technology including a reduction in the anode cathode distance, resulting in more efficient production. Opinion on the likely success and cost of inert anodes varies immensely in the literature. Industry suggests that they could be employed as early as 2012, however, the more conservative date of availability quoted by the IPCC is 2020-2025. We allow the technology to penetrate the market from 2025.

Relative operating costs are assumed to increase despite the decrease in labour. This is a result of an increase in the energy intensity of the electrolysis process. In the current electrolysis process, the oxidation of the carbon anodes provides some of the energy necessary for the chemical reactions to proceed. In the absence of carbon, this energy needs to be supplemented by an increase in electricity consumption per unit of aluminium produced. Currently, electricity intensity is around 14,000-15,000 kWh/t Al, and is estimated to increase by 20% with the inert anodes. Labour costs are assumed to decrease by 5%. These values are in the median of the range of estimates in the literature. Under these assumptions, the specific abatement cost for inert anodes is approximately $25-40 /t CO_2-e across the smelters under the assumption that the technology shall be successfully developed.

A.4.4 Iron and steel production

Primary steel is produced at the integrated steel works at Port Kembla and Whyalla, where metallurgical coke is used as a chemical reductant to reduce iron ore to pig iron in a blast furnace. This is then converted to steel via the injection of oxygen in the molten iron in a basic oxygen system (BOS) furnace. The steel is then rolled and cast. Secondary steel is made from the reduction of scrap metal in electric arc furnaces at three small OneSteel plants in NSW.

Quantifying the emissions from the iron and steel industry is not as transparent as in other industry areas. Under IPCC reporting guidelines, the use of coke at Whyalla and Port Kembla integrated steel works is considered as a chemical process rather than the direct

[28] US EPA, Mitigation potential of non-CO_2 gases

[29] J. Keniry, The economics of inert anodes and wettable cathodes for aluminium reduction cells, JOM: 44, 2001

combustion of fuel. Thus, the methodology adopted by NGGI is to count the emissions associated with these as Industrial Process emissions. Additionally, the volumes of coke products manufactured and consumed within the industry are not necessarily aligned, with the fuel often exported. Thus, emission counting is based upon the amount of coke consumed in production rather than the total volume produced, with this data obtained from ABARE/BREE. The emissions are then calculated using the relationship

$$Emissions\ (Mt) = (C - 0.02 * 44/12/(EF * OF)) * OF * EF/1000$$

where C is the amount of coke consumed (in PJ), 0.02% is the estimated carbon content in raw steel, EF = 119.5 Gg/PJ is the emission factor of coke and OF = 98% is the oxidisation factor of coke.

As carbon is essential to the chemical process, mitigation options are limited. An immediate option is to minimise the rate of reducing agent injected into the blast furnace. Substitution of waste plastics and pulverised coal injections (PCI) can be used to replace the use of coke as a catalyst for the chemical reactions. Coke is still used as a porous support material, with the total displacement ratio of coke to PCI of 1:1.4. As the energy balance of the blast furnace is delicate and essential to iron reduction, substitution is limited to 30%.

Investment costs include those for the coal grinding equipment. The net operating and maintenance costs decrease due to a reduction in the use of coke and the associated energy required in manufacturing coke on-site. This offsets the increase in cost of blast furnace maintenance. A conservative estimate of these savings was derived from the 2007 prices of coal and coking coal[30].

Other abatement options include the recovery of BOS gas, and the prevention of fugitive emissions from the distribution of coke oven gas. Assuming an 85% efficiency rate, the marginal abatement cost is around $16/t CO_2 in 2030.

The third mitigation option is the retrofitting of carbon capture units on the blast furnaces. The cost structure per unit abatement, taken from Gielen[31] is similar to that for cement CCS, however, given the larger size of blast furnaces, it is assumed that the earliest penetration of CCS is in 2025. When considered in aggregate, however, the overall abatement cost is lower for iron and steel due to the associated benefits of the PCI injection. In 2020, the abatement potential stabilises at around $20/t CO_2 as the limits of PCI injection and BOS gas recovery are reached.

A.5 Waste emissions models

Population growth, GDP growth and increasing waste per capita are the key drivers of waste. Waste generation has continued to rise as a result of increased household incomes, increasing household numbers (partially driven by fewer persons per household), busy lifestyles and reliance on pre-packaged foods.

The waste sub-sector covers the emissions of methane and carbon dioxide from the disposal of solid to landfill sites and from water wastes in the treatment locations as well as incineration of waste (mostly solvents and clinical wastes). Only small amounts of carbon dioxide are emitted during incineration of solvents and clinical wastes and small quantities of nitrous oxide are also emitted from decomposition of human wastes.

Solid wastes can be disaggregated into three major waste types according to waste generation sources and are classified as: Municipal solid waste (MSW), commercial and industrial waste (C&I), and construction and demolition waste (C&D).

Solid waste generated from various sources are collected and disposed into Landfill sites. In these landfill sites, methane is generated by anaerobic decomposition of organic material (i.e. food waste and garden waste). The generation of methane does not occur immediately upon disposal of waste as organic component slowly decays. Methane is slowly released into the atmosphere until stabilization, which roughly starts after a year and continues until 50 years later. Generation of methane in the landfill varies each year depending on the stock of organic material present and materials deposited over many preceding years.

Most of the greenhouse gas emissions from waste come from methane, which has a global warming potential of 21 times that of carbon dioxide. Carbon dioxide is produced in the process of aerobic decomposition but is considered carbon neutral as it has been derived from biomass sources and is not counted as a net source of emissions.

Water wastes include municipal sewage, commercial and industrial liquid waste. The emissions from waste are predominantly emissions of methane created by anaerobic decomposition of the organic matter contained in the waste stream. The volume of emissions produced depends on the quantity of water treated. The volume of municipal wastewater depends on the population served by the treatment plant.

The mitigation methods applicable to the waste sector that have been considered are as per Table 15.

[30] BREE, Mineral and Energy Statistics:2012

[31] D. Gielen, CO2 removal from the iron and steel industry, Energy Conversion and Management, 44 (2003) 1027-1037

Table 15: Description of waste sector emission abatement options

Sub Sector	Emission abatement option
Solid Waste	Landfill gas flaring
	Electricity Generation
	Diversion of degradable material from the waste stream
	Diversion of recyclable material from the waste stream
Wastewater	Capturing and flaring methane from municipal waste water treatment
	Capturing and flaring methane from industrial waste water treatment

A.5.1 Assumptions

The main physical assumptions for each of the waste sector mitigation options are detailed in Table 16. Each waste mitigation option has been assigned limits to the absolute quantity of emission reduction that may be implemented. Individual limits are assigned for the periods to 2020, 2030 and 2050.

Table 16: Waste Sector – physical and cost assumptions

	Units	Landfill Gas Flaring	Landfill Gas Recovery for Energy Generation	Divert Degradable Material	Divert Recyclable Material	Municipal Waste Water – capturing and flaring CH4	Industrial Waste Water – capturing and flaring CH4
Limit type		% total	% total	% diverted	% diverted	% CH_4 captured	% CH_4 captured
Limit 2020	%	35%	35%	50%	50%	50%	50%
Limit 2030	%	40%	40%	70%	70%	70%	70%
Limit 2050	%	45%	45%	80%	80%	80%	80%
Efficiency	%	99%	99%	99%	99%	99%	99%

A.5.2 Landfill gas flaring and power generation

Methane is generated in landfill by anaerobic decomposition of organic material, which occurs slowly and varies each year depending on the stock of organic materials present which are deposited over many preceding years. It is common for landfill to be vented to allow methane to escape. It is becoming increasingly common for methane to be captured and flared to control odour and gas emissions, or used for power generation. Flaring landfill gas converts methane to carbon dioxide and water vapour lessening CO2-e emissions. Use of methane for power generation will displace fossil fuel based electricity and is carbon neutral..

Where methane is captured, an average methane capture rate of 85% has been reported. SKM MMA assumes that with rapid improvement in methane capturing technology, the methane capture efficiency can be improved to over 90% for new landfill sites and is feasible by 2050. However existing capture rates are only around 25%.

Carbon dioxide produced from the flaring of methane is considered carbon neutral as it has been derived from biomass sources.

The limits for landfill gas flaring are set to 35% by 2020, 40% by 2030 and 75% by 2050 of the total methane generated form landfill sites. The limits for landfill power generation using landfill gas set to 35% by 2020, 40% by 2030 and 45% by 2050 of the total methane emissions from landfill sites.

The energy content of landfill methane is 37.7[32] MJ/m^3 and its density is 0.717 kg/m^3. Hence, the energy content of one tonne of methane is approximately 52.58 GJ. Assuming a heat efficiency of 38.5%, 5.6 MWh of renewable electricity can be generated per tonne of landfill. Assuming no energy is used to run the process of anaerobic digestion, this renewable electricity would displace 6.06 t CO_2e equivalent coal fired generation emissions per tonne of landfill.

A.5.3 Diversion of degradable components in municipal solid waste

If the degradable components in solid waste such as paper, cardboard, garden organics, wood and timber that contain degradable organic carbon can be separated and diverted to other uses, this will prevent anaerobic decomposition in the landfill and considerably reduce the potential for methane generation. Using technologies that are available to divert degradable components will enable recovery of landfill and other resources for other uses. Some of these technologies include: composting to prevent anaerobic decomposition, bio-char production to form a stable carbon, process-engineered fuel to be used to replace fossil fuels in coal fired power stations, as well as diversion of waste for use in cement kilns and standalone power stations.

We have imposed a limit on the fraction of degradable waste diverted to 50% by 2020, 70% by 2030 and 80% by 2050.

A.5.4 Capturing and flaring methane from municipal waste water treatment

Methane is generated in municipal waste water treatment by anaerobic decomposition of organic material. The generation of methane occurs in anaerobic ponds and these may be covered for the capture and flaring of the methane generated. .

The limits for flaring at waste water treatment plant are set to 50% by 2020, 70% by 2030 and 80% by 2050.

A.5.5 Capturing and flaring methane from industrial waste water treatment

Methane is also generated in industrial waste water treatment by anaerobic decomposition of organic material.

The limits for flaring at waste water treatment plant are set to 50% by 2020, 70% by 2030 and 80% by 2050.

A.5.6 Interplay with other sectors

Methane captured in the landfill and used to generate electricity is emissions neutral. The electricity generated would displace fossil fuel generation and offset emissions. Increasing or decreasing activity waste collection, recycling or degradable components will affect the transportation sector.

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[32] Fuel and Electiricity Survey 2008, Australian Bureau of Agricultureal and Resource Economics http://www.abareconomics.com/interactive/fuelsurveys/pdf/FES08_Fuelcodes.pdf