Zero Greenhouse Gas Emissions by 2050: What it means for the Australian Economy, Industries and Regions

CoPS Working Paper No. G-324, November 2021

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ISSN 1 921654 02 3

ISBN 978-1-921654-32-9

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Citation

Adams, Philip (2021), "Zero greenhouse gas emissions by 2050: What it means for the Australian economy, industries and regions", Centre of Policy Studies Working Paper No. G-324, Victoria University, November 2021.

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11 November 2021

Keywords: CGE, Climate policy, Industries, Regions, Employment

JEL: C68, Q52, Q58, R11

Acknowledgements

This research is funded by a grant provided by Victoria University to the Centre of Policy Studies (CoPS), the Mitchell Institute for Education and Health Policy and The Centre for International Research on Education Systems (CIRES). The research team involves Professor James Giesecke, Professor Philip Adams, Dr. Xiujian Peng, Dr. Chris King, Dr Peter Hurley, Dr Lizzie Knight, Sue Pennicuik, Professor Peter Dawkins and Dr Melinda Hildebrandt.

This paper is the first in a series of papers examining the economic impacts of a transition to net-zero emissions and possible policy responses in Australia. It reports on modelling that was completed just prior to the release on 26 October of the Morrison government's *Australia's Long Term Emissions Reduction Plan.*

The author would like to acknowledge the research team involved in the project and those who provided feedback and comments on earlier drafts of the paper.

Foreword

This paper by Philip Adams is the first output from a joint project between the Centre of Policy Studies and the Mitchell Institute for Education and Health Policy, funded by Victoria University.

It focuses on the impact on the Australian economy and its industries and regions, of achieving net zero carbon emissions by 2050. This is timely, being published at the time of the Glasgow Climate Change Conference, at which Australia has committed to achieving net-zero emissions by 2050, albeit with little detail yet about how it is to be achieved and what its impacts will be on different industries and regions.

Having made this commitment, it is important for the Australian government and Australian community to have a serious discussion about how achieving net-zero emissions can be expected to affect our industries and regions. Further it is important to consider how our public policies should both support the achievement of this goal and how it should manage the structural adjustment that will be required. The publication of this paper provides the first detailed analysis of those industries and regions that will benefit from the emissions reduction and those that will be negatively impacted.

This is exactly the kind of research that provides the information needed by policy makers to design the structural adjustment measures that will cushion the impact on negatively affected regions and industries and, in particular, their affected workers. The next paper led by the Mitchell Institute will focus on the role that the education and training system can play to help re-skill affected workers for new job opportunities.

The Mitchell Institute is delighted to be working with CoPS on this project and in particular to be working with Philip Adams, one of Australia's leading economic modellers of the implications of decarbonisation.

It is pleasing to learn from the modelling in this paper that technological progress since Adams' 2014 analysis of the economic impact of decarbonisation has resulted in larger than previously expected falls in renewable energy costs. This points to a much smaller negative impact on GDP than previously thought.

I look forward to being part of the Mitchell Institute team that will work closely with the Centre of Policy Studies on the next stage of the project, which will include an analysis of the possible interventions in the negatively affected regions that will cushion the impact on affected workers and give them the kind of employment opportunities that will exist in an increasingly decarbonised world.

Peter Dawkins

Emeritus Professor of Economics
Mitchell Institute for Education and Health Policy
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Summary

This report outlines detailed modelling of the impacts on the Australian economy of changes necessary to achieve net-zero Greenhouse emissions by 2050. We simulate two scenarios from 2021 to 2050. The first is a 'Base Case Scenario', which models the future development of the Australian economy under business-as-usual assumptions. In the Base Case, emissions continue to grow at a rate similar to the present. The second is a 'Zero-Emissions Scenario' which deviates from the Base Case due to Australia and parts of the Rest of the World taking action to progressively reduce net emissions to zero by 2050.

Our modelling assumes that Australia achieves a net zero emissions though domestic action, without purchasing abatement credits from overseas.

A guiding principle in our modelling is that with present policy settings Australia cannot reach zero net emissions because, on average, it is cheaper to emit than not to emit. Thus, to achieve net-zero, emissions must be priced beyond what current policies prescribe. The additional pricing will most likely come from a mix of market and non-market interventions. A good example of the former is a carbon tax, or emissions trading scheme. Non-market interventions will involve regulation, subsidies and the financing of new (green) technologies. For our modelling, we assume that a carbon price across all emissions is put in place to achieve the 2050-target. This achieves the least-cost changes to the economy necessary for decarbonisation.

A number of key findings emerge from the modelling.

1. Despite the requirement for deep cuts in emissions, the Australian economy continues to grow strongly in terms of production (real GDP) and employment. In terms of average annual growth, the difference is barely discernible between the two scenarios. In the Zero-Emissions Scenario, real GDP grows at an average of 2.56% per annum. In the Base Case Scenario real GDP grows at an average of 2.59% per annum.
2. The loss of real GDP in 2050 due to decarbonisation is projected to be around 1 per cent, or close to $30 billion (in 2021 prices). Our previous assessment in 2014 estimated a loss of 3.8 per cent, or nearly $150 billion (2021 prices). This time the negative GDP result is much smaller because the abatement task is easier due, in part, to lower than previously expected renewable generation costs and faster than previously expected penetration of electric vehicles for both light and heavy transport.
3. In 2050, fewer than 6,000 jobs are lost Australia-wide due to decarbonisation. It should be noted, however, that even though the total number of jobs is barely effected, for most industries and regions there are more significant employment responses to decarbonisation, compounding or defusing existing (Base Case) pressures for structural change.
4. Decarbonisation provides an impetus to many industries, especially industries producing electricity from renewable generation and industries directly and indirectly associated with forestry and wood production. But, there are some industries for which zero-emissions restrains output and employment. Examples include coal-based electricity generation and coal mining. However, it should be noted that with decarbonisation coal production in 2050 remains at a similar level to 2021 due, entirely, to exports.
5. Electricity use generally increases relative to GDP, and even more so with a high emissions price, because of two key factors: a modal shift in transport towards electric vehicles, and increased electrification of buildings and industry technologies.
6. Decarbonisation boosts forestry activity because of bio-sequestration opportunities. This leads to significant increases in forested land and increased sales of logs to downstream

manufacturing and of forest pulp for export. In the Zero-Emissions Scenario, the forestry industry increases in size to almost twice that in the Base Case.

7. Our modelling allows us to identify industries that are most vulnerable to decarbonisation. We can assess vulnerability in a number of ways, but prefer a relatively simple measure based on projected percentage changes in production. We classify vulnerable industries as ones having projected falls in production of 10 per cent or more relative to their levels in the Base Case Scenario. Under this criterion, 10 of the 84 industries recognised in our model are classified as vulnerable, but only three (coal generation, urban gas supply and petroleum refining) are projected to experience reductions in production and employment between 2021 and 2050 as a result of decarbonisation.
8. The pattern of decarbonisation effects across states and territories reflects the pattern of industry effects. Overall, real Gross State Product (GSP) is projected to fall relative to Base Case values in all states except Tasmania and South Australia. The state projected to experience the largest decline is Queensland because of an over-representation of coal mining, broadacre agriculture and coal generated electricity in its economy. But that decline has to be seen in its right perspective. For example, in terms of employment, QLD is projected to expand employment by around 1.2 million people without decarbonisation. With decarbonisation that expansion is slightly less, 1.1 million persons.
9. For Australia as a whole, vulnerable industries noted above account for less than 4 per cent of aggregate employment. However, some sub-state regions are much more heavily dependent on the vulnerable industries. We identify 9 out of 88 sub-state (SA4) regions as vulnerable in terms of potential loss of employment. These include coal-dependent regions such as Hunter in NSW, Fitzroy in QLD and Gippsland in VIC. On the other hand, 46 regions are identified as potentially gaining employment. These regions generally have an over-representation of the sectors that expand due to policies to decarbonise, especially forestry and renewable electricity generation and some of the service sectors that gain output because they have very little emission intensity to begin with. No region, vulnerable or otherwise, in the Zero-Emissions Scenario is projected to experience a decline in employment/production between 2021 and 2050.
10. While all regions in Australia are expected to grow relative to 2021, the constraints on production and employment warrant targeted policy interventions to support industries and regions disproportionately affected by net-zero emissions policies. The examination of effective policy responses will be the subject of further work by Victoria University's Centre of Policy Studies, the Mitchell Institute for Education and Health Policy, and the Centre for International Research on Education Systems.

We conclude with the following idea. Cutting greenhouse gas emissions is like buying an insurance policy: we incur a cost (a loss in GDP) to reduce a risk (catastrophic climate change). In any insurance decision, the cost matters. If a worthwhile reduction in risk costs 50 per cent of income, then then living with the risk may be preferable. However, if it costs only 1 per cent of income, as estimated in our modelling, then taking the insurance policy is a very good option.

Contents

1 Introduction

In 2014, the Centre of Policy Studies (CoPS), in collaboration with ClimateWorks, ANU and CSIRO, authored *Pathways to Deep Decarbonisation by 2050: How Australia can prosper in a low carbon world* as part of the global UN-sponsored 2050 Deep Decarbonisation Pathways Project[i]. The report explored four key ingredients to decarbonisation:

- improved energy efficiency.
- zero-emission electricity.
- electrification and fuel switching.
- technology-induced cuts in non-combustion emissions.

The situation has changed a lot since 2014. Importantly, business and governments have started to plan for a zero emission future. Under the Paris Agreement, many major economies have submitted ambitious 2050 emissions strategies, some in conjunction with net-zero emissions goals. In Australia, major companies such as BHP and Rio Tinto have made commitments to zero-emissions, as have most state and territory governments. In late October, in the lead up to the Glasgow COP26 meeting, the Australian Prime Minister launched his Government's plan to achieve net zero-emissions by 2050.

Current discussion has predominantly focused on targets and the technological feasibility of meeting those targets. Relatively little new work has been done to understand the economic implications of decarbonisation. In this paper, we aim to fill this void by updating our 2014 work, accounting for:

- larger than previously expected falls in in renewable-energy costs;
- the rise of hydrogen and bioenergy based technologies; and
- new insights from experts such as ClimateWorks on improved energy efficiencies.

We also take into account the re-framing of industrial and commercial opportunities, of the type suggested in Ross Garnaut's 2019 book *SuperPower: Australia's low-carbon opportunity*. However, we have been cautious, and have not factored in significantly large new investments in *green metal* and other green manufactured products of the scale thought possible by Garnaut. Our caution, at this stage, is based on history, which suggests that due to high transportation and labour costs Australia will always face completive challenges on world markets for manufactured products even with access to cheap raw inputs such as iron ore and electricity (green or brown).

As before, our analysis is based around scenarios to 2050 constructed using a Computable General Equilibrium (CGE) model. Previously we used a model calibrated to a base year of 2012. This time we use an updated model, the Victoria University Regional Model (VURM)[ii], calibrated to 2018. CGE models are detailed, as are the results reported in this paper, focusing on regions, industry composition and the profile of future labour-force training requirements.

The remainder of this paper is divided into four sections. VURM is described briefly in Section 2. Aspects of simulation design and the calculation of shocks are given in Section 3. Section 4 contains a discussion of results. Concluding remarks are in Section 5.

2 VURM

2.1 A bottom-up model of Australian states and Territories

As explained in Adams *et al.* (2015), VURM is a bottom-up model of Australia's six states and two territories. By bottom-up, we mean that each of the regional economies is modelled as an economy in its own right, with region-specific households, industries, prices, etc. The regions are linked via model-determined changes in inter-state trade and movement of labour and capital. In the version of VURM used for the study, there are 83 industry sectors, of which 34 are potentially affected directly by carbon tariffs.

Investment is allocated across industries to maximise rates of returns to investors (households, firms). Capital creators assemble, in a cost-minimizing manner, units of industry-specific capital for each industry. Each state has a single representative household and a state government. There is also a federal government. Finally, there are foreigners, whose behaviour is summarised by export demand curves for the products of each state and by supply curves for international imports to each state.

As is standard in CGE models, VURM determines the supply and demand for each regionally produced commodity as the outcome of optimising behaviour of economic agents. Regional industries choose labour, capital and land to maximise their profits while operating in a competitive market. In each region a representative household purchases a particular bundle of goods in accordance with the household's preferences, relative prices and its disposable income.

Interregional trade, interregional migration and capital movements link each regional economy. Governments operate within a fiscal federal framework.

VURM provides results for economic variables on a year-on-year basis. The results for a particular year are used to update the database for the commencement of the next year. In particular, the model contains a series of equations that connect capital stocks to past-year capital stocks and net investment. Similarly, debt is linked to past and present borrowing/saving and regional population is related to natural growth and international and interstate migration.

Finally, in addition to its economic core, VURM contains a number of enhancements to facilitate the modelling of environmental issues. These include:

1. an accounting module for energy and greenhouse-gas emissions that covers each emitting agent, fuel and region recognised in the model;
2. quantity-specific carbon taxes or prices;
3. equations for inter-fuel substitution in transport and stationary energy;
4. a representation of Australia's National Electricity Market (NEM); and
5. equations that allow for the adoption of abatement measures (for combustion and non-combustion emissions) as functions of the price of greenhouse emissions.

2.2 A top-down model of Australian sub-state (SA4) regions

VURM includes a top-down facility for generating base-case prospects and the effects of decarbonisation on Real Gross Regional Product (GRP) and regional employment for 88 SA4 regions[iii].

Under the top-down procedure, VURM's 84 industry sectors are split into two groups: the group whose outputs are readily traded between regions and the group producing outputs (mainly services) that are not readily traded between regions. For an industry in the first group, our assumption is that decarbonisation has the same percentage effect on output and employment in a SA4 region as it has on output and employment overall in the industry in the state to which the sub-state region belongs. If this assumption were applied to all industries, then differences between sub-state regions in the estimated effects of decarbonisation would depend simply on differences between regions in industries' shares in output or employment. But in addition to this, we recognise that for industries in the second (non-traded) group, demand in a sub-state region will be met by output in that region. This means that changes in activity in a sub-state region arising from changes in activity in industries in the first group have local multiplier effects.

The key data input to our top-down method for generating output and employment results for the sub-state regions is a database showing gross value added and employment by industry and region. From this, the shares of each region's gross regional product (GRP) and employment accounted for by each industry can be calculated. These shares allow the implications for a region's GRP or employment of a change in an industry's activity level within the region to be inferred. In this section, we concentrate on employment.

3 Simulation Design

3.1 Introduction

Using VURM, we project forward from the model's base year of 2018 to the current year 2021, called the reference year. This involves forcing the model to track known growth rates for most of the key macroeconomic variables and microeconomic variables for which there is a statistical record. For example, in the update to 2021 we impose on the model observed growth in GDP, with the model determining the rate of technological progress consistent with observed growth rate.

Having brought the model forward to 2021, the model is then used to simulate two scenarios out to 2050. One scenario is based on business-as-usual assumptions for the drivers of growth: population change; productivity improvement; and growth in the rest of the world. Included in this business-as-usual forecast (otherwise known as the Base Case Scenario) are policies currently in place designed to supress greenhouse gas emissions. These include state and federal schemes to support renewable energy generation, and rules and regulations designed to improve the energy efficiency of residential and commercial building.

The second scenario (otherwise known as the Zero-Emissions Scenario) deviates from the Base Case Scenario in response to changes that reduce net greenhouse gas emissions to zero by 2050. The effects of these changes (i.e., the effects of decarbonisation) are calculated by comparing values for variables in the Zero-Emissions Scenario with their values in the Base Case Scenario.

In the remainder of this section, we discuss the key inputs to the projections, and the main assumptions regarding the behaviour of the macro-economy in the VURM modelling.

3.2 Inputs to the Zero-Emissions Scenario

The main inputs that drive the Zero-Emissions Scenario relate to:

(1) greenhouse gas emissions (i.e., an imposed decarbonisation path) which drives values for the key policy instrument – an emissions price applied equally to all emissions;
(2) aspects of electricity supply;
(3) vehicle use by vehicle type (electric and internal combustion);

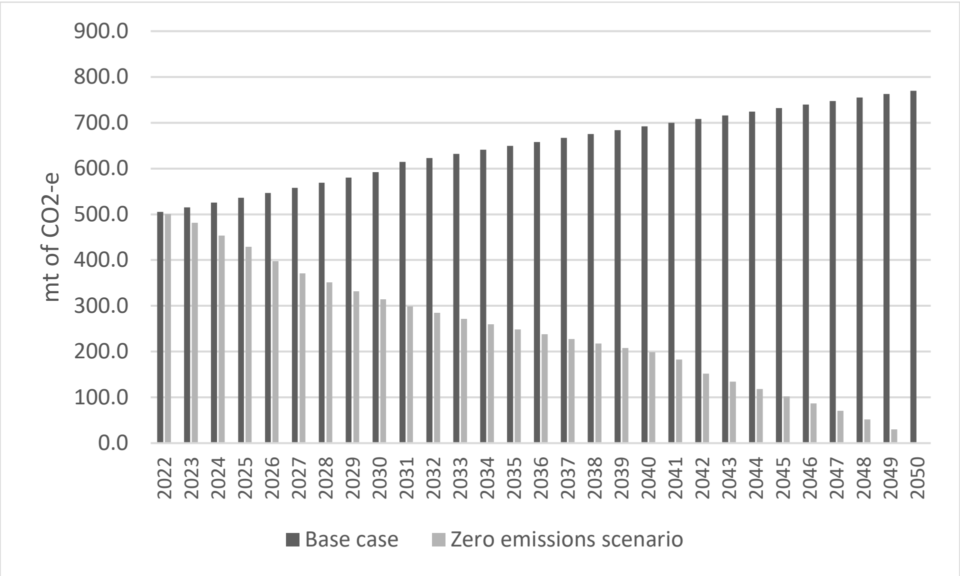
(4) land use in agriculture and forestry (and associated forestry bio-sequestration);
(5) foreign-currency import prices and the positions of foreign export-demand schedules for carbon intensive commodities; and
(6) autonomous energy efficiency, electrification and use of bioenergy.

3.2.1 Greenhouse emissions and price

Central to our modelling of the Zero Emissions pathway is that with present policy settings Australia cannot reach zero net emissions because, on average, it is cheaper to emit than not to emit. It follows that to achieve net-zero, emissions must be priced beyond what current policies prescribe. The additional emissions-cost will most likely come from a mix of market and non-market interventions. A good example of the former is a carbon tax, or emissions trading scheme. Non-market interventions will involve regulation, subsidies and the financing of new (green) technologies. For our modelling, we assume that a carbon price across all emissions is put in place to achieve the 2050-target. This achieves the least-cost changes to the economy necessary for decarbonisation.

In modelling the Zero-Emissions Scenario, we impose the pathway on total net emission given in Figure 1. The model achieves that pathway with a model-determined price for greenhouse gas emissions (per tonne of CO_2-e[iv]) shown in Figure 2.

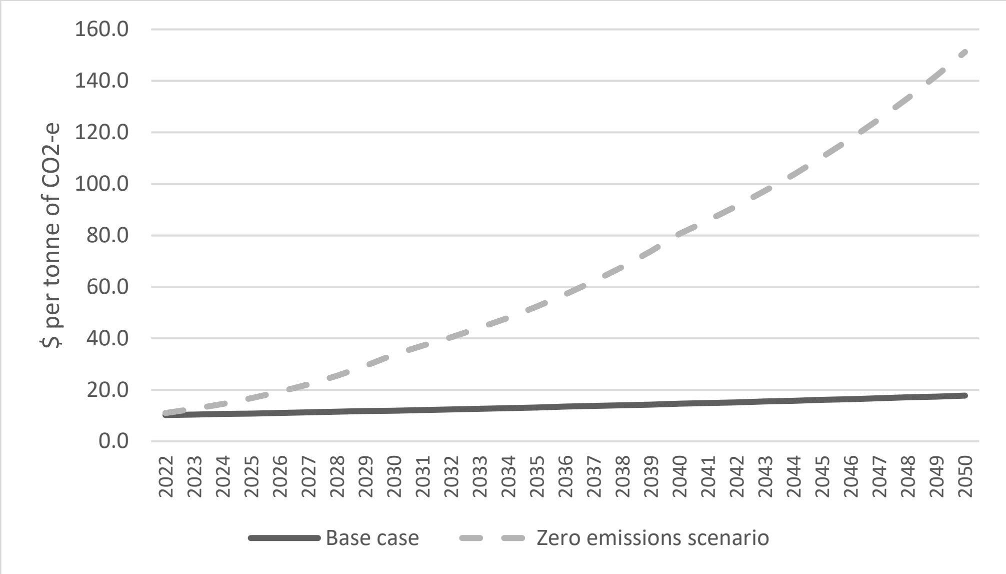
Figure 1: Total Emissions of CO_2-e



According to Figure 1, in the Base Case emissions increase from around 500mt of CO_2-e in 2021 to 591.7mt of CO_2-e by 2030 (*cf.* 611mt in 2005). In 2050 emissions reach 770mt without the abatement embodied in the Zero-Emissions Scenario. With that abatement, emissions fall to 314.2mt in 2030 and to zero by 2050.

Figure 2 show for the Zero-Emissions Scenario a price progressively rising to $33.6 per tonne of CO_2-e in 2030 and to $151 per tonne of CO_2-e in 2050. Note that the price in the Base Case Scenario is not zero, due to state and federal government policies in place designed to reduce emissions, such as the roof-top solar subsidy and the Renewable Energy Target. In 2020, we estimate the Base Case price to be around $10 per tonne of CO_2-e. This rises slowly to $18 in 2050.

Figure 2: Price of CO_2-e



The emissions price increases the cost of emitting activity. Raising the cost induces three broad abatement responses:

- relative-price substitution away from more expensive high emitting fuels;
- adoption of new technology in industry production that embodies lower emissions; and
- reduction in carbon-emitting activity such as conventional (coke-based) steel production.

Note that potentially each response might impact negatively on real GDP. Relative price substitution minimises costs but could entail a small allocative efficiency loss relative to the Base Case. If the new technology is less profitable than the old technology (thus requiring a subsidy), then adopting that technology is technological regress in modelling terms. Finally, if the activity which is displaced is profitable (without the carbon price) relative to activity that is crowded in (conventional steel replaced by wood products in building for example), then this will also be negative for GDP.

The permit price is modelled as a tax levied per unit of CO_2-e produced in Australia. It is imposed on all sources of emissions, including agriculture and transport. Initially, the price applied in some sectors is less than the full price to avoid modelling outcomes that are unrealistically large. But, from 2023 all emissions are priced at the same rate.

3.2.2 Electricity inputs

In our modelling for the 2014 report, we incorporated CSIRO projections for electricity generation, generation capacity, emissions and electricity prices drawn from their detailed technological modelling of the energy system. These projections were accommodated in the CGE model *via* a series of changes that essentially replace the existing modelling of electricity supply with CSIRO projections.

For the modelling reported in this paper, we revert back to the standard VURM description of electricity generation and supply with those changes being generated, in the main, by the emissions price. In doing so we use up-to-date data for the price of generation from each of the technologies recognised in VURM – Electricity from coal, Electricity from gas, Hydro generation (including storage and pumping) and non-Hydro renewable (including battery storage and rooftop solar). The updated data are drawn from Graham *et al.* (2020).

The updated numbers for generation cost suggest that renewable generation is the cheapest option for new investment even without a specific price on emissions. In initial runs of the Zero-Emissions Scenario, VURM projected a 100 per cent renewable share by 2040. Though technologically feasible, such a result so soon would seem unlikely given the number of large coal generation plants with economic lives beyond 2040 and the significant network upgrades necessary to accommodate such a high proportion of renewables.[v] Accordingly, we constrained the results so that gas generation in the NT continues through to 2050, and one coal-fired plant remains in QLD operating with Carbon Capture and Storage (CCS).

Table 1 shows national generation shares in 2021 and at the end of the projection period in the Base Case and Zero-Emissions scenarios.

Table 1: Electricity Generation Shares (%)

Generation Technology	2021	2050 Base Case	2050 Zero-emissions
Electricity – coal	54.1	40.6	2.1
Electricity – gas and oil	19.1	10.1	1.7
Electricity – Hydro	6.3	6.3	6.3
Electricity – Non-Hydro renewable	20.5	43.0	89.9

3.2.3 Inputs relating to vehicle electrification

At present, the VURM model does not contain an endogenous mechanism allowing the vehicle fleet to switch from internal combustion motors to electric power. In our 2014 study we used data from the CSIRO for growth in fuel use and emissions for road transport (private vehicles and commercial freight and passenger) by region. Fuels covered were LPG, gasoline, diesel, electricity and "other". The last mentioned includes Compressed Natural Gas (CNG) and Biofuel. Projections for the use of each fuel type were accommodated in the CGE system *via* model-determined (i.e., endogenous) shifts in fuel-usage coefficients in industries' production functions.

For the projections in this paper we use the same procedure based on updated information from the CSIRO published in Climate Works (2020). In that study, the upfront cost of battery electric vehicles reaches parity with the cost of conventional vehicles in 2025, even without an emissions price. After 2025, the CSIRO numbers show electric-powered vehicles taking significant market share away from vehicles relying on internal combustion technologies, with electric power achieving a 90 per cent share of light vehicles and a 60 per cent share of heavy vehicles by 2050. We impose the same penetration rates in the Zero-Emissions Scenario.

3.2.4 Agricultural and Forest land use

For the 2014 Climate Works study, action taken to achieve zero-emissions was assumed to have a significant impact on forestry production and forest bio-sequestration.[vi] CSIRO's estimates of land credits were accommodated in the CGE modelling via a combination of increased forestry production and endogenous shifts in sequestration per unit of forestry output. Corresponding changes in land under forestry were also imposed. With total land availability by region fixed, land available for agriculture falls.

We adopt the same approach in this study, using updated information published in Climate Works (2020). That study shows carbon forestry has the potential to sequester between 96 and 244 Mt of CO_2-e per year by 2050. The latter is equivalent to 24 Mha of area plantings. For the current study, we adopt the lower estimate of 96 Mt. The current level of forestry sequestration is around 20 Mt.

We make allowance for bio-sequestration from action to improve *soil carbon* levels by introducing one or more land management activities, such as applying nutrients and changing stocking rates, or the duration or intensity of grazing. Sequestration associated with soil carbon activity is included (as an offset) in the emission numbers for agriculture

3.2.5 International trade

VURM is a single country model which takes into account the rest of the world (RoW) by having exogenously-positioned export demand schedules for goods and services and exogenously imposed foreign currency prices for imports.

In the Base Case Scenario, RoW demands for Australian products grow in line with recent trends. For the Zero-Emissions Case we assume that most of our major trading partners pursue a course to zero-emissions. The exception is China and India. We assume that China takes limited steps, but this has relatively little impact on Chinese imports of Australian products, including coal, LNG and iron ore. India continues with current policy settings, meaning that its demand for Australian products (especially coal) continues to grow at rates of around 3 per cent per year.

Table 2 shows for the Zero-Emissions Scenario our assumptions for world export demand for key Australian commodities expressed in terms of horizontal shifts in export demand schedules relative to their Base Case Scenario positions.[vii] We assume that export demand schedules remain at Base Case positions for agricultural products, iron ore, food and metal products and all services. Export demand shifts out for forestry and wood products as parts of the rest of the world substitutes away from steel construction towards wood products. Small annual positive shifts in world demand for LNG are also assumed. Overall world demand for Australian produced coal is assumed to contract at a rate of 1.5 per cent per annum, while that for chemical products (especially with high greenhouse content) also contracts but at a much smaller rate.

Table 2: Horizontal changes from Base Case values in Position of Export Demand (%)

Commodity	Average annual % shift relative to Base Case position
Agricultural products	0.0
Forestry products	1.8
LNG	0.2
Coal	-1.5
Iron ore	0.0
Other mining	0.0
Food products	0.0
Wood and paper products	1.8
Chemical products	-0.2
Metal products	0.0
Services (including tourism)	0.0

3.2.6 Assumptions for Autonomous energy efficiency, electrification and use of hydrogen and bioenergy

VURM has a range of variables that allow for exogenous changes in overall energy usage and fuel shares by industry. For the simulations reported in this paper, we use inputs from Climate Works (2020) to impose changes in:

- autonomous rates of energy efficiency improvement in mining and manufacturing and in residential and commercial building;
- rates of electrification of non-transport industry technologies[viii]; and
- rates of uptake of new forms of energy (bioenergy and hydrogen).

The assumptions differ across time, energy-source and industry for each scenario, and so are difficult to summarise in a single table. Broadly, relative to Base Case, in the Zero-Emissions Scenario there is enhanced rates of autonomous energy improvement, increased rates of electrification and material uptake of bioenergy and hydrogen.

The economy-wide autonomous rate of energy efficiency improvement in the Base Case Scenario is, on average, 0.55 per cent per annum. In the Zero-Emissions Scenario, the overall rate is 0.95 per cent per annum. The increase of 0.4 percentage points is what was assumed in the 2014 study.

In the Zero-Emissions Scenario, two factors encourage industries to further substitute fossil fuels for electricity in their production processes. First, due to the emissions price, the cost of electricity drops relative to the cost of natural gas and petroleum. This puts in place an endogenous shift towards electricity by all users of energy. But more profound, are exogenous changes to technologies directly imposed using inputs from Climate Works. For example, two different processes can be used to produce steel: namely blast furnace (coke, oven-coal), using iron ore, and electric arc furnace (electricity), using scrap iron and steel. The second process consumes two to three times less energy than the first one. Based on the Climate Works information, in the Zero-Emissions Scenario, the Australian steel making industry shifts from coal-based blast furnace operation to electric arc-furnace technologies and can be fully electrified by 2035. Similarly, alumina production becomes less reliant on gas and more reliant on electricity after 2030.

Electrification and increased use of bioenergy involve a cost – the cost of investing in the new technologies. In VURM, the investment costs per unit of output are imposed as an all-input using technological deterioration in the production functions of the investing industries.

In the Zero-Emissions Scenario, we assume that the road transport (freight and passenger) industries and metal manufacturing sectors progressively replace their use of natural gas with hydrogen after 2025. However, our modelling of hydrogen production from electrolysis is not yet explicitly modelled in VURM. To model hydrogen uptake, we impose two technological changes on the road transport and metal manufacturing sectors. The first is a switch away from natural gas and towards electricity (used in the electrolysis process). The second is an increase in total unit cost of production to take account of the additional cost of a Pj from hydrogen relative to a Pj from natural gas.

By 2050, 3 per cent of light vehicles and 3 per cent of heavy vehicles are powered by fuel cells (hydrogen) and around 5 per cent of Base Case requirements of natural gas are replaced by hydrogen in metal manufacturing.

Development of an explicitly represented and appropriately calibrated hydrogen industry in VURM is currently underway.[ix] When activated, this industry will endogenously produce hydrogen uptake rates, and hydrogen unit costs, which we expect to be similar to those we currently exogenously impose as described above, and as such are unlikely to materially affect the results reported herein.

3.3 Assumptions for the Macroeconomy

The following assumptions are made for key aspects of the macro economy in modelling the Zero-Emissions Scenario.

Labour markets

At the national level, lagged adjustment of the real-wage rate to changes from Base Case imposed in the Zero-Emissions Scenario is assumed. These changes can cause the employment rate (employment/labour force) to deviate from its Base Case value initially, but thereafter, real wage adjustment steadily eliminates the short-run consequences, returning the unemployment rate to its Base Case value. This labour-market assumption reflects the idea that ultimately national employment is determined by demographic factors, which are unaffected by greenhouse emission policy. Ultimately, nearly all of the national labour market implications of moving to Zero-emissions is revealed as a change in the national real wage rate. The rest is captured by a change in the participation rate (ratio of the labour force to working-age population) which responds positively to changes in the real wage. A lower real wage, leads to lower participation. Lower participation, with population fixed, means a smaller labour force. A smaller labour force, with the employment rate fixed means less employment.

At the regional level, labour is assumed to be mobile between state economies. Labour is assumed to move between regions to maintain inter-state unemployment-rate differentials at their Base Case levels. Accordingly, regions that are relatively favourably affected by the shift to a zero-emissions pathway will experience increases in their labour forces as well as in employment, at the expense of regions that are relatively less favourably affected.

Private consumption and investment

Private consumption expenditure is determined via a consumption function that links nominal consumption to household disposable income (HDI), with the ratio of consumption to income being the Average Propensity to Consume (APC). In the Zero-Emissions Scenario, the APC is an endogenous variable that moves to ensure that the balance on current account in the balance of payments remains at its Base Case level. Thus, an increase (decrease) in aggregate investment brought about by a shift to zero-emissions is accommodated by an increase (decrease) in domestic saving, leaving Australia's call on foreign savings unchanged. An increase (decrease) in domestic saving is brought about by a decrease (increase) in the APC. For this reason, changes in real private consumption relative to Base Case values are a good indicator of changes in economic welfare.

Investment in all but a few industries is allowed to deviate from its Base Case value in line with deviations in expected rates of return on the industries' capital stocks. In the Zero-emission Scenario, VURM allows for short-run divergences in rates of return from their reference-case levels. These cause divergences in investment and hence capital stocks that gradually erode the initial divergences in rates of return.

Government consumption and fiscal balances

We model public consumption spending by maintaining a fixed ratio of public (federal and state) to private consumption spending in each region. The fiscal balances of each jurisdiction (federal, state and territory) as a share of nominal GDP are allowed to vary relative to Base Case values in line with projected changes in expenditure and income items.

Production technologies and household tastes

VURM contains many variables to allow for shifts in technology and household preferences. In the Zero-Emissions Scenario, most of these variables are exogenous and have the same values as in the Base Case projection. The exceptions are technology variables, used to introduce shocks to the model. For example

- changes in the fuel- and emission- intensity of electricity generation, to mimic the take up of CCS (relevant only to coal generation in Queensland)
- general shifts in input-using technological change required to achieve the reductions in emissions intensity required by the model's emissions response functions; and
- the replacement of gasoline and diesel with cleaner electricity and hydrogen in the provision of passenger and freight transport services.

4 Simulated Effects of Shifting from the Base Case to Zero-Emissions.

4.1 Nature of results

Figure 3 illustrates the interpretation of VURM results for the effects of moving to a zero-emissions economy on a particular variable, e.g., real GDP. VURM generates a base case, which is a projection through time for the variable without the exogenous changes imposed for zero-emissions (i.e., the Base Case Scenario). The value of the variable in the Base Case Scenario is depicted as the path between points A and B. The model is also used to produce an alternative projection in which values for endogenous variables depart from their base case values as they adjust in response to the exogenous shocks describing the interventions needed to achieve zero-emissions. A typical alternative Zero-Emissions Scenario projection for the variable considered in Figure 3 is shown as the path between points A and C.

Figure 3: Nature of Results

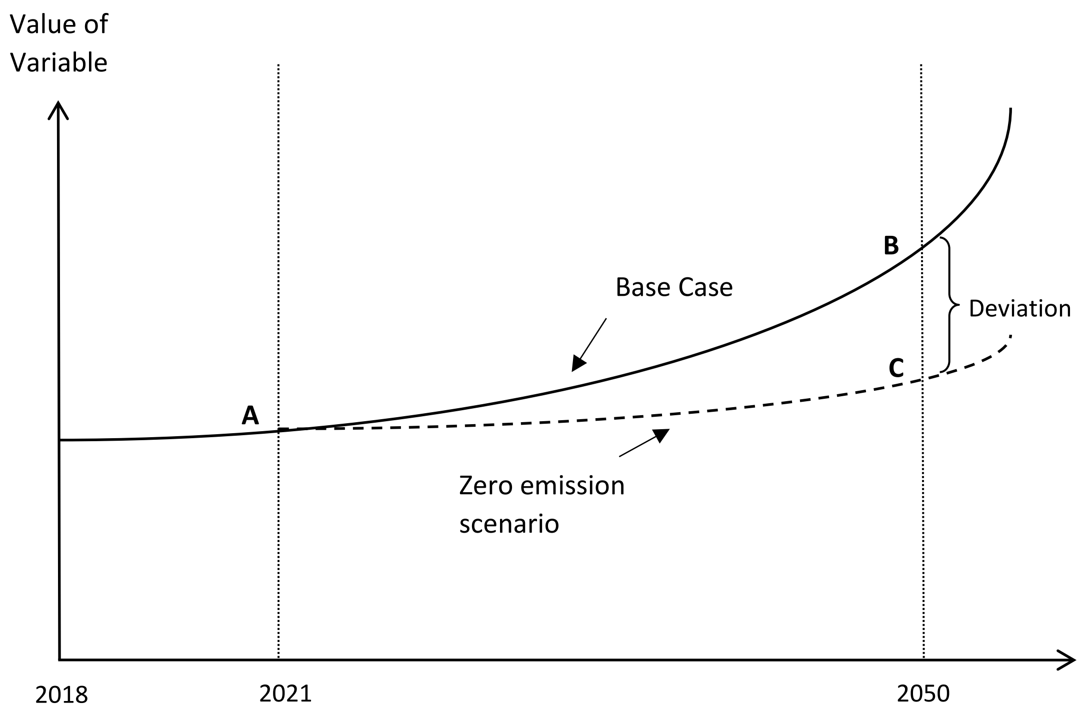


Figure 3 has been drawn with the base case path and the zero-emissions path both smooth and with the deviation of the zero-emissions path from the base case path also growing smoothly. In this case, it is apparent that there are a number of options for reporting the effects of shifting to zero-emissions, all of which will tell a similar story.

One option is to compare average annual growth in the Base Case Scenario (A to B) with average annual growth in the Zero-Emissions Scenario (A to C). Alternatively, deviations can be reported by comparing the value of variables in a specific year in the Zero-Emissions Scenario with values in the Base Case Scenario (C compared to B in 2050, for example). Deviations could be expressed as percentage changes from Base Case values, or as absolute change ($m, Pj, etc.) from Base Case values for any year of the simulation.

In the discussion of results below we use primarily the deviation-from-base approach. The exception is at the start when discussing results for real GDP. In this case, to emphasise a key finding that the macroeconomic consequences are small we compare the projected Base Case path with that for Zero-Emissions. For employment results at the industry and regional levels, in addition to reporting percentage and absolute deviations, we provide levels data for 2021 (point A) and for 2050 without Decarbonisation (B) and with Decarbonisation (C).

4.2 Results

National impacts are discussed first, followed by state and sub-state outcomes. Italicised headings outline the main features of the results.

4.2.1 National macroeconomic variables

Action to achieve zero-emissions has a small negative impact on overall economic activity as measured by real GDP.

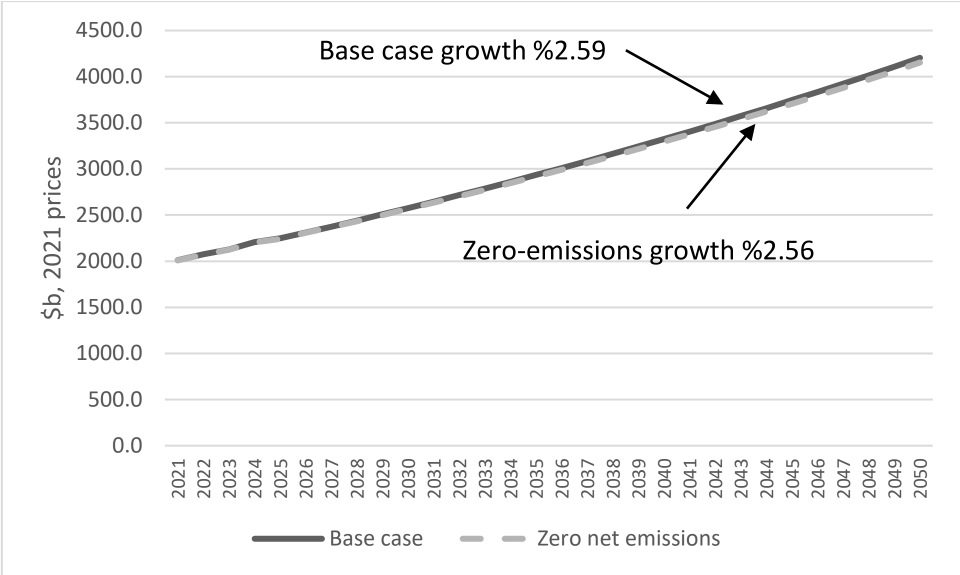
Figure 4 plots projected growth paths for real GDP in the Base Case and Zero-Emissions Scenario. Two things stand out. The first is that the two lines are almost identical. This implies that action to decarbonise the economy will have little impact on growth in real GDP. The second thing is that the Zero-emissions path does fall below the Base Case path, as we move through the projection period.

In quantitative terms, real GDP in the Base Case grows at an average annual rate of 2.59 per cent. In the Zero-Emissions Scenario growth is 2.56 per cent. By 2050, real GDP with Zero-emissions is 1.01 per cent below its Base Case level. This is equivalent to a loss of around $39 billion in 2021 prices.

Pursuing zero-emissions has a small negative impact on real GDP because, as outlined in Section 3.2.1, making emissions costly through an explicit emissions price or some other means such as regulation increases the average unit cost of production. This is due to a number of factors including small allocative efficiency losses, technological regress when relatively costly technologies are adopted, and reductions in relatively profitable activities.

It is of interest to note that last time we evaluated the economic impacts of moving to net-zero emissions (for the 2014 Climate Works report), the loss of real GDP was around 3.8 per cent or nearly $150 billion (2021 prices). The negative GDP result is smaller this time around because the abatement task is easier due, in part, to lower than previously expected renewable generation costs and faster than previously expected penetration of electric vehicles for both light and heavy transport.

Figure 4: Real GDP in the Base Case and Zero-Emissions Scenario ($b, 2021 prices)

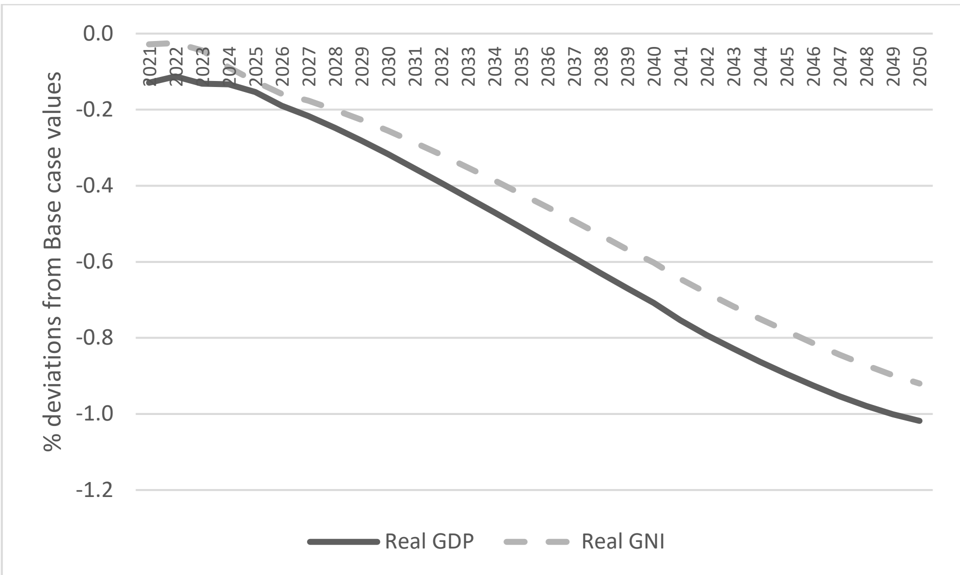


In line with the change in real GDP, a shift to net-zero emissions causes real income generated in the Australian economy (real Gross National Income (GNI)) to fall slightly.

Figure 5 shows projected deviations from Base Case values for real GDP and real GNI. By the end of the period, real GNI is down by 0.92 per cent, compared with the GDP fall of 1.01 per cent. Real GNI falls by less than real GDP because Australia's terms of trade are projected to rise slightly as Australian moves to decarbonise.[x]

The terms of trade rise because the average price that Australia receives for its exports increases. Increased export prices are a result of mild appreciation of the Australian dollar (see below) which causes export volumes to fall and the price at which Australia exports rise as we move up and along downward sloping export demand schedules.

Figure 5: Real GDP and Real GNI (% deviations from Base Case values)



In the short run, action to decarbonise reduces employment relative to its Base-case level. Over time, the employment deviation remains small as the national real wage rate adjusts downwards.

Figure 6a shows the national labour market effects of action to achieve zero net emissions. The effects are shown as percentage deviations away from Base Case values for national employment and the national real wage rate. The latter is defined as the ratio of the nominal wage rate to the price of consumption (the CPI).

According to the labour-market specification in VURM (Section 3.3), the real wage rate is sticky (i.e., the nominal wage moves with the price of consumption) in the first year or two, but adjusts with a lag downwards in response to a fall in employment demand. Initial actions to decarbonise increase the real cost of employing labour and hence induces a fall in employment demand[xi]. If there were no further shocks, over time the real wage rate would progressively fall relative to base case levels, reducing the real cost of employing labour and forcing the national employment rate back to its base-case level. In the Zero-emissions simulation, however, shocks continue with the permit price increasing under a progressively tighter constraint on emissions. Hence as shown in Figure 6a, the employment deviation is never fully eliminated and the real wage rate declines steadily relative to its base-case value. In 2050, the employment deviation is -0.05 per cent, while the real wage rate is down 2.6 per cent and the national participation rate is down 0.01 per cent.

Figure 6b shows employment deviations expressed in terms of annual job numbers. The initial loss of employment is equivalent to around 20,000 jobs. In the final year, action to achieve zero-emissions reduces employment by around 5,500 jobs. It should be stressed, though, that even though the eventual fall in national employment is small, this does not mean that employment at the individual industry or regional level remains close to Base Case values (see below). In most industries and regions, there are significant permanent employment responses to decarbonisation, compounding or defusing existing (base-case) pressures for structural change.

Figure 6a: National Employment and the National Real wage rate (% deviations from Base Case values)

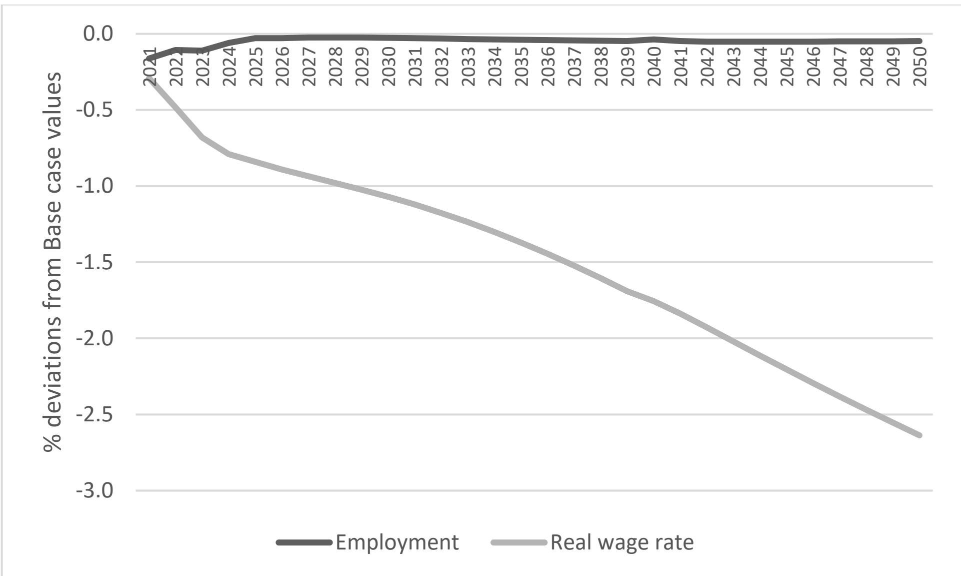
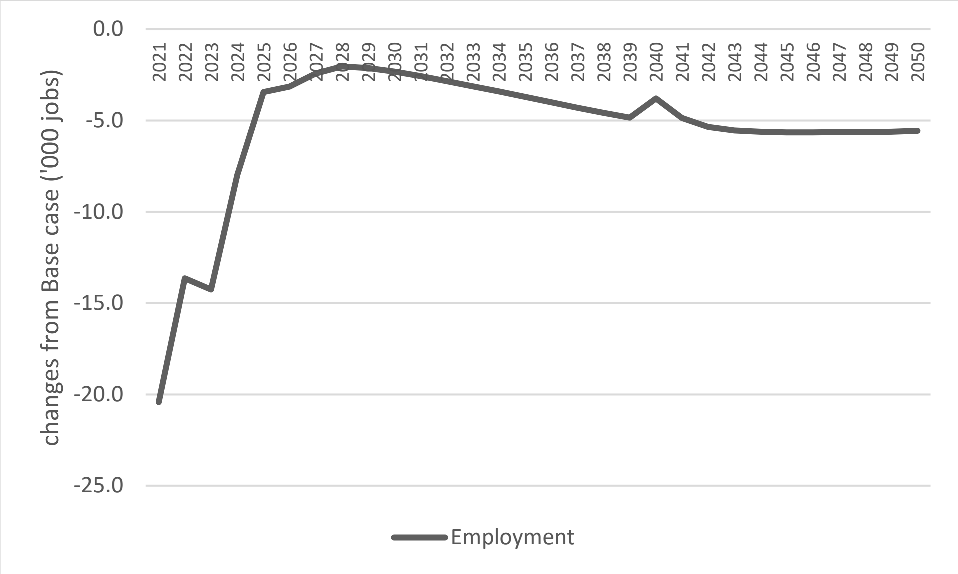


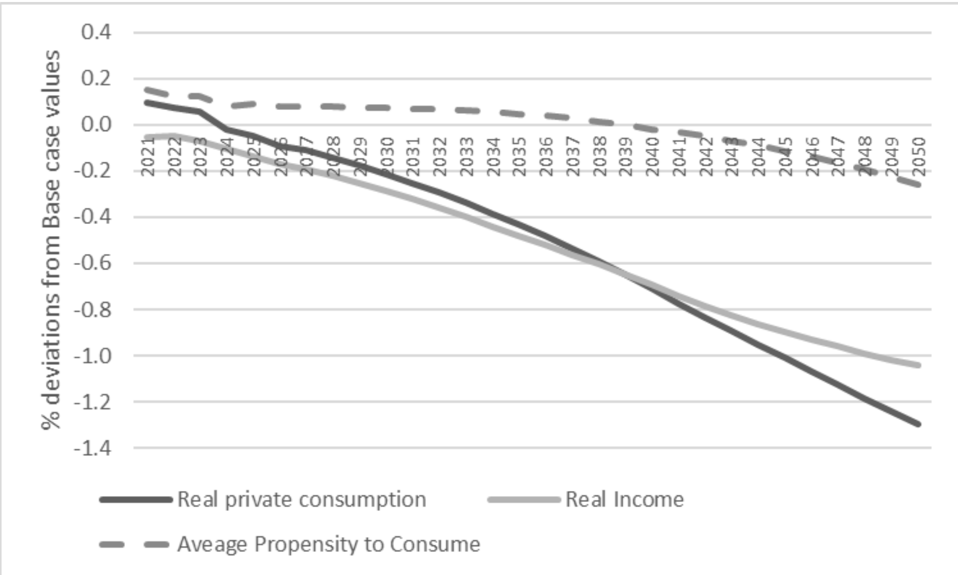
Figure 6b: National Employment
(deviations from Base Case values ('000 jobs))



Action to achieve net-zero emissions reduces real GNI and real private consumption, with the fall in consumption accentuated by a reduction in the Average Propensity to Consume.

Figure 7 shows percentage deviations from Base Case values for real private consumption, real household disposable income (HDI) and the national average propensity to consume (APC). The APC is the ratio of real private consumption to HDI. In 2050, real income is down 1.0 per cent relative to its base-case level (in line with real GDP), and real private consumption is down 1.3 per cent. The difference is due to a fall in the APC of 0.3 per cent.

Figure 7: Real consumption, Real income and Average Propensity to Consume
(% deviations from Base Case values)



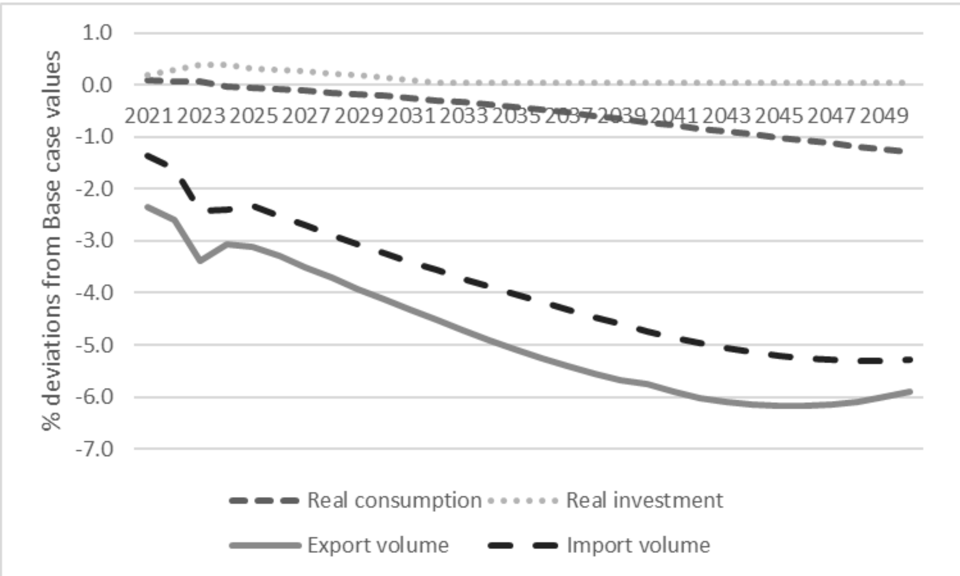
The shift to zero-emissions reduces HDI in line with real GDP. Recall from Section 3.3 that the APC is an endogenous variable, moving to ensure that domestic savings are sufficient to keep the national balance on current account at its Base Case level. To maintain an unchanged balance on current account, domestic savings must increase (the APC must decrease) to accommodate changes in aggregate investment. As will be shown in Figure 8, national investment rises a little over the projection period to accommodate a more capital-intensive economy.

Real domestic final demand (C+G+I) rises relative to real GDP (Y) leading to a fall in the net volume of trade (X-M).

Figure 8 shows percentage deviations from Base Case values for real consumption (C + G), real investment (I), real exports (X) and real imports (M). Deviations in C have already been discussed. Deviations in real public consumption (G) are nearly the same as deviations in real private consumption (see Section 3.3). Deviations in real investment (I) are small but positive, reflecting the greater replacement needs of a slightly more capital-intensive economy. Capital intensity increases due, in the main, to the shift away from petroleum (largely imported) to electricity (a capital intensive domestic industry) to power light and heavy vehicles.

On balance, real gross national expenditure (= C+I+G) rises slightly more than real GDP, implying a small movement in the net volume of trade towards deficit (X-M).[xii] To achieve the necessary fall in the net volume of trade, mild appreciation of the real exchange rate is necessary. This reduces the competitiveness of export industries on foreign markets and the competitiveness of import-competing industries on local markets. In 2050, the real exchange rate is 0.8 per cent above its Base Case value. In that year, imports have fallen by 5.3 per cent partly due to a reduction in petroleum imports. With imports down 5.3 per cent and the net volume of trade required to shift slightly towards deficit, export volumes fall by 5.9 per cent.

Figure 8: Real Expenditure Components of Gross Domestic Product (% deviations from Base Case values)



4.2.2 National industry production and employment

Production in some industries increases relative to Base Case, while production in other industries falls.

Table 3a gives deviations from Base Case values for national production and employment by ANZSIC division in the final year of the simulation period, 2050.[xiii] Percentage deviations in production are shown in the first column. The second and third columns relate to employment. Percentage deviations in employed hours are shown first. Absolute changes in persons employed expressed in units of a thousand are shown second. Note that a change in hours can be accommodated by a mix of changes in the number of persons employed and in hours worked per person. In our modelling, we allow for both. Additional data are shown in Appendix Table 3a for the number of employed persons in 2021 and in 2050 for both scenarios.

There are a number of divisions for which the shift to zero-emissions raises output significantly. The most favourably affected is *Utilities* (division D), with a projected increase in production of 20 per cent relative to Base Case level in 2050. With that increased output comes an employment increase of 5.6 per cent (equivalent to a gain of 5,200 jobs). Other divisions expected to experience increased output, include the service-providers, *Information media* (J), *Financial services* (K), and *Professional* and *administrative services* (M and N). By contrast, *Mining* (B), is projected to have a fall in production relative to Base Case levels of 10.7 per cent. Mining employment is down 8.8 per cent (or 39,100 jobs), but as shown in Appendix Table 3a, even in the Zero-emissions case mining employment in 2050 (446.5 thousand jobs) is well above its level in 2021 (331.5 thousand jobs).

Table 3a: National ANZSIC Divisions – Production and Employment in 2050

	ANZSIC Division	% Deviation in production	% Deviation in employment (hours)	Absolute deviation in employment ('000 persons)
A.	Agriculture, forestry, fishing	0.1	10.8	25.7
B.	Mining	-10.7	-8.8	-39.1
C.	Manufacturing	-2.2	-0.6	14.0
D.	Utilities	20.0	5.6	5.2
E.	Construction	-2.4	-4.8	-51.6
F.	Wholesale trade	-1.6	-1.5	-5.1
G.	Retail trade	-1.8	-2.2	-39.1
H.	Accommodation	-2.6	-2.8	-33.0
I.	Transport	-3.9	0.0	-2.5
J.	Information media	7.3	8.4	11.0
K.	Financial services	1.4	0.9	6.5
L.	Rental services	-1.9	-3.3	-1.9
M.	Professional services	4.1	3.8	58.1
N.	Administrative services	5.1	4.6	27.9
O.	Public administration	-1.2	-1.7	-18.3
P.	Education	0.8	0.4	4.6
Q.	Health	1.5	1.3	27.2
R.	Arts and recreation	-0.4	-1.8	-6.3
S.	Other services	0.9	0.5	10.9
T.	Dwelling ownership	0.9	0.0	0.0

Below, we deal in more detail with the first four divisions, but first we discuss the results for the service divisions (E to T).

Service providers (Divisions E to T)

Construction (E) sells investment related services. Investment overall rises slightly relative to its Base Case level (Figure 8), but the production of construction services is down 2.4 per cent in the final year. At the same time there are 4.8 per cent (or 51,600) fewer construction jobs. A fall in construction output relative to investment points to an increase in share of non-construction inputs (primarily equipment) in the overall investment requirement of the economy.

Wholesale Trade (F) and *Retail Trade* (G) sell widely through the economy. Thus both are expected to experience mild contractions in output and employment in line with the reduction in real GDP. For wholesale trade, in 2050 relative to Base Case values production is down 1.6 per cent and employment is down 1.5 per cent (or 5,100 jobs). Retail trade activity is reduced a little more reflecting its reliance on consumption demand which falls by slightly more than real GDP (see Section 4.2.1). Production of retail trade services falls by 1.8 per cent relative to Base Case values, with employment demand down 2.2 per cent (or 39,100 jobs).

Accommodation (H) comprises industries that produce hotel, restaurant and food services. It has a significant export share, reflecting sales in Australia to foreign visitors. As noted in Section 4.2.1, decarbonisation increases the real value of the Australian exchange rate, which reduces the competitiveness of internationally traded industries. Thus, the accommodation division is projected to experience a fall in production (2.6 per cent) primarily due to reduced sales to overseas visitors. With production down, so is employment – 2.8 per cent or 33,000 jobs.

Transport (I) sells road, rail, air and water transport services for passenger transport and freight. Our modelling includes all four modes, all of which other than rail are projected to have lower production and employment relative to Base Case levels. This reflects a number of factors. The first is the increased cost of petroleum products, which increases the cost of all transport services and induces rapid uptake of electric-powered vehicles. Despite electrification, the price of transport services remains above Base Case levels through the projection period, supressing demand. A second factor is that with the cost of private road transport rising, there is a switch towards public transport especially in the large urban areas. This switch favours rail over road. A third and final factor is that the air transport industry does not have access to the same abatement technologies as other sources of transport; there is no prospect of replacing jet fuel with electricity, for example. Consequently, the emissions prices increase the cost of air transport by more than road transport causing substitution away from air and to road for domestic transport needs. Overall, in 2050 transport production falls by 3.9 per cent relative to its Base Case level, with employment virtually unchanged.

Information media (J) produces telecommunication services. Its production rises 7.3 per cent relative to Base Case values, with employment up 8.4 per cent, or 11,000 jobs. The explanation here, is not dissimilar to the reason for a sharp uptake in telecommunication services during COVID-19 lockdowns. During lockdown, individuals are limited in their movement and so there is greater reliance on telecommunication services for streaming media, conferencing, etc. In a similar way, the shift to zero-emissions results in a reduction in use of physical transport (see above). To compensate, individual and businesses use more telecommunication services. Hence, production and employment levels in *Information media* increase significantly relative to Base Case levels.

Financial services (K) produces products sold throughout the economy and faces relatively little international competition. It output and employment is projected to rise relative to Base Case levels in 2050 by 1.4 per cent and 0.9 per cent (6,500 jobs). The reason is subtle and has to do with the demise of coal and gas electricity generation (and to some extent that of coal mining), and the rise of renewable generation. The coal and gas industries are operated by a few large companies. By contrast the renewable generation sector comprises a large number of small operators. Large companies require less externally provided financial services than do small companies. Hence, as shown in Table 3a, production and employment of *Financial services* rises relative to Base Case values.

Professional and *administrative services* (M and N) provide legal, real estate, accounting and other business services. Both divisions are projected to experience relatively significant expansions in output due to decarbonisation. On average, in 2050 production rises by 4.3 per cent and employment by 4.1 per cent (or 81,000 jobs). One contributing factor is like that affecting financial services: these divisions gain from an overall increase in the number of businesses. Another factor is that they have low levels of direct and indirect greenhouse gas emissions. Hence, relative to Base Case levels their price falls relative to other products, leading to favourable substitution effects in household and government demand.

Rental (non real-estate), *Public administration*, etc. (L, O-T) are the remaining service divisions. All have similar profiles – largely non-traded and hence dependent on local demand (education aside), and with little direct or indirect exposure to emission price cost increases. Production in these sectors is projected to change, relative to Base Case values, by between 1.5 per cent and -1.9 per cent with employment effects in line with the output changes.

Despite some divisions employing fewer people in 2050 with Zero-emissions, employment growth between 2021 and 2050 in every division is affected little by the shift to Zero-emissions. This can be seen by the levels data in Appendix Table 3a. The largest negative percentage deviation is for *Rental services* (division L), yet its employment level rises from a current level of 45.9 thousand to 70.8 thousand in the Base Case or 68.9 thousand in the Zero-Emissions Scenario.

Agriculture, Mining, Manufacturing and Utilities

Table 3b relates to the first four divisions – *Agriculture, forestry and fishing* (A), *Mining* (B), *Manufacturing* (C) and *Utilities* (D). It shows the same information as in Table 3a, but with detail for the VURM industries that comprise each of the Divisions. For example, for *Agriculture, forestry and fishing* we provide deviations in output and employment in 2050 for ten separate VURM industries. Additional data are shown in Appendix Table 3b for the number of employed persons in 2021 and in 2050 under both scenarios.

Agriculture, forestry, fishing (A) overall has little change in production relative to Base Case values, through the change in its employment is more significant (up 10.3 per cent, or 25,700 jobs). These outcomes result from general reduction in agriculture and fishing, offset by a significant expansions in *Forestry and logging* (industry 9) and *Agricultural services* (10). The emissions price effectively subsides bio-sequestration activities (see Section 3.2.4) which allows production of forest and logging to expand by 92.6 per cent in 2050 relative to Base Case levels, raising employment by nearly 160 per cent (or 16,500 jobs). Significant increases in activity also occurs in agricultural services, reflecting agriculture's efforts to employ new abatement technologies, including precision agriculture techniques and animal treatments to supress methane emissions. The general contractions in farming (industries 1-7) reflects, in the main, two factors. The first is a loss of farming land to forestry production (see Section 3.2.4). The second is a reduction in farming exports arising from real appreciation of the currency and the direct cost effects of emissions pricing that cannot easily be passed on to international customers. Though employment in farming overall is lower in the Zero-Emissions Scenario compared to the Base Case, Appendix Table 3b shows that no industry experiences a fall in employment relative to 2021 levels. Indeed, between 2021 and 2050 agricultural employment rises by around 200 thousand jobs in the Zero-Emissions Scenario.

Mining (B) industries are projected to experience falls in production across the board. Overall, production is down 10.7 per cent relative to Base Case levels and employment falls by 8.8 per cent (39,100 jobs). *Coal* production is projected to fall by 34 per cent compared to its Base Case level. The imposition of Zero emission policies almost eliminates domestic demand for coal used in electricity generation and metal (mainly steel) production, while exports, which contributes around 85 per cent to overall demand, is down 33 per cent (see Section 3.2.5). These projections are somewhat sanguine when compared to the dire predictions of some coal-industry representatives. In terms of average annual growth in production, our projections imply a reduction from 1.6 per cent in the Base Case to virtually nothing in the Zero-Emissions Scenario. The key factor underlying this outcome is uptake of clean-coal technologies for electricity generation outside of Australia. These include Carbon Capture and Storage (CCS) particularly in China. With Chinese and Indian demand for coal likely to remain strong, we project that Australia will continue to export coal even with a global shift to net zero-emissions. Appendix Table 3b shows what happens to the level of coal employment between 2021 and 2050. In 2021 the coal industry employs 74.3 thousand persons. In the Base Case that number rises to 87.6 thousand by 2050. In the Zero-emissions case, employment drops to 63.3 thousand.

Reductions in *Petroleum refinery products* (industry 27) account for the fall in *Oil mining* (12) production and employment. *Gas mining* (13) is projected to experience a 33.6 per cent reduction in output in 2050 relative to Base Case values, with employment down by nearly fifty per cent (4,800 jobs). The domestic market for gas contracts due to a reduction in gas-fired electricity and technological shifts away from gas towards electricity for industrial and residential heat. Contractions in export demand account for the production and employment falls (relative to Base Case values) in other mining industries apart from *Mining support services* (18). Support services is relatively dependent on coal industry demand, and thus experiences above-average negative deviations in production and employment in line with the significant falls projected for coal activity relative to baseline.

Projected changes for *Manufacturing* (C) industries show a mix of outcomes. For example, there is a significant increase in production of *Wood products* (industry 25). Wood production in 2050 is up 79.4 per cent relative to Base Case values, with employment up 62.7 per cent (40,200 jobs). Production rises off the back of the expansion in *Forestry and loggin*g. Wood products is the main downstream industry, taking the additional forest product and converting it into timber for export and domestic use.[xiv] In our modelling domestic timber use rises strongly as a result of a technological shift away from steel in construction.

In contrast, significant contractions in output are projected for *Petroleum and refinery products* (27), *Iron and steel products* (30), and *Alumina refining* (31). Petroleum demand dips in the Zero-Emissions Scenario due to vehicle electrification (see Section 3.2.3). A technical shift against the use of steel in construction is the main factor behind steel's loss of production and employment. Alumina is very energy-intensive and trade exposed. Real appreciation and an increase in the cost of energy reduces the competitiveness of this industry on world markets, cutting exports, production and employment. By the end of the period, relative to Base Case values production of alumina is down 10.8 per cent and employment has been reduced by 8.5 per cent (2,500 jobs).

Appendix Table 3b shows that in the Zero-Emissions Scenario employment grows in all industries, with the exception of petroleum products. For petroleum, employment between 2021 and 2050 is largely stagnant.

Utilities (D) comprises industries that generate and distribute electricity, and industries which supply urban gas and provide water, drainage and waste services. Overall, production of utilities in 2050 rises 20.0 per cent relative to Base Case values. Hours worked is up 5.6 per cent, resulting in 3,500 additional jobs.

Table 3b: National Industries in Divisions A-D – Production and Employment in 2050*

Division/Industry	% Deviation in production	% Deviation in employment (hours)	Absolute deviation in employment ('000 persons)
A. Agriculture, forestry, fishing	*0.1*	*10.8*	*25.7*
1. Sheep and Beef cattle	-6.7	-5.0	-3.2
2. Grains production	-12.3	-5.3	-1.6
3. Dairy cattle	-2.5	4.0	1.4
4. Other crop production	-4.3	6.3	5.8
5. Sugar cane production	-4.3	9.3	0.3
6. Raw cotton and ginning	-1.6	1.9	0.0
7. Other Agriculture	-2.1	3.7	1.5
8. Fishing, hunting and trapping	-2.0	5.9	0.5
9. Forestry and logging	92.6	159.5	16.5
10. Agricultural services	14.5	16.3	4.5
B. Mining	*-10.7*	*-8.8*	*-39.1*
11. Coal mining	-34.2	-37.1	-24.3
12. Oil mining	-20.4	-35.5	-1.8
13. Gas mining	-33.6	-48.9	-4.8
14. LNG production	-4.7	-3.4	-1.1
15. Iron ore mining	-0.2	5.8	4.4
16. Non-ferrous metal ore mining	-5.6	0.5	0.4
17. Non-metallic ore mining	-2.6	1.0	0.2
18. Mining support services	-11.8	-14.5	-12.1
C. Manufacturing	*-2.2*	*-0.6*	*14.0*
19. Meat products	-4.7	-5.2	-4.2
20. Dairy products	-2.7	-1.9	-0.4
21. Refined sugar processing	-3.8	-3.8	-0.7
22. Other food products	-1.7	-0.7	-0.8
23. Beverages and tobacco	-0.7	-0.6	-0.2
24. Textiles, clothing and footwear	-2.0	-2.5	-1.2
25. Wood products	79.4	62.7	40.2
26. Pulp and paper products	1.2	-1.6	-1.1
27. Petroleum refinery products	-57.9	-50.1	-7.0
28. Other chemical products	-3.8	2.3	3.1
29. Non-metallic mineral products	-2.5	-1.3	-0.3
30. Iron and steel products	-7.9	1.7	0.6
31. Alumina refining	-10.8	-8.5	-2.5
32. Aluminium smelting	0.5	-2.2	0.0
33. Other non-ferrous metals	-7.9	-5.4	-4.2
34. Motor vehicles and parts	0.2	0.3	0.2
35. Other transport equipment	-1.8	-2.4	-0.9
36. Other manufacturing	-0.7	-3.2	-6.6
D Utilities	*20.0*	*5.6*	*5.2*
37. Generation - coal	-98.6	-98.6	-14.6
38. Generation - gas	-92.1	-93.3	-9.1
39. Generation - hydro	23.5	22.1	0.6
40. Generation – other renewable	245.0	250.4	37.3
41. Electricity supply	42.5	6.8	2.5
42. Gas supply	-62.3	-70.7	-13.1
43. Water and drains	0.8	2.2	1.7

* Shown in red are industries that we regard as particularly vulnerable to a zero emission policy based on percentage reductions in production (relative to Base Case values) of more than 10 per cent.

Three industries are very favourably affected in the pursuit of zero-emissions: *Electricity generation – hydro* (industry 39), *Electricity generation - other renewable* (40) and *Electricity supply* (41). The first two are favoured by the emissions price which causes substitution in favour of these industries at the expense of high-emissions *Electricity generation – coal* (37) and *Electricity generation – gas* (38). Employment in the generation industries rises in total by around 9,000 jobs. The electricity supply industry distributes electricity to final customers. Its production rises strongly because of a shift in energy demand to electricity for a range of industrial and household processes and for vehicle power. *Gas supply* (42), which provides town gas services, is projected to experience a cut in production due to substitution away from natural gas as a source of heat.

Ten industries are identified as being vulnerable on the basis of projected losses in production and employment

The projections in Tables 3a and 3b help us to identify industries that are most vulnerable to policies directed at net-zero emissions. We can assess vulnerability in a number of ways, but perhaps the most useful is based on projected percentage changes in production. We classify vulnerable industries as ones having projected falls in production of 10 per cent or more.

Based on this criteria, there are ten vulnerable industries:

2. Grains production
11. Coal mining
12. Oil mining
13. Gas mining
18. Mining support services
27. Petroleum refining products
31. Alumina refining
37. Electricity generation – coal
38. Electricity generation – gas
42. Gas supply.

No individual industries within the service divisions meets the vulnerable criteria.

4.2.3 National Emissions

National emissions from all sources fall

Tables 4a to 4c show information for national greenhouse gas emissions compiled according to the United Nations Framework Convention on Climate Change (UNFCCC) standard. Table 4a shows emission levels in the Zero-emission Scenario for the years 2022, 2030, 2040 and 2050. Table 4b shows percentage changes from Base Case values and Table 4c absolute change for each of the four years. Similar information is available at the state and Territory level but is not reported here for sake of brevity.

Domestic emissions from stationary energy and fugitive sources deliver the bulk of the overall abatement in 2050. Emissions from stationary energy are down 355.8 Mt relative to their Base Case levels, with emissions from electricity generation cut by 257.2 Mt, and emissions from other forms of direct combustion falling by 98.6 Mt. Fugitive emissions are down by 96.8 Mt.

All of the emission reductions outside of electricity and transport occur *via* reductions in the output of the relevant emitting industry or reductions in emissions intensity brought about by the price-responsive mechanisms outlined in subsection 3.2.1. The fall in agricultural emissions is due, in the main, to projected drops in Enteric fermentation gases from 49 Mt in 2021 to 21 Mt in 2050, and a fall in agricultural soil emissions to from 14 Mt to -5 Mt.[xv] The abatement from stationary energy and transport is achieved *via* industry activity effects, fuel switching and technology changes.

Table 4a: National Greenhouse Gas Emissions
(Levels (Mt CO_2-e) in Zero-Emissions Scenario)

		2022	2030	2040	2050
1.	Energy sector, total	401.3	255.7	142.8	49.4
2.	Fuel combustion	349.2	217.1	116.8	41.4
3.	Stationary	264.5	144.0	63.4	25.4
4.	Electricity	190.9	80.0	10.1	7.4
5.	Other	73.7	63.9	53.3	18.0
6.	Transport	84.6	73.1	53.4	16.0
7.	Fugitive emissions from fuels	52.1	38.6	25.9	8.0
8.	Industrial processes	31.1	29.8	28.6	20.5
9.	Agriculture	61.3	49.3	36.9	19.2
10.	Waste	11.4	9.4	7.1	6.9
11.	Land Use, land use change and forestry	-20.3	-24.2	-52.0	-96.0
12.	Total	484.8	320.0	163.4	0.0

Table 4b: National Greenhouse Gas Emissions
(% deviations from Base Case values)

		2022	2030	2040	2050
1.	Energy sector, total	-5.5	-47.7	-75.2	-89.4
2.	Fuel combustion	-4.6	-48.1	-76.0	-89.8
3.	Stationary	-2.5	-52.8	-81.8	-91.2
4.	Electricity	0.0	-61.9	-95.7	-97.3
5.	Other	-8.3	-32.7	-52.1	-78.6
6.	Transport	-10.7	-35.1	-61.5	-86.5
7.	Fugitive emissions from fuels	-11.3	-45.5	-71.0	-87.5
8.	Industrial processes	-7.4	-28.0	-48.0	-66.0
9.	Agriculture	-10.3	-39.3	-63.9	-82.2
10.	Waste	-7.2	-30.8	-53.3	-72.8
11.	Land Use, land use change and forestry	3.0	17.0	40.2	72.8
12.	Total	-6.6	-47.1	-74.7	-90.7

Table 4c: National Greenhouse Gas Emissions
(absolute (Mt CO_2-e) deviations from Base Case values)

		2022	2030	2040	2050
1.	Energy sector, total	-23.4	-233.1	-433.9	-596.0
2.	Fuel combustion	-16.8	-200.8	-370.2	-499.2
3.	Stationary	-6.7	-161.3	-285.0	-355.8
4.	Electricity	0.0	-130.3	-227.0	-257.2
5.	Other	-6.7	-31.0	-58.0	-98.6
6.	Transport	-10.1	-39.6	-85.2	-143.4
7.	Fugitive emissions from fuels	-6.7	-32.3	-63.7	-96.8
8.	Industrial processes	-2.5	-11.6	-26.3	-47.1
9.	Agriculture	-7.1	-32.0	-65.3	-103.2
10.	Waste	-0.9	-4.2	-8.1	-12.4
11.	Land Use, land use change and forestry	-0.6	-3.5	-9.0	-17.6
12.	Total	-34.5	-284.3	-542.7	-776.3

4.2.4 State variables

Real gross state product falls relative to Base Case in all states/territories, except TAS and SA.

Figure 9 shows projected percentage deviations from base-case levels for Real Gross State product (GSP). Percentage deviations in production and employment (hours) in 2050 are given in Table 5. Table 5 also shows the absolute chance in employment of persons in 2050 expressed in units of '000 persons. Additional data are shown in Appendix Table 5 for state levels of employed persons in 2021 and in 2050 under both scenarios.

Figure 9: Real Gross State Product
(% deviations from Base Case values)

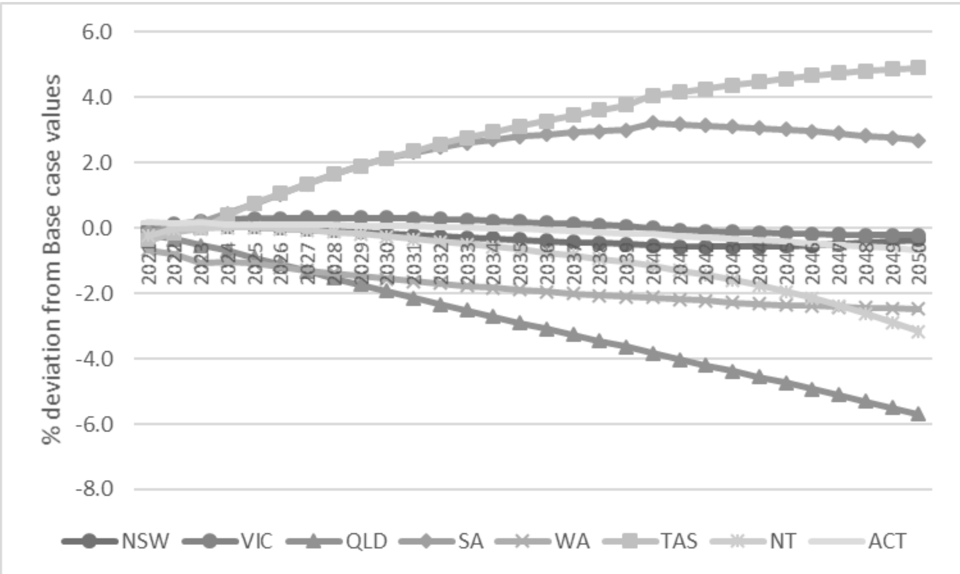


Table 5: States and Territories – Production and Employment in 2050

State/Territory	% Deviation in real GSP	% Deviation in employment (hours)	Absolute deviation in employment ('000 persons)
New South Wales	-0.3	0.9	43.6
Victoria	-0.2	1.1	41.8
Queensland	-5.9	-3.8	-97.8
South Australia	2.6	2.3	21.9
Western Australia	-2.5	-1.5	-25.0
Tasmania	4.9	4.2	11.6
Northern Territory	-3.5	-0.7	-1.2
Australian Capital Territory	-0.7	-0.2	-0.6

The pattern of impacts on real GSP reflects the industry effects of decarbonisation. Just as some industries experience output gains relative to the Base Case and some industries experience output loss, so some states and territories experience output gain and others output loss, with differences between regions explained by the differences in the industrial compositions of the regions.

Queensland has an over-representations of *Agriculture, Coal mining,* and *Electricity generation - coal*, which is the main reason why decarbonisation is expected to reduce its share in the national economy. In 2050, Queensland is projected to have a real GSP 5.9 per cent lower than in the Base Case. Employment is down 3.8 per cent which translates into almost 100,000 fewer persons employed. Appendix Table 5 provides another perspective on the 2050 employment loss in Queensland. In 2021, QLD employment totals 2,455 thousand. In the Base Case, that increases to 3,628 thousand in 2050 – a gain of around of almost 1.2 million jobs. In the Zero-Emissions Scenario, the gain is around 1.1 million jobs.

The Northern Territory is also projected to experience a contraction in output – down 3.5 per cent relative to Base Case levels in 2050. The main negative for the NT is an over-representation of gas mining and LNG manufacturing and on emission-intensive livestock agriculture. A similar story applies to Western Australia, where real GSP is projected to fall by 2.5 per cent and employment by 1.5 per cent (or 25,000 jobs) relative to Base Case values.

By contrast, Tasmania does not have coal fired generation, or gas and coal mining. It is over-represented in hydroelectricity, forestry and wood products. Thus, it is no surprise that real GSP and employment should expand in that state. According to Table 5, real GSP in Tasmania will be up 4.9 per cent relative to Base Case levels in 2050, with employment expanding 4.2 per cent and generating an additional 11,600 jobs. South Australia has a relatively large forestry sector and an over-representation of non-hydro renewable generation. These positives offset its reliance on the contracting gas industry allowing state-wide real GSP and employment to expand significantly. As shown, real GSP in SA is projected to rise 2.6 per cent relative to Base Case in 2050, with employment up 2.3 per cent or 21,900 jobs.

The ACT is the capital territory of Australia. Its economy is almost entirely service oriented and therefore its production and employment tend to follow the Australia-wide average for real consumption.

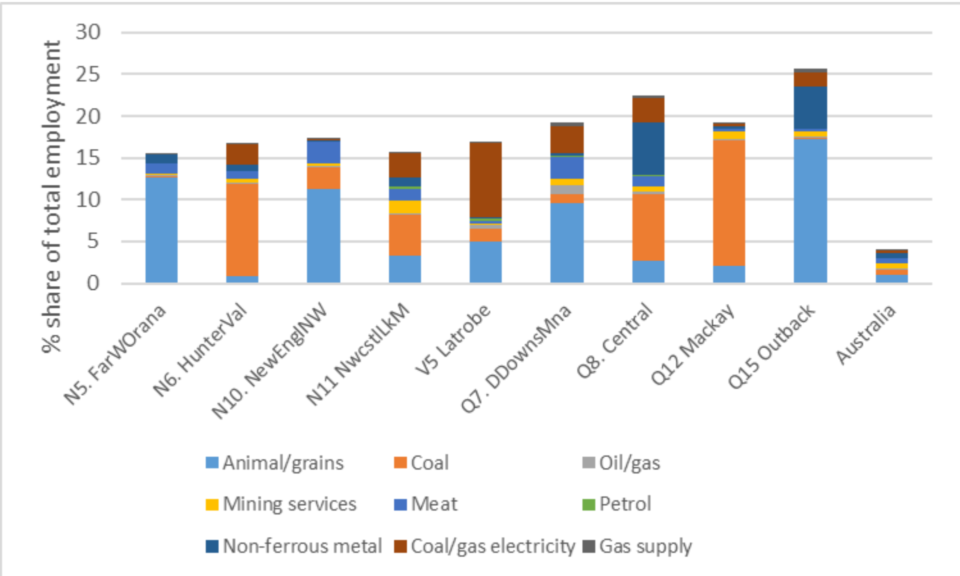
The two largest states, New South Wales and Victoria, are affected by decarbonisation in similar ways. Real GSP in NSW (VIC) falls by 0.3 per cent (0.2 per cent) relative to Base Case, while employment is up slightly in both cases. These outcomes are a little surprising, especially given that both economies have relatively large coal and coal generation sectors at the start of the period. The answer lies, in part, with what happens to electricity. Victoria's reliance on coal generation falls away quickly in both the Base Case and Zero-Emissions Scenario, and it expands more than proportionately its reliance on renewable generation. In NSW, generation from coal is eliminated in the Zero-Emissions Scenario by 2040, though it continues to produce coal for export. It also picks up a more than proportional increase in non-renewable generation. In both cases, increases in non-hydro renewable generation are above the national average uptake primarily due to their large population base giving rise to strong growth in roof-solar capacity. Overall, both states gain relative to the national average as their uptake of new renewable electricity capacity expands faster than the national average.

4.2.5 Sub-state results

Projected changes in real gross regional product (GRP) and employment relative to Base Case values for all 88 SA4 sub-state regions in 2050 are given in Table 6. Additional data are shown in Appendix Table 3a for the number of employed persons in 2021 and in 2050 under both scenarios.

As explained in Section 2.2, the sub-state results rely on a database showing gross value added and employment by industry and region. An extract of the data is given in Figure 10. The extract refers to ten industries (before aggregation for the chart) that are particularly vulnerable to zero emission policies and to nine regions in which the ten industries in total account for relatively large shares of gross product or employment. As a benchmark, we show in the last bar of the figure the industries' shares in aggregate national employment. For Australia as a whole, the ten vulnerable industries account for less than 4 per cent of aggregate employment. However, some sub-state regions are much more heavily dependent on these industries. Hence, we should expect that these regions will be much more vulnerable to decarbonisation policies than is the Australian economy overall.

Figure 10: Employment by Selected Industry and SA4 Region in 2021



Nine vulnerable sub-state (SA4) regions can be identified.

We assume that a region is particularly vulnerable to decarbonisation if the share of vulnerable industries (identified above) in the region's total employment is greater than 15 per cent. The vulnerable SA4 regions identified in red lettering in Figure 10 are:

N5 Far West and Orana

N6. Hunter Valley (ex. Newcastle)

N10. New England and North West

N11. Newcastle and Lake Macquarie

V5 Latrobe - Gippsland

Q7. Darling Downs – Maranoa

Q8. Central Queensland

Q12 Mackay – Isaac – Whitsunday

Q15. Queensland – Outback.

Note that although these regions are vulnerable, as shown in Appendix Table 6 in all cases employment grows between 2021 and 2050 in the Zero-Emissions Scenario

One issue that arises in presenting sub-state regional employment results is the issue of scale: some regions are small while others are large. However, scale is unimportant if the results are presented as percentage deviations between the level of employment attained with decarbonisation in the Zero-Emissions Scenario and the Base Case level of employment. For example, we might identify a region for which decarbonisation has a large adverse *percentage* effect but which is very small so that the effect of the policy is small in terms of overall numbers employed. In such a case, although the shift to Zero-emissions has a large effect from the point of view of the particular region, the significance of the effect from a wider (e.g., national or state) point of view would be small. An implication would be that any adjustment policy necessary to assist the region to cope with the effects of the policy might be manageable.

The scale issue is dealt with by reporting in Table 6 the regional employment effects of moving zero-emissions in two ways: as percentage deviations from Base-case values and as absolute changes in the number of jobs. Our understanding of the scale issue is also assisted by the levels data in Appendix Table 6.

*Table 6: SA4 Regions – Production and Employment in 2050**

SA4 Region	% Deviation in real GSP	% Deviation in employment (hours)	Absolute deviation in employment ('000 persons)
N1. Region near ACT	2.2	2.6	3.4
N2. Central Coast	0.6	-2.5	-4.3
N3. Central West	0.3	1.6	2.0
N4. Coffs harbour	3.8	15.2	10.1
N5. Far West and Orana	1.0	0.5	0.3
N6. Hunter valley (ex. Newcastle)	-5.7	-15.2	-22.2
N7. Illawarra	0.6	-2.3	-4.1
N8. Mid-north coast	3.7	4.9	4.1
N9. Murray	0.7	2.2	1.5
N10. New England and North West	-0.1	-1.4	-1.4
N11. Newcastle and Lake Macquarie	-0.8	-7.0	-14.6
N12. Richmond-Tweed	2.0	4.5	5.4
N13. Riverina	3.4	8.8	9.0
N14. Southern Highlands	1.0	-3.5	-2.3
N15. Sydney - Baulkham hills	1.6	2.7	4.4
N16. Sydney - Blacktown	1.5	1.2	2.6
N17. Sydney - City and Inner South	1.5	2.4	7.5
N18. Sydney - Eastern Suburbs	1.6	3.8	8.3
N19. Sydney - Inner South West	1.0	0.2	0.8
N20. Sydney - Inner West	1.5	2.4	5.5
N21. Sydney - North Sydney and Hornsby	1.6	4.1	13.5
N22. Sydney - Northern Beaches	1.5	2.4	4.6
N23. Sydney - Outer South West	1.1	0.3	0.6
N24. Sydney - Outer West	1.3	0.7	1.4
N25. Sydney - Parramatta	1.4	0.7	1.9
N26. Sydney - Ryde	1.8	2.5	3.3
N27. Sydney - South West	1.2	1.4	2.8
N28. Sydney - Sutherland	1.3	-0.2	-0.3
V1. Ballarat	3.8	5.4	5.6
V2. Bendigo	2.6	1.5	1.3
V3. Geelong	0.1	-0.3	-0.5
V4. Hume	4.6	10.1	10.5
V5. Latrobe - Gippsland	-6.0	-5.0	-7.4
V6. Melbourne - Inner	1.9	2.9	16.4
V7. Melbourne - Inner East	1.6	2.2	5.8
V8. Melbourne - Inner South	1.6	1.8	5.3
V9. Melbourne - North East	1.4	0.0	-0.2
V10. Melbourne - North West	1.1	-1.0	-2.3
V11. Melbourne - Outer East	0.9	-0.2	-0.7
V12. Melbourne - South East	1.1	0.3	1.2
V13. Melbourne - West	0.7	-1.4	-6.3
V14. Mornington Peninsula	2.7	2.1	3.6
V15. North West	1.3	4.1	3.4
V16. Shepparton	1.6	3.1	2.2
V17. Warrnambool and South West	3.5	4.5	3.9

*Table 6 (continued): SA4 Regions – Production and Employment in 2050**

SA4 Region	% Deviation in real GSP	% Deviation in employment (hours)	Absolute deviation in employment ('000 persons)
Q1. Brisbane - East	-5.7	-5.7	-8.1
Q2. Brisbane - North	-3.1	-2.9	-4.2
Q3. Brisbane - South	-3.4	-2.2	-5.0
Q4. Brisbane - West	-3.1	-0.7	-0.9
Q5. Brisbane - Inner	-3.8	-1.7	-3.7
Q6. Cairns	-2.4	-1.4	-1.9
Q7. Darling Downs - Maranoa	-9.0	-7.1	-4.2
Q8. Central Queensland	-10.9	-15.2	-22.5
Q9. Gold Coast	-3.2	-3.1	-10.0
Q10. Ipswich	-3.7	-3.3	-5.7
Q11. Logan - Beaudesert	-3.9	-3.4	-5.9
Q12. Mackay - Isaac - Whitsunday	-10.6	-16.9	-18.1
Q13. Moreton Bay - North	-3.6	-1.7	-2.0
Q14. Moreton Bay - South	-3.2	-2.2	-2.8
Q15. Queensland - Outback	-6.6	-3.7	-1.9
Q16. Sunshine Coast	-3.5	-3.6	-6.1
Q17. Toowoomba	-3.8	-4.4	-3.2
Q18. Townsville	-2.3	-2.1	-2.9
Q19. Wide Bay	-3.2	3.0	3.2
S1. Adelaide - Central and Hills	3.5	3.3	5.9
S2. Adelaide - North	1.8	-1.3	-3.0
S3. Adelaide - South	2.4	-1.1	-2.3
S4. Adelaide - West	1.6	-4.1	-5.8
S5. Barossa - Yorke - Mid North	9.4	9.6	5.4
S6. South Australia - Outback	7.6	8.2	3.6
S7. South Australia - South East	13.0	17.9	18.0
W1. Bunbury	-1.7	-5.6	-6.1
W2. Mandurah	-1.8	-4.2	-2.7
W3. Perth - Inner	-0.9	-0.2	-0.2
W4. Perth - North East	-0.4	-1.0	-1.6
W5. Perth - North West	-0.6	-1.4	-4.4
W6. Perth - South East	-0.4	-1.3	-4.1
W7. Perth - South West	-1.6	-3.0	-8.0
W8. Western Australia - Wheat belt	0.9	4.1	3.0
W9. Western Australia – Outback (North)	-0.8	-0.3	-0.3
W10. Western Australia - Outback (South)	-1.0	-0.5	-0.4
T1. Hobart	5.8	-1.5	-1.6
T2. Launceston and North East	10.0	7.3	5.3
T3. South East	10.0	12.8	3.5
T4. West and North West	8.9	6.4	4.4
NT1. Darwin	-2.8	0.0	0.0
NT2. Northern Territory - Outback	-1.1	-3.2	-1.3
A1. ACT	-0.1	-0.2	-0.6

* Shown in red are regions that we regard as particularly vulnerable to a zero emission policy based on the share of vulnerable industries of greater than 15 per cent.

5 Concluding Remarks

The information reported in this paper will be useful for all policy makers and thought-leaders in the private sector, but especially for those with responsibilities for:

- Workforce training;
- Industrial and regional development;
- Urban infrastructure planning;
- Adjusting portfolios of equity investments; and
- Ecological and environmental management

Key findings are as follow.

1. Despite the requirement for deep cuts in emissions, Australia's real GDP falls by only just over 1.0 per cent in 2050 relative to its Base Case level. Indeed, in terms of average annual growth, in the Zero-Emissions Scenario real GDP grows at a rate barely discernable from growth in the Base Case.
2. The negative impact on real household consumption, which is the preferred measure of national welfare, is a little greater than the negative effect on real GDP reflecting a mild terms of trade deterioration. Relative to its base-case level real household consumption is down by 1.3 per cent in 2050.
3. While the national macroeconomic impacts of decarbonisation are modest in the context of the policy task, this does not carry through to the industry and regional levels.
4. Relative to Base Case, there are a number of industries for which decarbonisation significantly raises output in percentage terms. The most favorably affected industries produce forest and wood products and generate renewable electricity.
5. Adversely affected industries include fossil-fuel generators, the coal and oil sectors and parts of agriculture.
6. The pattern of impacts on Australian regions in 2050 reflects the industry effects of decarbonisation. At the state/territory level, Queensland is the most adversely affected region, due to an over representation of coal and coal-fired generation, and Tasmania is the most favorably affected, due to the importance of forestry and hydro generation.
7. 9 out of 88 sub-state (SA4) regions are identified as particularly vulnerable in terms of potential loss of employment relative to Base Case levels. These include coal-dependent regions such as Hunter in NSW, Fitzroy in QLD and Gippsland in VIC. On the other hand, more than half of the regions gain employment. These regions generally have an over-representation of the sectors that expand due to policies to decarbonise, especially forestry and renewable electricity generation and some of the service sectors that gain output because they have very little emission intensity to begin with. Finally, it is important to note that in both scenarios all regions, vulnerable or otherwise, gain employment between 2021 and 2050.

We conclude our summary of results with the following idea. Cutting greenhouse gas emissions is like buying an insurance policy: we incur a cost (a loss in GDP) to reduce a risk (catastrophic climate change). In any insurance decision, the cost matters. If a worthwhile reduction in risk costs 50 per cent of income, then then living with the risk may be preferable. However, if it costs only 1 per cent of income, as estimated in our modelling, then taking the insurance policy is a very good option.

Paper is all about computing the cost of taking action and makes no attempt of looking at the net benefits arising in the form of climate change damage foregone.

The approach to environmental modeling described in this chapter using a single-country economy model with inputs from other modelling systems and expert sources has an obvious parallel with integrated assessment models (IAMs). Unlike our modelling with VURM, IAMs aim to deal with the benefit side of emissions control as well as its costs.

For the simulation reported in this paper, no effort is made to include the possible effects of climate change in the Base Case projection. Not including climate change means that we do not account for any of the possible direct economic benefits arising from the abatement achieved. Including the potential benefits, and hence being able to show a net economic gain from decarbonisation, is an important item for further research.

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Appendix: Additional Data for Numbers of People Employed in 2021 and 2050

Appendix Table 3a: National ANZSIC Divisions – Number of Employed Persons

	ANZSIC Division	2021 ('000 persons)	2050 Base Case ('000 persons)	2050 Zero-emissions ('000 persons)
A.	Agriculture, forestry, fishing	310.3	492.9	518.6
B.	Mining	331.5	485.6	446.5
C.	Manufacturing	934.9	1,470.4	1,484.4
D.	Utilities	172.6	231.1	236.3
E.	Construction	949.2	1,410.0	1,358.4
F.	Wholesale trade	360.4	601.6	596.5
G.	Retail trade	1,391.6	2,293.5	2,254.4
H.	Accommodation	771.9	1,465.4	1,432.4
I.	Transport	715.2	1,023.2	1,020.7
J.	Information media	93.3	173.8	184.9
K.	Financial services	395.9	665.3	671.8
L.	Rental services	45.9	70.8	68.9
M.	Professional services	1,124.0	1,959.1	2,017.2
N.	Administrative services	449.6	803.2	831.1
O.	Public administration	977.5	1,259.3	1,241.0
P.	Education	1,150.8	1,542.4	1,547.0
Q.	Health	1,789.0	2,469.7	2,496.8
R.	Arts and recreation	250.2	356.7	350.4
S.	Other services	381.0	625.4	636.3
T.	Dwelling ownership	0.0	0.0	0.0

Appendix Table 3b: National Industries in Divisions A-D – Number of Employed Persons

Division/Industry	2021 ('000 persons)	2050 Base Case ('000 persons)	2050 Zero-emissions ('000 persons)
A. Agriculture, forestry, fishing	*310.3*	*492.9*	*518.6*
1. Sheep and Beef cattle	103.8	170.0	*166.8*
2. Grains production	25.4	38.9	*37.3*
3. Dairy cattle	29.9	47.4	*48.8*
4. Other crop production	80.7	121.7	*127.5*
5. Sugar cane production	2.6	3.9	*4.1*
6. Raw cotton and ginning	0.6	0.9	*0.9*
7. Other Agriculture	31.6	52.7	*54.2*
8. Fishing, hunting and trapping	6.4	10.6	*11.1*
9. Forestry and logging	5.7	10.7	*27.2*
10. Agricultural services	23.6	36.1	*40.6*
B. Mining	*331.5*	*485.6*	*446.5*
11. Coal mining	74.3	87.6	*63.3*
12. Oil mining	9.7	6.9	*5.1*
13. Gas mining	9.5	12.9	*8.1*
14. LNG production	29.9	41.6	*40.6*
15. Iron ore mining	59.6	100.0	*104.4*
16. Non-ferrous metal ore mining	50.8	101.2	*101.6*
17. Non-metallic ore mining	15.0	24.6	*24.7*
18. Mining support services	82.6	110.8	*98.7*
C. Manufacturing	*934.9*	*1470.4*	*1484.4*
19. Meat products	63.9	97.8	*93.6*
20. Dairy products	18.3	26.8	*26.4*
21. Refined sugar processing	15.1	23.5	*22.8*
22. Other food products	107.5	159.5	*158.7*
23. Beverages and tobacco	42.5	57.5	*57.3*
24. Textiles, clothing and footwear	44.9	62.7	*61.6*
25. Wood products	41.7	83.7	*123.9*
26. Pulp and paper products	55.1	87.7	*86.6*
27. Petroleum refinery products	11.7	18.3	*11.3*
28. Other chemical products	108.3	173.0	*176.1*
29. Non-metallic mineral products	21.9	31.5	*31.2*
30. Iron and steel products	29.2	49.4	*50.0*
31. Alumina refining	18.4	39.0	*36.5*
32. Aluminium smelting	0.3	0.5	*0.5*
33. Other non-ferrous metals	59.4	102.2	*98.0*
34. Motor vehicles and parts	56.7	95.8	*96.0*
35. Other transport equipment	33.0	47.6	*46.7*
36. Other manufacturing	207.0	314.1	*307.5*
D Utilities	*172.6*	*231.1*	*236.3*
37. Generation - coal	22.1	19.9	*5.2*
38. Generation - gas	14.9	13.1	*4.0*
39. Generation - hydro	3.1	3.7	*4.3*
40. Generation – other renewable	6.0	19.4	*56.6*
41. Electricity supply	35.9	49.1	*51.6*
42. Gas supply	19.3	24.5	*11.4*
43. Water and drains	71.4	101.4	*103.1*

Appendix Table 5: States and Territories – Number of Employed Persons

State/Territory	2021 ('000 persons)	2050 Base Case ('000 persons)	2050 Zero-emissions ('000 persons)
New South Wales	3,969.8	6,232.8	6,276.4
Victoria	3,220.6	5,205.9	5,247.7
Queensland	2,454.8	3,628.4	3,530.6
South Australia	843.2	1,261.6	1,283.5
Western Australia	1,409.2	2,136.3	2,111.2
Tasmania	243.0	359.6	371.1
Northern Territory	186.0	223.4	222.2
Australian Capital Territory	268.8	351.5	350.9

Appendix Table 6: SA4 Regions – Number of Employed Persons

SA4 Region	2021 ('000 persons)	2050 Base Case ('000 persons)	2050 Zero-emissions ('000 persons)
N1. Region near ACT	113.3	170.8	174.1
N2. Central Coast	151.3	225.6	221.3
N3. Central West	106.5	163.4	165.4
N4. Coffs harbour	54.3	87.4	97.5
N5. Far West and Orana	55.9	89.9	90.2
N6. Hunter valley (ex. Newcastle)	138.9	193.3	171.1
N7. Illawarra	152.3	234.3	230.2
N8. Mid-north coast	71.1	111.4	115.5
N9. Murray	59.2	92.5	94.0
N10. New England and North West	84.7	130.0	128.6
N11. Newcastle and Lake Macquarie	192.3	275.8	261.1
N12. Richmond-Tweed	100.7	157.4	162.8
N13. Riverina	87.1	134.6	143.5
N14. Southern Highlands	57.9	87.2	84.9
N15. Sydney - Baulkham hills	136.0	213.9	218.3
N16. Sydney - Blacktown	178.7	272.8	275.4
N17. Sydney - City and Inner South	233.7	407.2	414.7
N18. Sydney - Eastern Suburbs	176.5	291.0	299.3
N19. Sydney - Inner South West	281.0	447.3	448.1
N20. Sydney - Inner West	186.0	304.0	309.5
N21. Sydney - North Sydney and Hornsby	262.6	438.4	451.9
N22. Sydney - Northern Beaches	147.6	247.7	252.3
N23. Sydney - Outer South West	141.7	213.8	214.3
N24. Sydney - Outer West	169.2	253.0	254.4
N25. Sydney - Parramatta	216.4	343.3	345.1
N26. Sydney - Ryde	106.7	173.5	176.8
N27. Sydney - South West	173.4	269.5	272.3
N28. Sydney - Sutherland	134.5	203.9	203.6
V1. Ballarat	86.2	135.6	141.1
V2. Bendigo	75.2	117.4	118.7
V3. Geelong	149.3	228.0	227.5
V4. Hume	85.7	136.6	147.0
V5. Latrobe - Gippsland	130.7	194.2	186.8
V6. Melbourne - Inner	423.9	741.2	757.5
V7. Melbourne - Inner East	203.9	344.6	350.4
V8. Melbourne - Inner South	237.6	395.6	400.9
V9. Melbourne - North East	272.3	427.9	427.7
V10. Melbourne - North West	184.8	288.6	286.4
V11. Melbourne - Outer East	274.6	443.1	442.4
V12. Melbourne - South East	370.2	601.9	603.1
V13. Melbourne - West	386.7	612.0	605.7
V14. Mornington Peninsula	139.9	221.4	224.9
V15. North West	68.7	109.4	112.8
V16. Shepparton	59.6	94.1	96.3
V17. Warrnambool and South West	71.2	114.4	118.2

Appendix Table 6 (continued): SA4 Regions – Number of Employed Persons

SA4 Region	2021 ('000 persons)	2050 Base Case ('000 persons)	2050 Zero-emissions ('000 persons)
Q1. Brisbane - East	130.4	188.2	180.1
Q2. Brisbane - North	130.0	188.1	184.0
Q3. Brisbane - South	205.0	303.6	298.6
Q4. Brisbane - West	113.8	166.8	165.9
Q5. Brisbane - Inner	180.4	279.4	275.7
Q6. Cairns	113.3	170.4	168.5
Q7. Darling Downs - Maranoa	54.0	77.7	73.5
Q8. Central Queensland	132.4	194.2	171.7
Q9. Gold Coast	279.6	432.3	422.2
Q10. Ipswich	160.1	230.9	225.2
Q11. Logan - Beaudesert	156.4	227.2	221.4
Q12. Mackay - Isaac - Whitsunday	104.2	142.4	124.3
Q13. Moreton Bay - North	101.0	147.6	145.7
Q14. Moreton Bay - South	115.8	167.9	165.1
Q15. Queensland - Outback	40.6	66.1	64.2
Q16. Sunshine Coast	146.9	221.8	215.7
Q17. Toowoomba	69.2	97.3	94.0
Q18. Townsville	125.6	185.2	182.3
Q19. Wide Bay	96.2	141.4	144.6
S1. Adelaide - Central and Hills	158.9	236.7	242.6
S2. Adelaide - North	209.4	307.8	304.8
S3. Adelaide - South	181.5	265.3	263.0
S4. Adelaide - West	129.6	187.7	181.9
S5. Barossa - Yorke - Mid North	46.7	75.2	80.6
S6. South Australia - Outback	35.7	57.6	61.2
S7. South Australia - South East	81.3	131.4	149.4
W1. Bunbury	94.6	143.3	137.2
W2. Mandurah	49.9	84.2	81.5
W3. Perth - Inner	100.2	150.4	150.2
W4. Perth - North East	136.9	207.3	205.7
W5. Perth - North West	274.9	413.5	409.1
W6. Perth - South East	272.5	414.4	410.2
W7. Perth - South West	240.6	358.8	350.7
W8. Western Australia - Wheat belt	66.2	95.9	98.8
W9. Western Australia – Outback (North)	89.4	138.3	138.0
W10. Western Australia - Outback (South)	83.9	130.2	129.8
T1. Hobart	96.0	137.8	136.2
T2. Launceston and North East	64.6	96.3	101.6
T3. South East	21.6	35.6	39.0
T4. West and North West	60.8	89.9	94.3
NT1. Darwin	144.8	171.7	171.7
NT2. Northern Territory - Outback	41.2	51.7	50.4
A1. ACT	268.8	351.5	350.9

Endnotes

[i] https://www.climateworksaustralia.org/resource/pathways-to-deep-decarbonisation-in-2050-how-australia-can-prosper-in-a-low-carbon-world/ .

[ii]Our 2014 modelling was undertaken using the Monash Regional Forecasting Model (MMRF). VURM incorporates the MMRF structure and adds a number of new features. The core equations of VURM are documented in Adams, *et al.* (2015).

[iii] Statistical Areas Level 4 (SA4) are geographical areas are the largest sub-State regions in the Main Structure of the Australian Statistical Geography Standard (ASGS).
[iv] Carbon dioxide equivalent" or "CO_2 e" is the common term used to describe different greenhouse gases in a common unit. For any type of greenhouse gas, its quantity measured in tonnes of CO_2-e signifies the number of tonnes of CO2 which would have the equivalent global warming impact.

[v] The Energy Transition Hub has published a detailed comprehensive analysis of possible futures for Australia's electricity system (Energy Transition Hub, 2019)). In that review they used 4 numerical energy-economic models from 5 partner institutes, and modelled 6 scenarios. They found that:

- costs in a renewable-based system are similar or lower than today;
- there are multiple options which will secure reliable supply from 100 percent renewables.

[vi]Suitably managed planation forests can maintain carbon in growing trees while producing an annual yield of timber which retains a large proportion of carbon stored during the growing stage.

[vii] A horizontal shift in export demand schedule of x per cent means that if there is no change in the export supply schedule, then export volume and price will increase. However, there will be changes in export supply and as always the final outcome for export volume and price will depend on the interaction between the shifts in supply and demand.

[viii] Electrification means the replacement of fossil-fuel energy with electricity energy, especially for process heat. In many applications, 1 Pj of electricity is equivalent to around 2 Pj from fossil fuel.

[ix]Our modelling will follow the approach of Young *et al.* (2021), who added a number of hydrogen based industries into their version of the VURM model.

[x] The terms of trade is the ratio of the average price of exports to the average price of imports. If the terms of trade improve, then this creates a benefit to the nation in terms of a reduction in the number of goods that need to be exported to buy a given amount of imports.
Real GDP is GDP deflated by the price of production. Real GNI is GDP that accrues to domestic residents deflated by the price of consumption. All else unchanged, a rise in the terms of trade increases the price of production relative to the price of consumption, thereby increasing real GNI relative to real GDP.

[xi] The real cost of labour is the nominal wage rate deflated by the price of output. Action to increase the price of emissions tend to raise the price of spending (i.e., the price of consumption) relative to the price of output. If the real wage rate is sticky, then that tends to increase the real cost of labour. A higher real cost of labour reduces the incentive to employ.

[xii] Recall the basic GDP identity: Y = C + I + G + (X-M).

[xiii]The Australia and New Zealand Standard Industrial Classification (ANZSIC) system classifies industry classes based on their main business activity, and is the primary classification used by the Australian Bureau of Statistics to collect and analyse data across industries. It is arranged into 20 broad industry divisions (as shown in Table 3a), 96 industry subdivisions and two more detailed levels called Groups and Classes.

To keep charts and figures manageable we report results for just one year, 2050. For most sectors, the effects of policies to decarbonise build smoothly over the projection period, reflecting the smooth paths for the inputs described in Section 3.2.

[xiv] Forests sequester carbon when growing. They release less than 50 per cent of the carbon when cut down and the wood is processed into timber. They release a bit more if the timber harvested is pulped for paper. In most cases nearly all of the carbon retained remains sequested until decay sets in. Hence, certainly for 2050 having lots of young fast growing plantations is good. This means lots of logs produced for timber or pulp to keep the primary rate of sequestration as high as possible.

[xv] Enteric fermentation (fermentation that takes place in the digestive systems of animals.) is the main (projected) source of Agriculture emissions in 2021, contributing 69 per cent of the sector's emissions. The next largest source is agricultural soils (18 per cent). In the Zero Emissions scenario, we allow for significant abatement of animal emissions in line with estimates in Climate Works (2020). Emissions from agricultural soils turn negative along the zero-emission pathway due to a strong increase in carbon sequestered in soil arising from improved land management practices. Just as the emissions price is a subsidy for forest bio-sequestration, so it is a subsidy for soil bio-sequestration.