REPORT

Impact of timing of emissions abatement

Prepared for
Victorian Department of Environment, Land, Water and Planning

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CANBERRA

Centre for International Economics
Ground Floor, 11 Lancaster Place
Majura Park

Canberra ACT 2609
GPO Box 2203
Canberra ACT Australia 2601

Telephone +61 2 6245 7800
Facsimile +61 2 6245 7888
Email cie@TheCIE.com.au

Website www.TheCIE.com.au

SYDNEY

Centre for International Economics
Suite 1, Level 16, 1 York Street
Sydney NSW 2000

Telephone +61 2 9250 0800
Email ciesyd@TheCIE.com.au

Website www.TheCIE.com.au

BRISBANE

Centre for International Economics
Nous House
Level 12, 259 Queen Street
Brisbane QLD 4000

Phone +61 419 040 735
Email cie@TheCIE.com.au

Website www.TheCIE.com.au

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Summary

The issue

- This report uses information from a range of studies to consider the relative costs of different Victorian emission reduction pathways.
- We consider four pathways, each consistent with:
  - Victoria achieving net zero greenhouse gas emissions (of CO_2e) by 2050; and
  - Total Victorian emissions between 2017 and 2050 being constrained to an emissions budget of 1.9 $GtCO_2e$ for Victoria.
- The four pathways involve different targets for 2030 emissions relative to 2005. These are 28, 45, 55 and 65 per cent reductions (relative to 2005).
- In contrast to most literature, the issue here is specifically one of relative costs of different paths to achieve a specified endpoint and budget.

What factors determine optimal timing of abatement?

- Essentially, the best timing for abatement is determined by:
  - The discount rate.
    - … Higher discount rates tend to imply later abatement, and lower discount rates imply early abatement
  - The evolution of the cost of abatement over time, partly determined by technology.
    - … If costs are declining over time because of exogenous (outside Victoria) developments, then other things equal abatement should be delayed
    - … If costs decline in response to previous abatement ('learning by doing') then other things equal, abatement should take place earlier
  - Policy developments.
    - … The cost of abatement in the future will be affected by policy choices today.

What does existing modelling suggest?

- We use existing studies to derive 'cost curves' for abatement: the implied loss of GSI (relative to baseline) for given reductions in emissions (relative to baseline).
- As there are a range of results in existing studies, we capture this range by deriving both a 'steep' and a 'flat' cost curve.

- **We calculate the loss of GSI (implied by the derived cost curves) under each of the four scenarios using 3 different discount rates: 1.4 per cent, 4 per cent and 7 per cent.**
- **The results of these calculations are set out in table 1 below.**

1 Interaction of discount rate and cost curve: summary

Discount rate	Nature of abatement cost curve	
	Flat cost curve *Incremental abatement comes at low additional cost; consistent with learning by doing; no regrets options; good policy configuration*	Steep cost curve *Incremental abatement comes at higher cost: limited learning by doing, abatement opportunities used up in early actions*
1.4 per cent *Rate used for long term (>50 years) intergenerational decisions (in Stern 2006 , for example). Based on zero (or very low) pure discount rate, but allows for some growth in real consumption.* *Some also argue that current real risk-free discount rate is very low.*	GSI reduction: 0.3 per cent to 0.5 per cent Lowest GSI loss in *VIC emissions (65% 2030)* followed by (*55% 2030*).	GSI reduction: 2.4 per cent to 3.6 per cent Lowest GSI loss in *VIC emissions (65% 2030)* followed by (*55% 2030*).
4 per cent *Designed to represent the market return on capital over the long term. In climate change, this is a rate typically used by analysts such as Nordhaus (2008)* *Also, frequently used as a lower bound in cost-benefit analysis.*	GSI reduction: 0.3 per cent to 0.4 per cent Equal lowest GSI loss in *VIC emissions (65% 2030), VIC emissions (55% 2030)* and *VIC emissions (45% 2030)*	GSI reduction: 2.1 per cent to 2.9 per cent Lowest GSI loss in *VIC emissions (65% 2030)* followed by (*55% 2030*).
7 per cent *Represents opportunity cost of capital; a rate often used for Government cost-benefit analysis and regulatory impact analysis. Generally, applies to periods less than 50 years.*	GSI reduction: 0.2 per cent to 0.3 per cent Equal lowest GSI loss in *VIC emissions (65% 2030)* and *VIC emissions (55% 2030)*	GSI reduction: 1.8 per cent to 2.2 per cent Equal lowest GSI loss in *VIC emissions (65% 2030)* and *VIC emissions (55% 2030)*

Note: Emissions scenarios are ranked based on results to one decimal place. GSI loss between 2021 and 2050 is calculated in present value terms and expressed as a share of GSI in the baseline over the same time period.

Source: CIE calculations

- **These results show that:**
  - **Of the four paths for emissions reduction, the path *VIC emissions (65% 2030)*, consistently implies the lowest or equal lowest loss of GSI (in present value terms) under different assumptions.**
  - **If a flat cost curve is assumed, the differences between implied GSI loss across the scenarios are very small, almost negligible.**
  - **While there are differences in the absolute amount of GSI loss for different choices of cost curve, the choice of cost curve does not affect the ranking of the options.**
  - **While there are differences in outcomes from different discount rates, the rankings of the pathways are not affected by the choice of discount rate.**

- **Overall, for different combinations of cost curves and discount rates the ranking of options is consistent, with emissions paths that imply higher initial reductions implying lower total GSI losses (relative to paths that imply lower initial reductions)**
  - **These results also hold for a range of sensitivity analyses.**
- **In considering these pathways results, it is important to note that both academic reviewers for this project, and the CIE, considered that the 65 per cent pathway may not be credible as it involves periods of time with no abatement required in later years. The CIE has similar concerns about the 55 per cent pathway, particularly when it is compared with business as usual emissions.**

What factors are missing from the modelling?

- **There are several factors not explicitly considered in the modelling which are likely to affect the relative costs of alternative pathways.**
- **First, emission reduction requires capital and labour to be reallocated from emissions intensive industries into low emissions industries. This will likely create adjustment costs not incorporated in the modelling.**
- **Second, the adoption and integration of new technologies into the economy and sequestration and afforestation may also create adjustment costs depending on the policy framework adopted.**
- **Third, the modelling assumes that policy is implemented through an 'ideal' carbon tax. Policies actually implemented may involve additional distortions and costs not covered in the modelling.**
- **Concentrating emissions reduction in one particular period will likely exacerbate any costs associated with adjustment and actual policies. This implies planned emission reductions should be even over time.**

1 Introduction and context

The Victorian Government has legislated that Victoria should achieve net zero greenhouse gas emissions (emissions of CO_2e) by 2050. The Government has appointed an Independent Expert Panel[1] to provide advice on the path net emissions should take in achieving this target.

The Department of Environment, Land, Water and Planning (the Department), on behalf of the Panel, has commissioned the CIE to review studies on emissions reductions policies and provide advice on the potential macroeconomic impacts of proposed emission reductions paths for Victoria.

For this work the Department has provided The CIE with alternate emissions reduction paths for consideration. Each of these paths meets the legislated goal of net zero emissions by 2050 and also meets an assumed emissions budget between 2017 and 2050 of 1.9 $GtCO_2e$. Note that the reference year under the Act is 2005.

Given the dual constrains (net zero by 2050 and a fixed emissions budget), the policy question that motivates this study concerns the timing of emissions reduction. What are the relative costs of different paths for emissions reductions within these constraints? Or what are the implications of changing the timing of emissions reductions?

Paths being considered for abatement

For our analysis, the starting point is recorded net emissions in 2016 of 114 $MtCO_2e$.[2]

From this point, the Department assumes that net emissions fall to 102 $MtCO_2e$ in 2020 in all scenarios.

The Department has provided The CIE with four different emissions reduction scenarios from 2021 to 2050 (Chart 1.1). Each scenario sees net emissions fall to 0 $MtCO_2e$ in 2050, and sets total net emissions equal to an assumed budget of 1.9 $GtCO_2e$ between 2017 and 2050.[3] The scenarios differ in the path of emissions reductions. The scenarios are defined by different goals for the intermediate target of net emissions in 2030. Note that interaction between the two constrains (net zero emissions by 2050, and an assumed emissions budget) reduces variance across the scenarios: slower initial emissions

1 See: https://www.climatechange.vic.gov.au/reducing-emissions/interim-targets (accessed 14 May 2018)

2 In climate change analysis, the term 'net' emissions is used as 'gross emissions' (from transport, industry, electricity generation, etc.) can be offset by sequestration and/or afforestation.

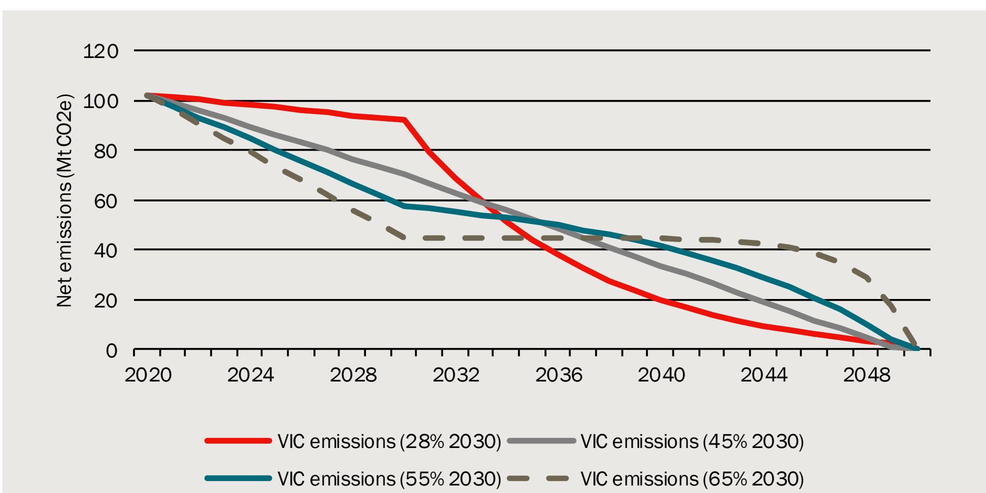
3 A 5th path was provided but we do not consider this as it does not meet the dual criteria.

reductions uses up more of the budget, and thus requires sharper reductions later, while faster initial reductions allows for slower reductions later.

- The scenario *VIC Emissions (28% 2030)* initially sees slow emissions reductions compared to the other scenarios (in 2030, emissions are only 28 per cent below 2005 levels). However, to meet the emissions budget, it requires a relatively sharp reduction in emissions after 2030.
- The scenario *VIC Emissions (45% 2030)* sees emissions fall to a level in 2030 that is 45 per cent below 2005 levels. The scenario essentially sees even emission reductions over time.
- The scenario *VIC Emissions (55% 2030)* initially sees a sharp fall in emissions, to a level in 2030 that is 55 per cent below 2005 levels. This leaves enough room in the emissions budget for emission reduction efforts to continue, but at a slower rate than before 2030.
- The scenario *VIC Emissions (65% 2030)* initially sees a sharp fall in emissions, to a level in 2030 that is 65 per cent below 2005 levels. This leaves enough room in the emissions budget for emission reduction efforts to then be slowed significantly (until the last few years of the period).

For the analysis presented below, we take these scenarios as given. It is important to note, however, that academic reviewers for this project considered that the 65 per cent scenario has some credibility issues associated with it in that it each involves a substantive slowing of abatement in the middle years of the period. The CIE also considers that similar concerns may apply to the 55 per cent scenario, particularly when it is compared with BAU emissions (see below).

1.1 Victorian emissions: the panel's reduction paths (Mt CO_2e)



Data source: DELWP

Studies used

The studies we consider are drawn from a list provided by the Department with a number of additions. These are listed in References. Some of these studies are publicly available.

One set of studies use 'Dynamic Computable General Equilibrium' (Dynamic CGE) models to estimate the impact on macroeconomic variables (state GVA, consumption, real wages, etc.) of reductions in emissions over time. These studies do not explicitly consider the timing of emissions reduction. However, we have derived cost curves for emissions reduction (the loss of GSI relative to baseline, given emissions reductions relative to baseline) from selected studies and applied these to the emission paths provided by DELWP. Details on how this is done are described in Chapter 3 and Appendix A. The CGE studies we use the most are:

- DEWLP 2016
- CSIRO 2015
- Treasury & DIICSRTE 2013

Some studies consider the relative cost of different policies:

- CCA 2016 (including Jacobs and COPS), BAE 2012

There are few studies that explicitly consider the impact of timing. The ones we considered are:

- Goulder & Mathai 1999, Pearce & McKibbin 2007

The Stern review of 2006 and Garnaut Review (2008 and updated in 2011) did not explicitly consider the issues considered in this report: the relative costs of different scenarios for a specific emissions end-point and budget over a fixed period of time.

2 What determines the optimal path of abatement

The theoretical literature (see for example Goulder & Mathai 1999, Pearce & McKibbin 2007, etc.) provides three suggestions about optimal abatement pathways.

- First, the marginal cost of abatement needs to be the same at all points in time, so that abatement is optimally spread. This in turn requires that the implicit cost of abatement — what would be the carbon price in an explicit pricing policy — rises at the discount rate. With a higher discount rate, more abatement is delayed to the future. With a lower discount rate, abatement is brought forward.
- Second, consistent with this first point, the amount of optimal abatement at each point in time depends upon the evolution of the cost of abatement which is itself partly a product of technology. Technological outcomes will be a combination of two distinct types of technological change:
  - If the cost of abatement (technology) is exogenous, and falling, this tends to suggest delaying abatement over time, all other things equal.
  - If the cost of abatement (technology) depends on 'learning by doing' so that the cost of abatement in the future depends on the amount of abatement in the past, then while the optimal path is difficult to predict, this does tend to suggest more abatement early on.
- Third, the cost of abatement in the future may be a function of specific policy choices today, such that the optimal abatement path depends specifically on policy choices.

These broad insights give an indication of the factors that need to be included when calculating the relative costs of different abatement pathways.

Most of the modelling literature does not explicitly consider the best pathway to achieve a given end target with a specific budget along the way. Rather, most of the literature considers the relative costs of different overall targets in cases where the overall budget is either implicit, or not considered at all.

In some of the literature (for example Stern 2006) the use of a low discount rate implies that abatement should be substantively brought forward. In contrast, a slightly higher discount rate (Nordhaus 2008) implies a slower abatement path. However, these insights do not themselves allow us to rank the different specific options.

To provide a quantitative analysis, we repurpose original modelling results to generate a relationship between abatement and GSI in order to calculate the costs of different pathways.

3 Using results from existing CGE modelling exercises

Overview of approach and required data

To understand which emissions reductions path is less costly (relative to the others) it is sufficient to rank them by comparing each one to a reasonable, pre-specified **baseline** for emissions.

For each emissions reduction path, we calculate the deviation in emissions relative to baseline and then calculate the implied cost of this, expressed in terms of a deviation in some macroeconomic variable from baseline. The cost curve (deviation in a given macroeconomic variable from baseline, given a deviation in emissions from baseline) can be derived from published results.

The variable that is considered in the three recent studies we focus on is Gross State Income (GSI, the income that accrues to Victorians in Victorian focused studies) and Gross National Income (GNI, the income that accrues to Australians in Australian focused studies).

The form of the relationship we derive between GSI and emissions is an **elasticity:** the per cent deviation in GSI from baseline against the per cent deviation in emissions from baseline. As studies generally project emissions and economic variables (in scenarios and in the baseline) in each year, for multiple decades into the future, they provide us with many observations for deviation in macroeconomic variables (from baseline), given a deviation in emissions (from baseline).

Finally, to compare GSI losses in future years across scenarios on the same basis we need to discount all future losses using an appropriate **discount rate**. The discount rate captures the opportunity cost of resources used to achieve emissions reduction. Total, future, discounted losses of GSI are divided by total, future, discounted GSI in the baseline, and we identify which scenario implies the smallest loss of GSI as a per cent of GSI in the baseline.

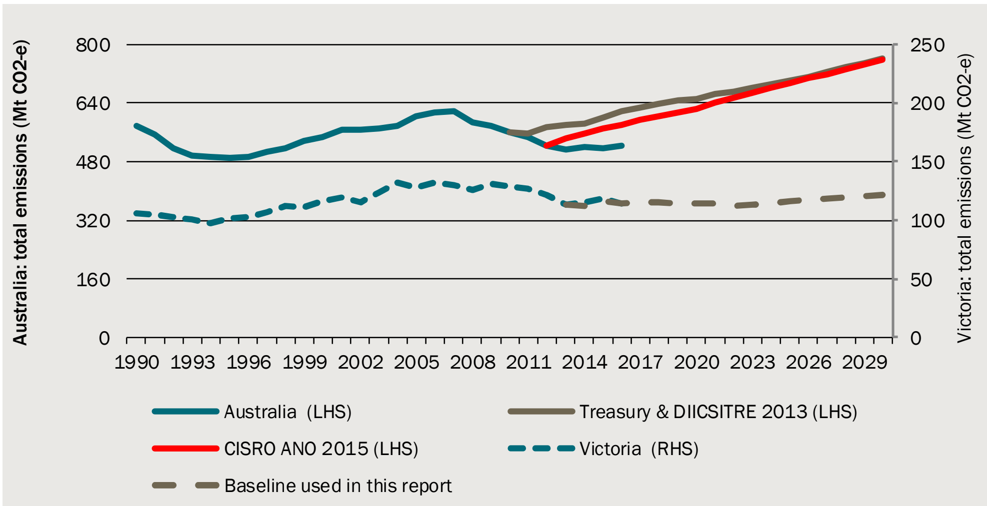
Baseline

It is not necessary for this baseline to be 'business as usual' (as the question here is *not* estimating the cost of emissions reduction *per se*) for an optimal path for emissions reduction (given the stated constraints). We use DELWP (2016) to generate a baseline for both emissions and Victorian Gross State Income. This baseline includes the continuation of existing national level policies and Victorian policy announced in 2016[4].

4 In particular, this baseline includes retention of the ERF, the RET of 33,000 GWh by 2030, and the state based Victorian Energy Efficiency Target (VEET). It also assumes a moderate

Chart 3.1 shows the history of emissions in Victoria and Australia, the baseline we adopt, and baselines adopted by other earlier studies. In other studies, assumed baselines tended to see emissions grow over time. Emissions have dropped in recent years. This drop at least partially reflects the imposition of emissions reducing policies (e.g. the Renewable Energy Target at the Commonwealth level). We perform sensitivity analysis on our results by using alternative baselines (see Appendix B). Overall, the conclusions are the same as those drawn below (i.e. switching baselines does not impact the results).

3.1 Emissions: history and baseline scenarios by modeller (Mt CO_2e)

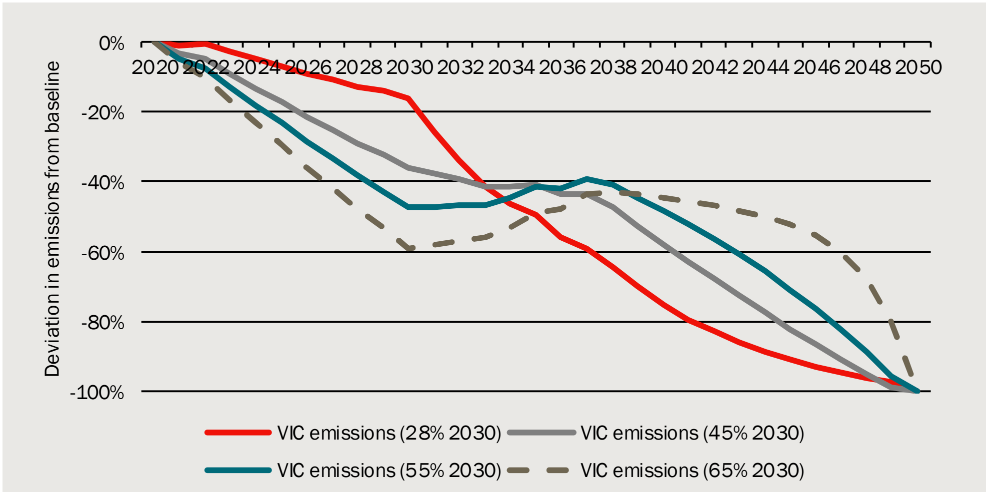


Data source: Sources as noted; The CIE

Chart 3.2 shows emissions in each of the paths the Panel is considering, expressed as a percentage deviation from baseline emissions.

strengthening of national policy action to reflect Australia's agreement global action to avoid 2 degrees of warming.

3.2 Victorian emissions (per cent deviation from baseline)



Data source: The CIE

Cost curves

It is impossible to accurately predict the precise economic costs of future paths for emissions reduction. Rather, the goal here is to present different estimates of the 'cost curves' and to understand: (1) how and why the costs curves are different and (2) the implications of this for timing of emissions reduction.

We derive 'cost curves' from existing studies. These are defined as the implied loss of GSI (relative to baseline) given a reduction in emissions (relative to baseline).[5] As explained, we apply cost curves derived from studies done on the Australian economy to the Victorian economy. We are obliged to do this because of a lack of Victorian-focused studies. This issue is discussed below as a sensitivity.

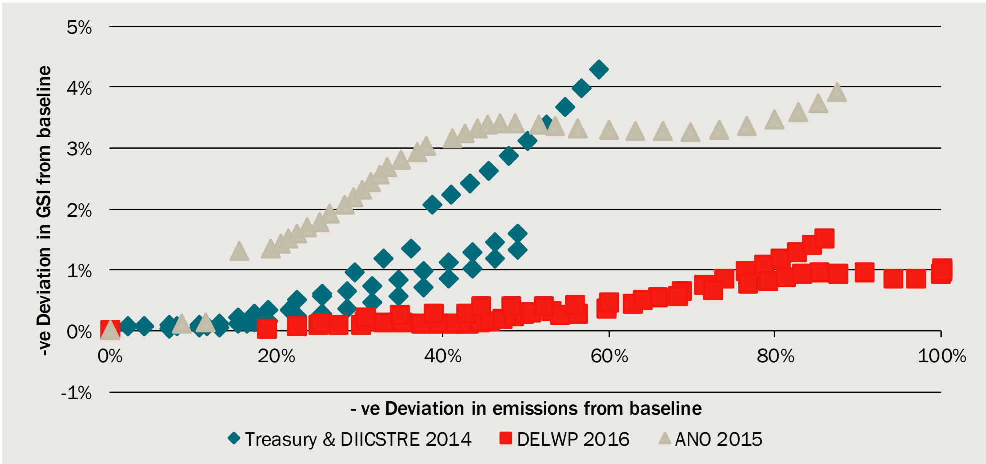
The level of the cost curve

Different studies make different assumptions, and thus generate different estimates of the *level* of costs associated with emissions reduction. For example, given emissions reduction of 40 per cent to 80 per cent relative to baseline, the cost curve derived from DELWP 2016 implies GSI will be around 0.5 per cent to 1.0 per cent below baseline (i.e. in each year where emissions are lower than baseline by 40 per cent to 80 per cent, GSI is lower than baseline by 0.5 per cent to 1 per cent). However, according to results published in CSIRO 2015, this cost is around 3 per cent to 3.5 per cent of GSI (see Chart 3.3). The results from Treasury & DIICSTRE 2013 sit between these two for abatement up to around 40 per cent, but increases rapidly after that.

As we will argue below, the slope or steepness of the cost curve is key for understanding the relative effects of different abatement timing.

5 We provide more specific information on how we have used these studies, including the scenarios used, in Appendix A.

3.3 Cost curves for the reduction of emissions



Note: Cost curves express the 'cost' (measured as a deviation – a loss - of GSI relative to baseline) given a reduction in emissions relative to baseline.

Data source: The CIE

The steepness of the cost curve

Different studies make different modelling assumptions, and thus generate different estimates of the *steepness* or *slope* of the cost curve. For example, if you increase emissions reduction over time from 0 per cent to around 50 per cent (compared to baseline), the impact on GSI increases relatively sharply from 0 per cent to between 1 and 3 per cent, according to results published in Treasury & DIICSTRE 2013. The cost curve is much flatter according to DELWP 2016: the loss of GSI increases to around only 0.5 per cent of GSI (for the same reduction in emissions).

All modelling assumptions made by the respective studies contribute to this difference in the slope of the cost curve. We can make following comments based on the available information.

The effect of the carbon price vs exogenous emissions reduction

The key to different slopes of the cost curve lies in how the CGE models operate and the assumptions made by the modellers. CGE models are used by economists to estimate how the level of measured economic activity changes as a result of changes in relative prices (as changes in relative prices cause the allocation of resources to change, and this causes measured activity to change). In climate change analysis, the change in relative prices is driven by the imposition of a carbon price.

In the Treasury & DIICSTRE 2013 results, the carbon price essentially acts to reduce emissions using only the response parameters within the model.

- For low amounts of emissions reduction, relatively easy (or cheap) abatement projects are undertaken. The result is that low levels of emissions reduction require a low carbon price and thus result in modest re-allocations of resources. Therefore, low levels of emissions abatement result in modest economic losses.

- At larger amounts of emissions reduction, the easy opportunities have been exhausted, and thus relatively difficult (and expensive) emissions reducing projects must be undertaken. The result is that high levels of emissions reduction require a high carbon price. Therefore, higher levels of emissions reduction result in larger re-allocations of resources and drive larger economic impacts.
- The overall result is a cost curve that tends to become steeper as emission reduction increases (as shown above).

A much flatter cost curve arises through making different assumptions. For example, it can be assumed that the emission reducing impact of the carbon price is significantly helped by other trends not captured *within* the model and which are imposed on the model exogenously. These exogenous factors reduce the steepness of the cost curve in a number of ways.

- 'Energy efficiency' (or 'no regrets') trends can be captured within the policy scenario in addition to anything in the baseline. These energy efficiency trends see the energy intensity of normal household and business activities decline over time — reducing emissions in the scenario relative to the baseline.
- These additional factors include:
  - transport electrification,
  - reductions in non-combustion emissions (e.g. agriculture, industry, etc.) and
  - forestry sequestration.
- These trends (energy efficiency and additional trends) are imposed on the model exogenously. They reduce emissions in the scenarios but not in the baseline (by assumption) without the imposition of a carbon tax.
- Because these trends reduce emissions without the imposition of a carbon tax, there is no change in relative prices, and thus no economic loss.
- The practical effect of this is to produce a 'flat' cost curve.

These sorts of adjustments are justified in cases where CGE models do not fully capture the response of the economy to the imposition of a carbon price.

We consider the cost curves derived from these two studies give a reasonable range for costs, given the purposes of this report.

A basic narrative on the cost curves

The two separate cost curves (steep versus flat) present alterative narratives for emissions reduction efforts in Victoria.

Accepting the steeper cost curve is consistent with thinking:

- the mechanisms implicit in CGE models do a reasonable job of capturing change in the Victorian economy, and
- in general, changes in behaviour result from changes in the incentives faced by households and businesses.

Accepting the flatter cost curve is consistent with thinking the following points.

- CGE modellers have consistently overestimated the level and steepness of the cost-curve for emissions
- the costs of emission reductions are endogenous to reduction efforts and policies
  - for example, the experience of current efforts to reduce emissions in Victoria will lower the costs of future efforts to reduce emissions in Victoria (this is called 'learning by doing' in economic jargon), or
  - alternatively, the imposition of emissions reducing policies in Victoria incentivises research which lowers emissions reductions costs in Victoria.
- The government policies and strategies that are required to facilitate the adoption and integration of low emissions technologies into the economy (e.g. planning policies required for afforestation, storage required for renewables, policies that support the integration of electric vehicles into the wider fleet) exist and are of sufficiently high quality to ensure that as adoption rates increase, costs do not increase disproportionately.

Discount rates

GSI losses (implied by emissions reduction, across all years) are converted into present value terms by discounting. We then add the losses across all years in each scenario.

There are different views about which discount rate is most appropriate for this type of analysis. To test the importance of the discount rate, we use three scenarios for the discount rate (1.4 per cent, 4 per cent and 7 per cent). The commentary in Table 3.4 on the discount rates provides some indication of the basis for different rates.

3.4 Alternative discount rates

1.4 per cent	4 per cent	7 per cent
Rate used for long term (>50 years) intergenerational decisions (in the Stern 2006, for example). Based on zero (or very low) pure discount rate, but allows for some growth in real consumption. *Some also argue that current real risk-free discount rate is very low.*	*Designed to represent the market return on capital over the long term. In climate change, this is a rate typically used by analysts such as Nordhaus (2008)* *Also, frequently used as a lower bound in cost-benefit analysis.*	*Represents opportunity cost of capital; a rate often used for Government cost-benefit analysis and regulatory impact analysis. Generally, applies to periods less than 50 years.*

Source: CIE, and discussions with DELWP

Assuming a low discount rate results in treating all losses (whether they occur in the near-term or long-term) as relatively equal in importance. Assuming a high discount rate implies that near-term losses are more important than long-term losses.

An academic reviewer of this report notes the 1.4 per cent per year discount rate is 'more applicable' than the 4 per cent per year and 7 per cent per year discount rates (further adding there is 'little justification' and 'no justification' for the 4 per cent per year and 7 per cent per year discount rates).[6]

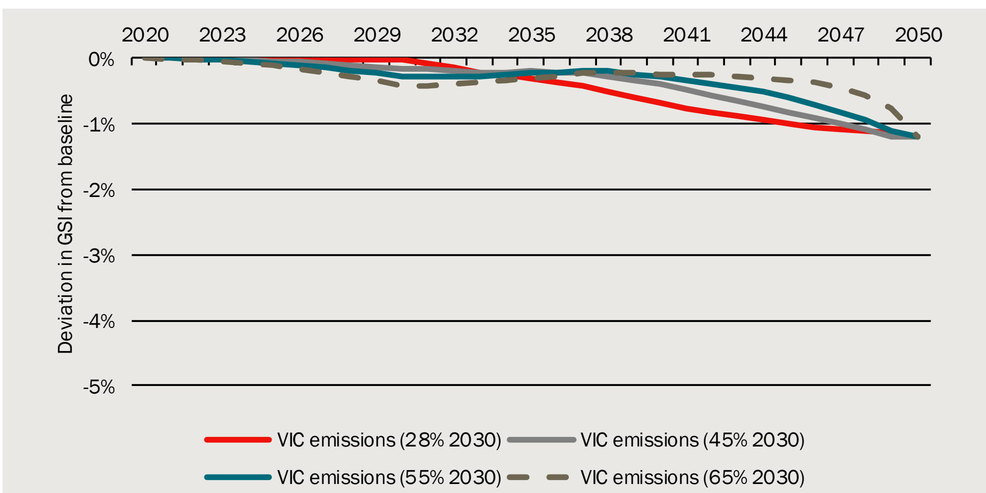
Results

The emission path than generates the lowest loss of GSI is a function of the assumption made for the slope of the cost curve and for the discount rate. These are treated in turn.

The effect of the slope of the cost curve

If we assume the cost curve is flat, there is little difference in the GSI loss that is implied by the different emission paths for Victoria that the panel is considering. This is shown in Chart 3.5, where implied GSI loss is calculated by multiplying emissions reductions with a flat cost curve.

3.5 Deviation in GSI from baseline (undiscounted), implied by panel emissions reduction scenarios using a flat cost curve



Data source: CIE estimates

If we assume a steeper cost curve, the different emission reduction paths imply significantly different GSI losses over time. This is shown in Chart 3.6, where implied GSI loss is calculated by multiplying emissions reductions with the steep cost curve.

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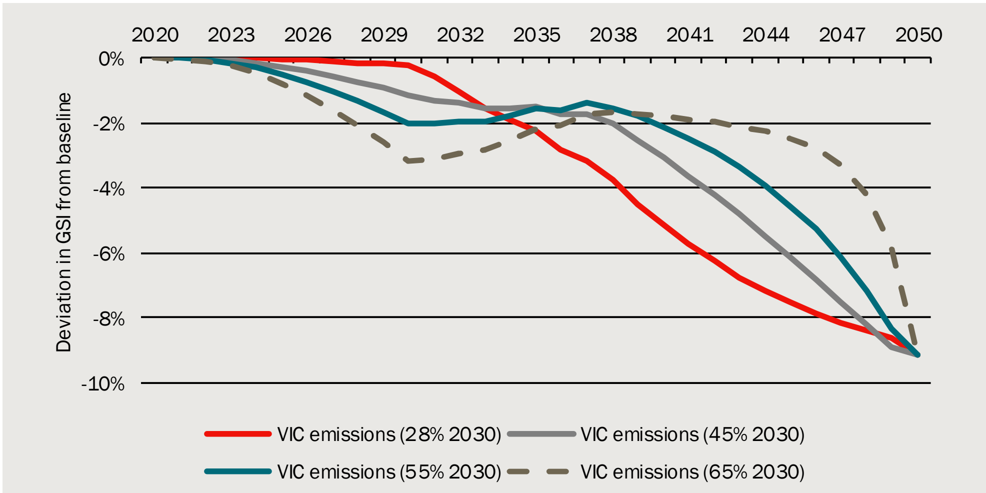
6 The academic reviewer provided the following reasons for this view: 'When discounting future GSP (as distinct from project-based costs/benefits), there is no solid economic/ethical case for using "high" discount rates' and 'discounting future societal welfare (here proxied by GSP) has ethical justification only on account of expected future growth in real per capita income'

3.6 Deviation in GSI from baseline (undiscounted), implied by panel emissions reduction scenarios using a steep cost curve



Data source: CIE estimates

The effect of the discount rate

For each scenario for emissions, and for each assumption for cost curves and discount rates, table 3.7 shows total discounted GSI losses in all years, discounted to present value terms and summed up, and then expressed as share of total discounted GSI in the baseline.

The charts 3.5 and 3.6 (above) show that there are larger differences in implied GSI losses as we get closer to 2050 (especially if a steeper cost curve is assumed). A **lower** discount rate implies these differences in GSI loss across scenarios retain importance. A **higher** discount rate implies these differences become less significant.

We focus on the results implied by the flat versus steep cost curves. With both cost curves, across all discount rates, path *VIC emissions (65% 2030)*, consistently implies the lowest or equal lowest loss of GSI (in present value terms) under different assumptions. If a flat cost curve is assumed, the differences between implied GSI loss across the scenarios are very small, almost negligible.

3.7 Discounted change in GSI due to emissions reduction between 2020 and 2050 (share of baseline GSI 2020-2050), by scenario

Cost curve	*Discount rate*	Scenario: level of emissions in 2030 (reduction relative to 2005)			
	-	28 per cent	45 per cent	55 per cent	65 per cent
Flat	*1.4 per cent*	-0.5	-0.4	-0.4	-0.3
	4.0 per cent	-0.4	-0.3	-0.3	-0.3
	7.0 per cent	-0.3	-0.3	-0.2	-0.2
Steep	*1.4 per cent*	-3.6	-3.1	-2.7	-2.4
	4.0 per cent	-2.9	-2.5	-2.3	-2.1
	7.0 per cent	-2.2	-1.9	-1.8	-1.8
ANO 2015	*1.4 per cent*	-4.2	-4.1	-4.0	-3.8
	4.0 per cent	-2.5	-2.4	-2.4	-2.4
	7.0 per cent	-1.4	-1.4	-1.5	-1.5

Note: The academic reviewers for this project, and the CIE, consider that the 65 per cent scenario (and to a lesser extent the 55 per cent scenario) have some credibility issues associated with them in that they each involve a substantive slowing of abatement in the middle years of the period.

Source: The CIE

Overall

Overall, these results confirm a number of expected outcomes:

- With a higher discount rate, earlier abatement is more strongly preferred, although the absolute magnitude of the difference is very small.
- With a steeper cost curve, the absolute value of the GSI loss is higher under all scenarios. This simply reflects the greater costs of technology switching.
- Under all combinations, the ranking of options (when they can be distinguished) remains the same.

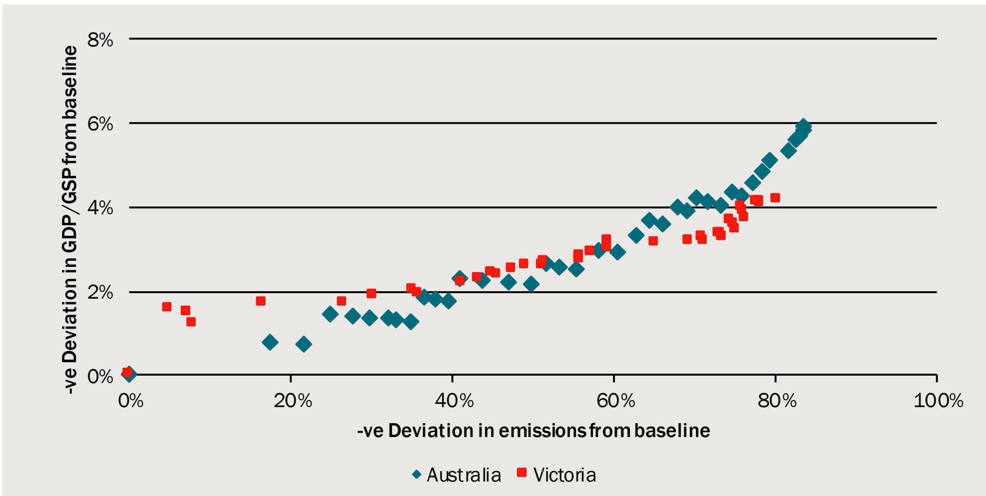
Sensitivities

Victorian cost curve vs Australian cost curve

In the above results, we have applied cost curves derived for Australia (from Treasury & DIICSTRE 2013 and CSIRO 2015) to Victoria. We do this due to a lack of studies at the Victoria level. Given the purposes of this study, this is broadly reasonable if the cost curve for Victoria is of a similar steepness to the cost curve for Australia. Our starting position is that this is likely to be true. While Victoria starts with some sectors that will be relatively hard hit if emissions decline (certainly coal fired electricity generation and probably some sectors of manufacturing) – what will ultimately drive long-run economic impacts is the flexibility of markets, businesses and households, including the ability to respond to changing incentives (inflexibility implies high costs, while flexibility implies low costs). For the purposes of making long-run forecasts, it is reasonable to assume the Australian states are have similar levels of flexibility.

Chart 3.8 shows cost curves taken from a single study (Treasury 2008) for Australia (deviation in GDP vs deviation in emissions) and for Victoria (deviation in GSP vs deviation in emissions). Overall, it shows the cost curves for Victoria and Australia are of similar steepness for the vast majority of emissions reduction levels (though the Australian cost curve may be slightly steeper at higher levels of emissions reduction). Our interpretation is that Chart 3.8 does not provide sufficient evidence to conclude the steepness of the cost curve in Victoria is fundamentally different to the steepness of the cost curve in Australia.

3.8 Cost curves for the reduction of emissions (by jurisdiction level)



Data source: Treasury studies, as noted; The CIE

The use of different economic measures

Some of the studies we draw on provide different measures for the cost of emissions reductions. In particular, some report changes in real consumption rather than changes in GSI. Our analysis indicates that using alternative costs measures, where available does not change the results presented above.

Endogenous behaviour of Victorian households and businesses

A number of economic studies use the Monash Multi-Region Forecasting (MMRF) model (or a variant) to generate results. This model does not allow households and businesses to adjust their behaviour in anticipation of policy changes that are announced before they are implemented (they are not 'forward looking').

This aspect of household and firm behaviour makes our interpretation and application of the results reasonable: we treat the relationship between economic impacts and emissions reduction derived from the modelling results (shown here as a cost curve) as essentially a static curve, which we apply to projections of emissions reduction over time.

Final comment: a bottom-up approach?

The emissions projection paths being considered by the panel are predicated on a 'top-down' view of emissions reduction. A path for the whole economy is set, and individual industries and households integrate into this plan.

The cost of adopting low emissions technologies in individual industries will depend on the existence, timing and quality of government policies that facilitate their integration in individual industries. This may create an opportunity to take a 'bottom-up' approach to planning emissions reduction. Drawing on work from, for example, ClimateWorks[7], the panel could identify individual industries and sectors where emissions reduction could occur through the adoption of new technology (e.g. electricity, private transport, households, public transport-planning, forests, agriculture) and the specific policies that are required for these technologies to be adopted and integrated into the economy (policy set X, policy set Y, etc., respectively). The panel could then recommend a path for emissions reduction in individual sectors, in order, predicated on the implementation of the relevant policy sets, in order. The total path would amount to an emissions reduction path for the whole economy.

The Department notes The Climate Change Act 2017 assumes that the detailed policy development comes after the targets are set, which may limit the scope to apply a bottom-up approach.

7 ClimateWorks 2010, *Low Carbon Growth Plan for Australia* (accessed here: https://climateworks.com.au/project/national-projects/low-carbon-growth-plan-australia)

4 Factors outside the models which impact the cost curve

The left-hand columns in Table 4.1 list various factors that, in general, are not addressed in CGE modelling, but which impact the costs created by emission reduction policies and thus would impact the 'true' cost curves of emissions reduction.

The right-hand columns explain how these factors might impact the ideal *timing* of emissions reductions (whether emissions reductions should be brought forward or delayed, etc.). Note these observations are drawn from judgement and logic. We cannot be more precise than this, because we cannot incorporate these factors into our modelling.

4.1 Implication for timing of reductions of factors not included in CGE modelling

Factor not included in CGE modelling		Probable impact on timing	
Factor	Explanation	Impact on emissions path	Comment
Adjustment costs	Moving labour and capital from higher to lower emissions intensive industries may involve real adjustment costs (as distinct to technology costs *per se*) which are generally not picked up in modelling	Even spread of reductions (i.e. not favouring one period over another)	To minimise adjustment costs, abatement path should be communicated well in advance Further, adjustment costs are probably minimised by spreading them across time periods, assuming a low discount rate If the discount rate is high, adjustment costs may be minimised by pushing them into the future
Actual policy used to achieve abatement	Abatement is achieved in models with a CO2 tax; the actual policy used may be much less efficient than this Some policies (in and outside of models) do not allow trading between years, which reduces efficiency	Even spread	Same as adjustment costs: extra cost of policy should probably be spread across time periods, if discount rate is low (or delayed if discount rate is high)
Strategy/end-point of 'net zero emissions'	Net zero emissions could be: (1) reductions in gross emissions (concentrated in certain industries) or (2) smaller gross reductions and an increase in sequestration	Implement target setting after goals and policies for sequestration are established	The cost of sequestration may increase further if strategies and policies not put in place at the beginning

Source: The CIE.

Adjustment costs

Reducing emissions in Victoria will require the reallocation of capital and labour from emissions intensive industries into lower emissions industries. At the same time, in many cases this will involve a reallocation of resources between regionals within Victoria, and even between Victoria and other states.

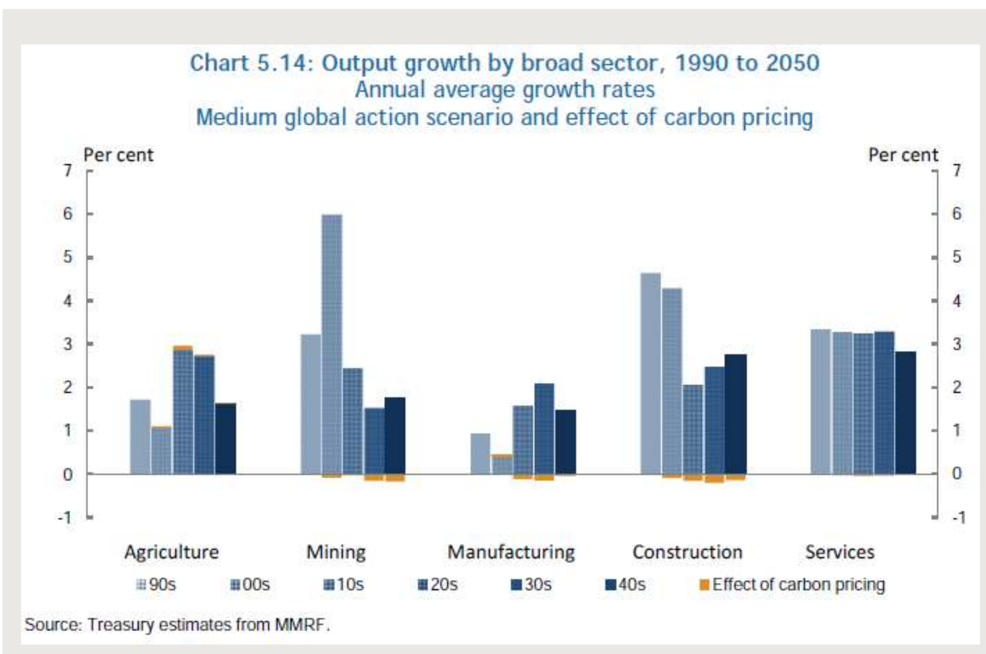
These reallocations are likely to involve 'adjustment costs', at term which refers to the real costs involved in transferring resources from one activity to another. Adjustment costs include, for example, the need to retrain workers to attain employment in expanding activities (as they shift away from contracting ones) or the costs associated with capital losses from 'stranded assets' that are no longer productive in their current uses.

The potential for these costs is illustrated by the fact that most modelling studies do show large changes in activity in different sectors and regions. See, for example, the results summarised in Treasury (2011).

It is likely that adjustment costs, if they could be incorporated, would impact both the level and the steepness of the cost curve. However, for our purposes, it may not be necessary to discover the details of this. The simple point, shown in table 4.1, is that, in the absence of definite evidence to the contrary, adjustment costs should probably be spread over time.

It is also important to note that adjustment costs are usually 'once off' consequence of policy implementation. Further, as Treasury (2011) notes, 'at the broad sectoral level, structural changes due to carbon pricing are much smaller than the effects of ongoing changes in the 'terms of trade or tastes'[8] and shows its Chart 5.14 to illustrate this point.

4.2 Treasury 2011 Chart 5.14



Data source: Treasury 2011

8 Treasury 2011, *Strong growth low pollution* 2011 pg 104

Policy risk

In CGE models, the policy used to achieve emissions reduction is usually a carbon tax, which is generally considered by economists to be the most efficient policy to achieve abatement. If the Victorian government uses policies other than a carbon tax to achieve emissions reduction, costs and changes in the economy (driven by emissions reduction) could be larger than what is reported in modelling results.

BAE 2012 examined the impact of different emissions reduction policies on the economy, given emission reduction goals. BAE found the combination of the RET and ETS reduces the level of Australian GDP by 0.8 per cent, whereas an expanded ETS (working by itself) reduces the level of GDP by only 0.6 per cent. Further, the reduction in GDP is lower if Australia is able to access international permits (and thus lower cost options for abatement).

It is likely that additional costs associated with imperfect policy costs would impact both the level and the steepness of the cost curve. However, for our purposes, it may not be necessary for us to discover the details of this. The simple point, shown in Table 4.1, is that, in the absence of definite evidence to the contrary, additional costs created by imperfect policy should probably be spread over time.

4.3 Key results from BAE 2012: *Comparison of economic effects under alternative climate policy scenarios (2020, percentage differences from the reference case)*

Policy:	ETS	ETS + RET	ETS (linked to EU)	ETS (linked to EU) + RET
Impact on Real GDP (per cent)	-0.6	-0.8	-0.4	-0.7

Source: BAE Economics (2012), Table 4.1

CCA 2016 (drawing on Jacobs 2016) estimates the ‘direct costs’ (defined as resource costs in electricity sector) of different policies that achieve given abatement in the electricity sector. As shown, ‘market mechanisms’ that allow more flexibility impose lower direct costs on electricity sector than other policies.

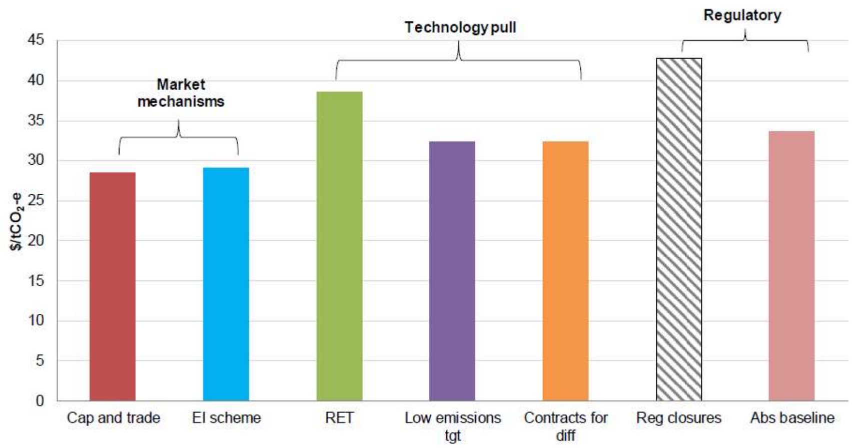
Other factors

Incorrect cost assumptions

When undertaking studies of the impact of emissions reductions on the economy, modellers are obliged to form expectations and assumptions on technology costs (for example, battery costs, the cost of electricity generated from solar cells, etc.). If technology costs turn out to be different than these expectations and assumptions then the realised impacts of emissions reduction will (naturally) be different from modelled impacts. While the potential for incorrect assumptions is an issue in modelling generally, we deal with this issue (to some extent) by using a range of cost curves. As noted, our main results do not change with this assumption.

4.4 CCA 2016 Figure 1

Figure 1 Average cost of abatement by policy, 2 degrees, 2020–2050



Note: See Table 3 in Chapter 3 for a summary of the policies. 'EI scheme' = emissions intensity scheme; 'RET' = Renewable energy target; 'Low emissions tgt '= Low emissions target; 'Contracts for diff' = contracts for difference; 'Reg closures' = regulated closures, 'Abs baseline' = absolute baselines. Average direct cost of abatement over 2020–2050 using a seven per cent discount rate for resource costs. Direct costs are the additional costs arising from the policy in the electricity sector. Emissions not discounted. Figures account for the reduction in welfare from a fall in electricity demand compared to the reference case resulting from increased retail electricity prices. The regulated closures policy breaches the common cumulative emissions budget by about 200 Mt CO_2-e or 15 per cent, so the cost of abatement here is not directly comparable with other policies. See Appendix C.1. All dollar figures in this report are in 2014 Australian dollars unless otherwise specified.
Source: Climate Change Authority based on Jacobs 2016c.

Note: Direct costs are defined as resource costs in electricity generation sector
Data source: CCA 2016

Exogenous vs endogenous costs

There is a deeper issue of whether technology costs and abatement costs (more generally) are exogenous or endogenous. Costs are exogenous if they are independent of efforts to reduce emissions. An explicit assumption of Treasury & DIICSTRE 2013 is that technology costs are exogenous (i.e. determined by outside trends).[9] As explained in Chapter 3, it is likely we have accounted for this (to some extent) by using a range of cost curves, as accepting a flatter cost curve is consistent with thinking endogeneity in costs is a factor that will lower future costs of emissions reduction in Australia.

9 Treasury & DIICSTRE 2013 pg 93

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A Detailed elasticity calculations

This Appendix discusses the data and estimated relationships we use to calculate the GSI losses implied by emissions reduction.

Cost curve data

Chart 3.3 illustrated the percentage deviation in GSI from baseline against the percentage deviation in emissions from baseline, derived from different CGE studies.

- From Treasury & DIICSTIRE 2013 we showed data from all three scenarios: ‘low’ ‘central’ and ‘high’ carbon price. The data are deviation in GNI per capita, which is equivalent to deviation in GNI, as there is no variation in population across scenarios.
- From DELWP 2016 we showed data from one particular scenario. The data are GSI data for Victoria.
- From CSIRO 2015 we showed data from the ‘mixed’ scenario against the materials intensive baseline. CSIRO also report a ‘stretch’ scenario where annual net emissions drop to -216MtCO_2e. We do not use this scenario.

Estimated relationship between emissions and GSI

From these cost curves, we derive mathematical relationships between deviation in GSI and deviation in emissions, which is what we use to derive implied GSI loss from the emissions scenarios under consideration.

Treasury & DIICSTRE (2013)

An exponential trend line may fit the data for Treasury & DIICTRE (2013) well. However, an exponential relationship would generate extremely large deviations in GSI for very large reductions in emissions (i.e. economic activity falls by a large amount relative to baseline). Reductions in emissions of the order of 100 per cent were beyond the scope of the study of Treasury & DIICTRE 2013.

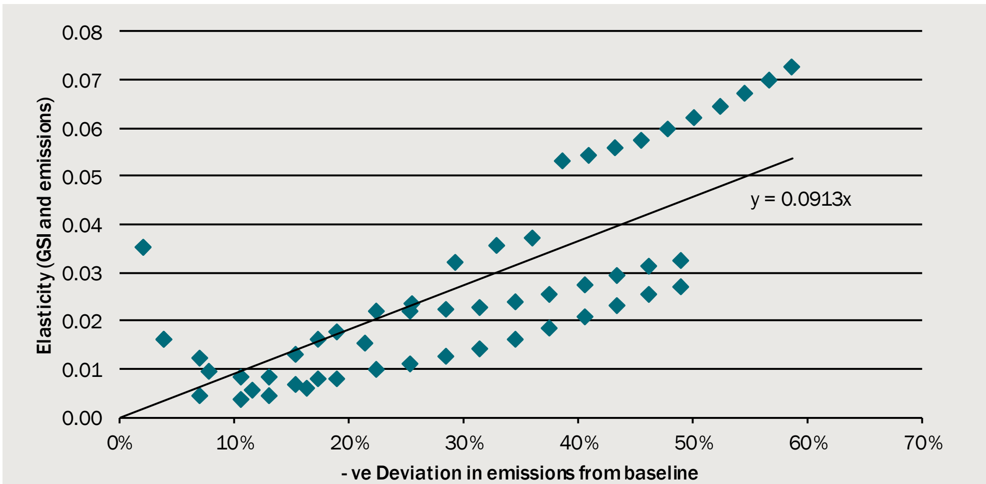
The following strategy (which we follow) has the effect of linearising the relationship between emissions reductions and GSI losses (relative to assuming an exponential relationship between the two).

We estimate a relationship between the elasticity of GSI losses (relative to baseline) and emissions reductions relative to baseline.

$$\text{elasticity of GSI with respect to emissions} = \frac{\text{per cent deviation in GSI from baseline}}{\text{per cent deviation in emissions from baseline}}$$

The data for this relationship (multiplied by -1) are shown in Chart A.1.

A.1 Elasticity between deviation in GSI and deviation in emissions vs deviation in emissions (Treasury & DIICSTRE 2013)



Data source: Treasury & DIICSTRE 2013; The CIE

We assume the intercept of the linear relationship between elasticity and emissions is zero. Using ordinary least squares regression analysis, we estimate a slope coefficient of 0.0913 (t-stat: 17.1). The estimated relationship has an adjusted R-squared of 0.83

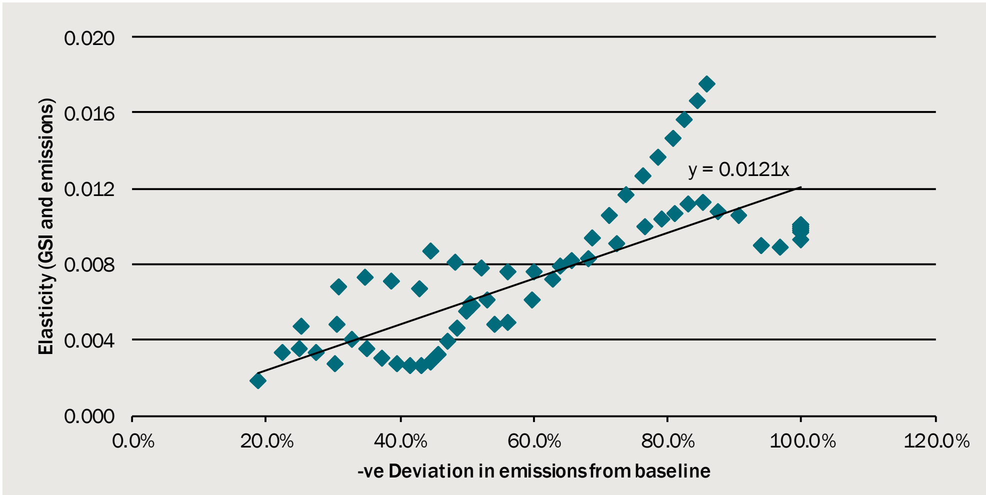
Using this information, the total impact between deviation in GSI and deviation in emissions is:

$$\text{deviation in GSI from baseline} = \text{elasticity} \; [\text{a linear fuction of deviaiton in emissions from baseline}] * \text{deviation in emissions from baseline}$$

DELWP 2016

We follow the same approach in using the DELWP 2016 data. We estimate a slope coefficient for the elasticity between GSI and emissions of 0.0121 (t: stat 29.6). The estimated relationship has an adjusted R-squared of 0.91.

A.2 Elasticity between deviation in GSI and deviation in emissions vs deviation in emissions (DELWP 2016)



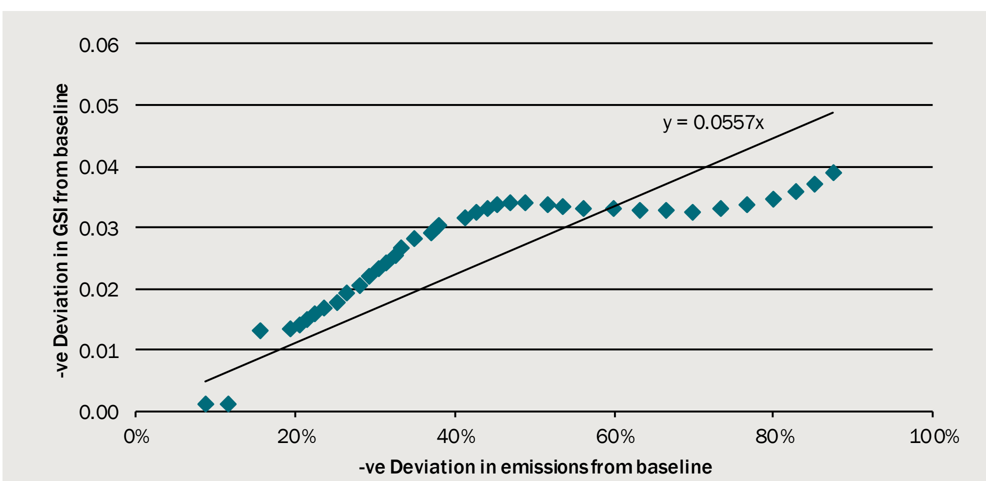
Data source: The CIE

CSIRO 2015

The shape of the cost curve implied by the CSIRO data means it is inappropriate to model the elasticity between GSI and emissions as a linear function of emissions.

Instead, we use ordinary least squares to model a linear relationship between deviation in GSI from baseline and deviation in emission from baseline directly, assuming an intercept of zero. The slope coefficient has an estimate of 0.0557 (t-stat = 24.77) and the adjusted R-squared is 0.916.

A.3 Deviation in GSI vs deviation in emissions (CSIRO 2015)



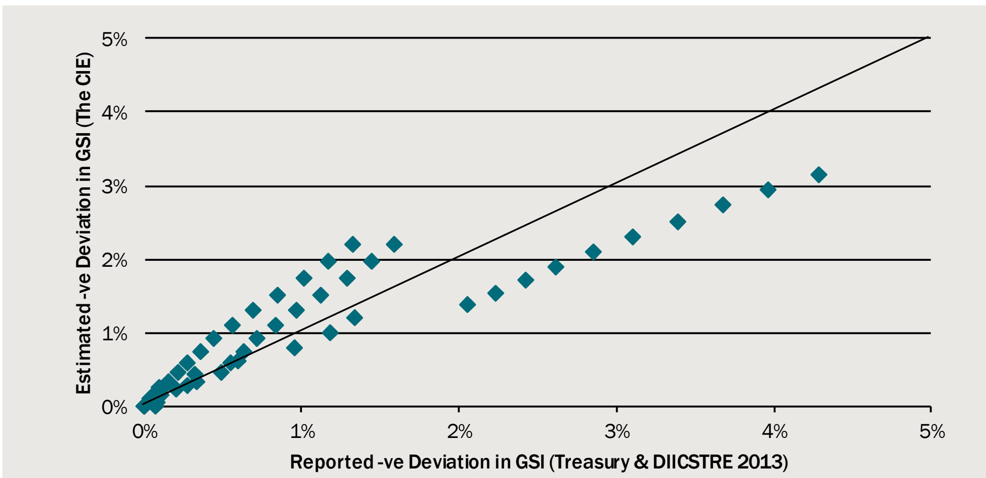
Data source: The CIE

Cross-check

We use the relationships we estimated for Treasury & DIICSTRE 2013 and DELWP 2016 for our results and discussion, so it is necessary to cross-check their accuracy and reasonableness.

If we apply the relationship we estimated from Treasury & DICISTRE 2013 to emissions deviations reported in that study, we generate reasonable estimates for deviations in GSI. Chart A.4 shows that our estimates, when plotted against reported deviations in GSI track either side of a 45 degree line (perfect estimates would sit on the 45 degree line). The relationship is less accurate at higher levels of emissions reduction.

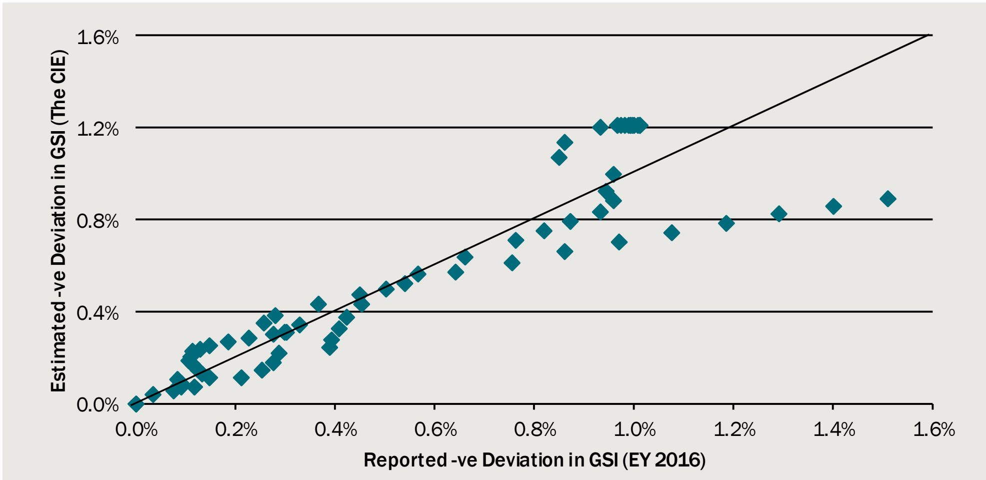
A.4 Estimates of deviation in GSI (CIE estimates) vs actual deviation in GSI (Treasury & DIICSTRE 2013



Data source: The CIE

If we apply the relationship we estimated from DELWP 2016 to emissions deviations, we generate estimates for GSI that align reasonably well with data reported. Chart A.5 shows that our estimates, when plotted against reported deviations in GSI track either side of a 45 degree line (perfect estimates would sit on the 45 degree line). The relationship is less accurate at higher levels of emissions reduction.

A.5 Estimates of deviation in GSI (CIE estimates) vs actual deviation in GSI (DELWP 2016)



Data source: The CIE

B Sensitivity analysis

Baseline sensitivity

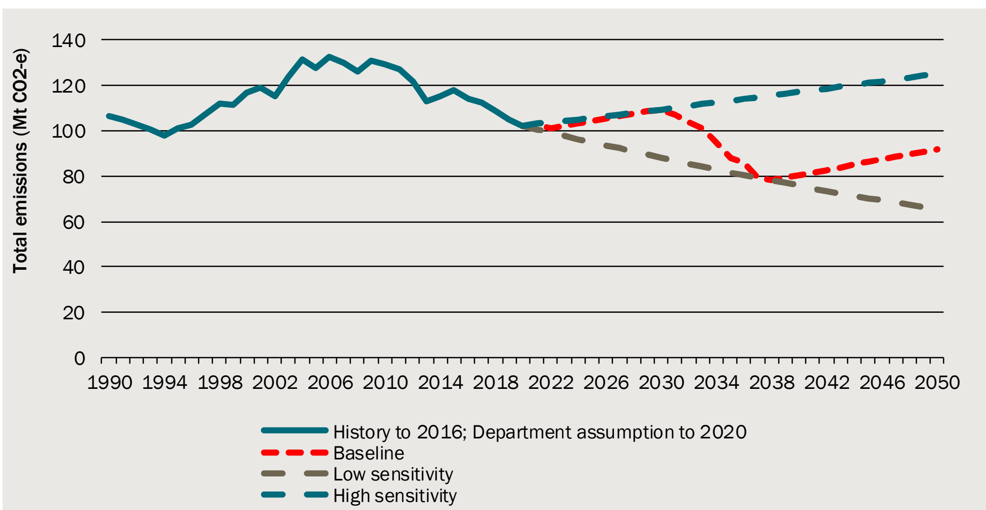
The results presented in Chapter 3 are the loss of GSI, implied by the Department's scenarios for emissions reductions relative to baseline emissions.

In this appendix we show the sensitivity of these results under alternative assumptions for baseline emissions. Chart B.1 shows our core baseline compared with high and low sensitivities.

- In the Department's scenario for emissions, emissions are constant across scenarios until 2020 (where they reach 102 $MtCO_2e$). So our baseline assumptions apply from 2021 onwards.
- To develop sensitivity analysis on the low side, we assume emissions decline at 1.5 per cent per year from 2021 onwards.
- To develop a sensitivity on the high side, we assume emissions grow at 0.7 per cent per year form 2021 onwards.

These alternative baselines are shown in Chart B.1.

B.1 Alternative baselines for Victoria emissions (Mt CO_2e)



Data source: CIE estimates

The key results do not substantively change under different alternatives for the baseline. The scenario for emissions that sees emissions in 2030 65 per cent below 2005 levels (labelled *VIC emissions (65% 2030)* by the Department) implies the smallest or equal smallest loss of GSI relative to baseline. Overall, the differences are small. If a flat cost curve is assumed, the differences are almost negligible. These results are robust to different scenarios for discount rates.

B.2 Discounted loss of GSI due to emissions reduction between 2020 and 2050 (share of baseline GSI 2020-2050), by scenario relative to the core baseline

Cost curve	*Discount rate*	Scenario: level of emissions in 2030 (reduction relative to 2005)			
	-	28 per cent	45 per cent	55 per cent	65 per cent
Flat cost curve	*1.4 per cent*	-0.5	-0.4	-0.4	-0.3
	4.0 per cent	-0.4	-0.3	-0.3	-0.3
	7.0 per cent	-0.3	-0.3	-0.2	-0.2
Steep cost curve	*1.4 per cent*	-3.6	-3.1	-2.7	-2.4
	4.0 per cent	-2.9	-2.5	-2.3	-2.1
	7.0 per cent	-2.2	-1.9	-1.8	-1.8

Note: Reduction in emissions implied by scenarios is measured relative to the core baseline (i.e. these results are the same as those presented in Table 1 and Table 3.7

Source: The CIE

B.3 Discounted loss of GSI due to emissions reduction between 2020 and 2050 (share of baseline GSI 2020-2050), by scenario relative low sensitivity baseline

Cost curve	*Discount rate*	Scenario: level of emissions in 2030 (reduction relative to 2005)			
	-	28 per cent	45 per cent	55 per cent	65 per cent
Flat cost curve	*1.4 per cent*	-0.5	-0.4	-0.3	-0.2
	4.0 per cent	-0.4	-0.3	-0.2	-0.2
	7.0 per cent	-0.3	-0.2	-0.2	-0.2
Steep cost curve	*1.4 per cent*	-3.4	-2.7	-2.3	-1.9
	4.0 per cent	-2.7	-2.1	-1.8	-1.6
	7.0 per cent	-2.0	-1.6	-1.4	-1.4

Source: The CIE

B.4 Discounted loss of GSI due to emissions reduction between 2020 and 2050 (share of baseline GSI 2020-2050), by scenario relative high sensitivity baseline

Cost curve	*Discount rate*	Scenario: level of emissions in 2030 (reduction relative to 2005)			
	-	28 per cent	45 per cent	55 per cent	65 per cent
Flat cost curve	*1.4 per cent*	-0.5	-0.5	-0.5	-0.4
	4.0 per cent	-0.4	-0.4	-0.4	-0.4
	7.0 per cent	-0.3	-0.3	-0.3	-0.3
Steep cost curve	*1.4 per cent*	-4.1	-3.7	-3.4	-3.2
	4.0 per cent	-3.3	-3.0	-2.9	-2.8
	7.0 per cent	-2.6	-2.4	-2.3	-2.4

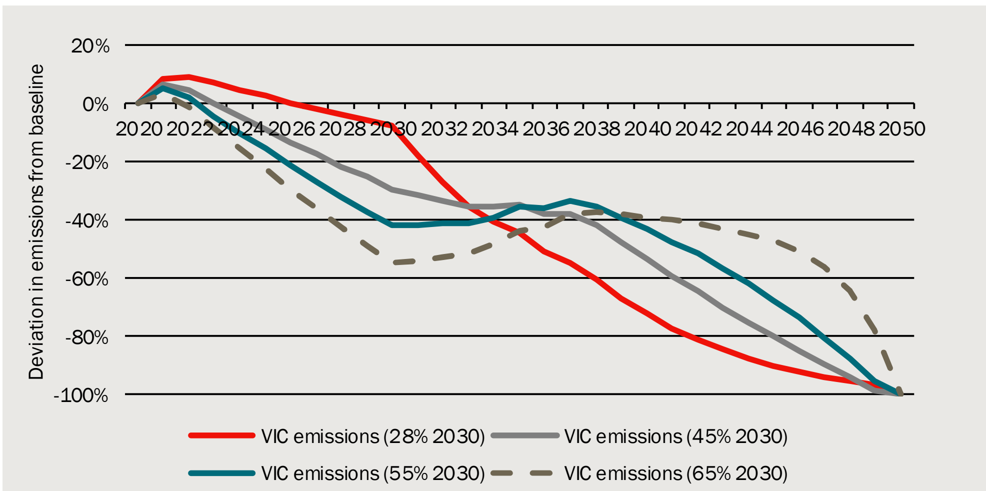
Source: The CIE

Budget sensitivity

As noted the Department has assumed a constant emissions budget across scenarios between 2017 and 2050. In each scenario, emissions are constant between 2017 and 2020. Emissions vary across scenarios between 2021 and 2050.

As a sensitivity, we add 10 per cent to emissions in each scenario between 2021 and 2050 (except for baseline). This increases the effective emissions budget by 7 per cent. The deviation in emissions from baseline is shown in Chart B.5. Table B.6, which uses the steep cost curve, shows the key results don't change — while the absolute value of impacts is smaller with a higher budget, the ranking of the options remains unchanged.

B.5 Deviation in emissions from baseline (by scenario)



Data source: The CIE

B.6 Discounted loss of GSI due to emissions reduction between 2020 and 2050 (share of baseline GSI 2020-2050), by scenario relative to core baseline

Cost curve	*Discount rate*	Scenario: level of emissions in 2030 (reduction relative to 2005)			
	-	28 per cent	45 per cent	55 per cent	65 per cent
Steep cost curve, with DEWLP budget	*1.4 per cent*	-3.6	-3.1	-2.7	-2.4
	4.0 per cent	-2.9	-2.5	-2.3	-2.1
	7.0 per cent	-2.2	-1.9	-1.8	-1.8
Steep cost curve with DEWLP budget, with 10 per cent added from 2021	*1.4 per cent*	-3.4	-2.8	-2.4	-2.0
	4.0 per cent	-2.7	-2.2	-2.0	-1.8
	7.0 per cent	-2.0	-1.7	-1.5	-1.5

Source: The CIE

C Growth rates

Table C.1 shows average annual growth rates in GSI over 5 year periods for different scenarios for emissions, for different cost curves. Discount rates do not affect the results because they are used to convert data into present value terms. Comparison of growth rates across scenarios is not an appropriate way to evaluate and compare scenarios.

C.1 Average annual growth in Victorian GSI in the 5 years to the year noted

	2025	2030	2035	2040	2045	2050
Baseline GSI	2.7%	2.6%	2.6%	2.4%	2.3%	2.2%
Flat cost curve						
VIC emissions (28% 2030)	2.7%	2.6%	2.5%	2.4%	2.3%	2.1%
VIC emissions (45% 2030)	2.7%	2.6%	2.6%	2.4%	2.3%	2.1%
VIC emissions (55% 2030)	2.7%	2.6%	2.6%	2.4%	2.3%	2.1%
VIC emissions (65% 2030)	2.7%	2.5%	2.6%	2.5%	2.3%	2.0%
Steep cost curve						
VIC emissions (28% 2030)	2.7%	2.6%	2.2%	1.8%	1.8%	1.8%
VIC emissions (45% 2030)	2.6%	2.4%	2.5%	2.1%	1.7%	1.5%
VIC emissions (55% 2030)	2.6%	2.3%	2.7%	2.3%	1.8%	1.2%
VIC emissions (65% 2030)	2.5%	2.1%	2.8%	2.5%	2.2%	0.7%

Source: The CIE

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