Melbourne Sustainable Society Institute

Australia's Clean Economy Future: Costs and Benefits

Issues Paper Series

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Executive Summary

This Issues Paper offers the first-ever comparison of the costs of emission reduction in Australia relative to the potential damages from climate change under current policy settings.

The Issues Paper considers the options available to state governments in Australia – specifically the Queensland and Victorian governments – to transition to a clean economy and considers the costs of these options, compared against the costs of doing nothing and the cost benefits of avoiding potential damages in the future.

While the costs of mitigation are substantial, this is one of the first times these costs are considered relative to the environmental, social and economic benefits and damages that can be avoided when an economy transitions from fossil fuels to renewables.

These findings will equip the Queensland and Victorian governments to transition to a clean economy and:

- avoid future damages due to climate change
- be at the forefront for low-carbon business and innovation
- smooth and enhance the transition to a low-carbon economy
- reduce financial, legal and strategic risk for the state and the economy.

The costs of climate change

The potential damages from climate change to Australia at current global emissions patterns are quantified as:

- $584.5 billion in 2030
- $762 billion in 2050
- more than $5 trillion in cumulative damages from now until 2100.

These costs are conservative – they exclude the bulk of costs of floods and bush fires, pollution, damage to environmental assets and biodiversity losses.

Conversely, the national costs of effective emissions reduction – based on a carbon price or renewables target – are estimated at $35.5 billion from 2019 to 2030, or 0.14% of cumulative GDP; a negligible impact.

Overall, the costs of emissions reduction are far less than the damages of inaction – even with modelling underestimating damages from climate change and overestimating the costs of emissions reduction.

High-level business case for States

Further quantifying what this means for Australia's states and territories allows governments to understand the real costs and benefits of effective climate policy.

Best-practice options include:

- incorporating state-wide climate-related financial risk management measures
- introducing emissions management schemes
- promoting emissions reduction in agriculture, including carbon sinks
- rapidly electrifying transport

- promoting energy efficient buildings
- incorporating green urban design.

Assessing the social, economic and environmental consequences of these options has found many co-benefits beyond emissions reductions, including:

- access to more affordable investment capital
- enhanced agricultural productivity
- reduced energy use and costs for households and businesses
- improvements in biodiversity
- improved urban air quality
- improved comfort and lower health risks
- commercial benefits from developing and selling emissions reduction technology.

The cost benefit analysis (CBA) finds that:

- These options would lead to a reduction in greenhouse gas emissions over a business-as-usual scenario of 627 million tonnes from 2020 – 2075.
- This would come at a total cost of $3.6 billion.
- The net benefit is $16.2 billion at a discount rate of seven per cent.

Even when the benefit of reduced emissions ($7.5 billion) is excluded under conservative assumptions, the analysis shows that the transition to a low-carbon economy is a sound strategic objective generating (co-)benefits that outweigh the costs at 2.8 to 1.

What this means for Australia's state and territory governments

This Issues Paper finds that transitioning to a clean economy is sound economic development: even when the benefits of reduced emissions are ignored, the economic benefits of a transition to a clean economy easily outweigh the costs.

Of the options available to states and territories, increasing renewable power generation and use should be a priority, as should state-based emissions management schemes for the energy sector. Sector-specific options targeting transport, agriculture and land use will also drive change and create new employment opportunities as these sectors undergo drastic change.

As state and territory procurement processes require climate-related risk disclosure, the benefits will ripple through the economy, enhancing the risk profile of the entire investment climate of Queensland and Victoria.

Governments that transition to a clean economy are strengthening their economic competitiveness. The global business community is less likely to invest in economies that do not address climate-related risks. Already, for example, the world's largest investment firm Blackrock, requires all firms they invest in to disclose and manage climate-related risks.

Australia cannot afford to be viewed as a high-risk investment location. Businesses and governments that understand and plan for their climate-related financial risks and disclose their efforts to address these risks (and opportunities), will have a healthier risk profile.

Introduction

This Issues Paper finds that developing clean economies and tackling climate change will deliver economic benefits.

Many countries, states/provinces and businesses around the world are already transitioning to clean economies. Further, reserve banks, the financial sector and many businesses now consider the management of risk due to exposure to the increasing impacts of climate change and the transition to a clean economy a central issue. Governments around the world and at every level recognise the opportunities and benefits from clean economies, especially by attracting investment and jobs.

In line with this global practice, the Melbourne Sustainable Society Institute at the University of Melbourne (MSSI), together with experts from SGS Economics & Planning (SGS) have developed this Issues Paper to assess the economic consequences, costs and benefits of a future with effective climate policy. The Issues Paper presents a business case that focuses on the states of Queensland and Victoria, although some policies are calculated at an Australia-wide level and apportioned to states and territories.

The business case assesses the benefits of avoided damages, the savings due to emissions reductions and the co-benefits of a transition to a clean economy. It also examines the cost of the transition to a clean economy.

This business case shows the net return and the benefit cost ratio of effective climate policy. The cost benefit analysis adheres to the relevant Queensland and Victorian Treasury guidelines.

This Issues Paper includes:

Section 2: the costs that states and territories, particularly Queensland and Victoria, will face if nothing is done to mitigate and adapt to climate change, and the framework for the business case.

Section 3: the options that states and territories have at their disposal to move towards a low-carbon economy.

Section 4: the cost benefit analysis, including analysis of options compared to the base case, and the key findings and sensitivity analysis.

Appendix 1: a supporting paper detailing the economic damages from worldwide climate change and how this will affect Australia, and the costs of emissions reduction.

Appendixes 2 and 3: assumptions underlying the cost benefit analysis

Appendix 4: the differences between the options.

The cost of doing nothing

The strategic need for states and territories to transition to a low-carbon future is two-fold: it strengthens economic competitiveness and helps to avoid catastrophic climate change impacts.

The global business community is addressing climate-related risks to transition to a low-carbon economy. Clearly, to create a sustainable investment climate is to disclose and manage climate-related financial risks. The Australian economy will lose its international competitiveness if it stays behind.

The science on climate change is clear: without a global concerted effort to curb emissions to net zero over time, the world will experience devastating impacts that put the natural environment, human livelihoods and resources at risk.

Economic prosperity and keeping up with the global business community

Climate change threatens the assets and operations of businesses, communities and governments. Most countries have signed the Paris Agreement and are transitioning to low-carbon economies.

The global business community is making significant strides to address strategic risks. The wave generated by the Taskforce of Climate-related Financial Disclosures (TCFD) is an exemplar.

On 29 June 2017 the TCFD, chaired by Michael R. Bloomberg, delivered guidelines that urge companies to consider and report their exposure to climate-related risks. In relation to the guidelines, Bloomberg said:

> *The risk climate change poses to businesses and financial markets is real and already present. It is more important than ever that businesses lead in understanding and responding to these risks—and seizing the opportunities—to build a stronger, more resilient, and sustainable global economy….*
>
> *Adoption of these recommendations will also help companies better demonstrate responsibility and foresight in their consideration of climate issues. That will lead to smarter, more efficient allocation of capital, and help smooth the transition to a more sustainable, low-carbon economy.* (Michael Bloomberg, TCFD, 2017)

Since then, key bodies such as the Australian Prudential Regulation Authority (APRA), Australian Securities and Investments Commission (ASIC), Australian Institute of Company Directors (AICD) and now the Reserve Bank of Australia (RBA) have confirmed the strategic need and the legal liabilities that require businesses to consider and report their climate-related risks.

On 12 March 2019 Guy Debelle, RBA deputy governor, stressed the need for financial institutions to address climate change in order to manage their financial risks:

> *The impact of climate change will prompt substantial structural adjustments to the global economy….*
>
> *While mortgage portfolios in coastal areas may be exposed to the physical impact of climate change through rising sea levels and flooding, massive amounts of capital and new financial products will be required to fund the transition and finance climate resilience, creating demand for bank services. Meanwhile, regulators are beginning to act, and investors, clients, and civil society are looking for actions, mitigation, adaptation, and transparency on the issue* (Debelle, 2019).

As Barret & Skarbek (2019) observe:

> *By measuring [financial risks from climate change]…by allocating capital such that we avoid them — we not only increase our chances of avoiding dangerous climate change, we also reduce financial risk*

According to TCFD, categories of climate-related risks and opportunity are:

- Physical impacts of climate change – natural hazards and ecological impacts due to gradual onset and extreme/catastrophic events, including sea level rise, more frequent and more severe storms, droughts, rainfall and heat events.
- Economic transition – the introduction of policies, responses[1] and innovation towards a low-carbon economy that will change business prospects and opportunities.
- Liability consequences – possible liability risks from the failure to mitigate (reduce emissions), adapt (reduce vulnerability) or disclose. Directors must consider issues that have a reasonably foreseeable impact on performance or prospects (Hutley, material issue).[2] Climate change is reasonably foreseeable.

Irrespective of local and regional climate policies, large-scale international investors, including the world's largest investment firm Blackrock, require all firms they invest in to disclose and manage climate-related risks. If Australian governments and businesses do not adhere to this, Australia will increasingly be perceived as a high-risk location for investment; this, in turn, will be reflected in the ability to attract (affordable) investment capital and grow the economy.

Australia has competitive advantages in the low-carbon era due to the availability of minerals required in low-carbon economies and the availability of land (Hartcher, 2019). Advantages include:

- abundance of opportunities for renewable power generation
- minerals processing and chemical manufacturing (silicon, lithium, titanium, vanadium, nickel, cobalt, copper)
- carbon sequestration (biomass, and geological).

Effective climate policy will determine how rapidly and effectively Australian businesses can manage climate-related risks, attract investment capital and remain internationally competitive. States and territories are well positioned to enable and support the transition of their economies.

The cost of climate change to Australia and its states and territories

Much of the debate on climate change focuses only on the costs of mitigation, which can be significant depending on how quickly an economy transitions from fossil-based energy to renewable energy. It is essential to understand the breadth of those costs relative to the avoided damages once there is a transition to a low-carbon future.

This Issues Paper provides the first-ever comparison of the costs of emission reduction in Australia, relative to the potential damages from climate change that could occur under current policy.

The potential damages of doing nothing to reduce emissions

The potential damages from climate change to Australia, with the continuation of current global emissions patterns,[3] are: (see Steffen et al. 2019 and Appendix 1)

- $584.5 billion in 2030
- $762 billion in 2050

- more than $5 trillion in cumulative damages from now until 2100.

Over time, the total cumulative damages ramp up dramatically from 2050, illustrating the importance of acting quickly to reduce emissions now.

These damage estimates are conservative – the modelling is limited to reduced agricultural and labour productivity, loss of arable land due to sea level rise, some health impacts and losses from infrastructure (Appendix 1).[4] The modelling excludes the bulk of the costs of floods and bush fires, pollution, damage to environmental assets, and biodiversity losses that result from temperature increases.

Effective global climate policy can largely avoid these damages, but action will not avoid the damages that are already locked in due to past and current emissions.

Indicative potential damages are $115 billion for Victoria and $171 billion for Queensland by 2030 (see Appendix 3).

The costs of transitioning to a low-carbon economy

The costs of effective emissions reduction at a national level are estimated to be $35.5 billion from 2019 to 2030. This equates to 0.14 per cent of cumulative gross domestic product (GDP) over this period; in other words, GDP growth would be very slightly lower. With effective emissions reduction, on this modelling and using baseline prices, cumulative GDP from 2019 rises to reach $25.4 trillion in 2030, with negligible impact from the costs of emissions reduction.

The modelling assumes that Australia, in line with the rest of the world, will effectively reduce its emissions by 26 per cent compared to 2005 to meet the minimum Paris Agreement emissions target by 2030, and all other countries reduce emissions by 12 per cent (or double, on average, of the Paris Agreement globally). Importantly, these costs assume effective and efficient emissions reduction policies in the form of a carbon price or a renewables target. While this is not current policy in Australia, states and territories may implement alternative policies to achieve zero emissions by 2050. This Issues paper provides more details of the likely costs of emissions reduction for Queensland and Victoria in Section 4.

The costs of emissions reduction are measured by the fall in GDP with a carbon price. A renewables target as a percentage of the energy mix would give a similar outcome in the model. The carbon price represents a shift of revenues to the government budget which can be redistributed to households through lower income taxes, for example, or through other mechanisms.

A key driver of the costs of emissions reduction is the relative price of renewable energy compared to fossil fuels. Model results are generated mostly in terms of a substitution effect or a change in the composition of demand between fossil fuel sources of energy relative to renewable energy sources. Levelized Cost of Energy (LCOE) is a measure of the cost of producing one extra unit of electricity with a newly constructed electricity generation plant. As a result, it is equivalent to the long-term marginal cost of power at a given point in time. The formula for calculating LCOE is based on investment costs, operation and maintenance expenditures, fuel expenditures, and the discount rate over a given number of years. The volume metric is normally expressed as million tonnes of oil equivalent (MTOE).

The cost of mitigation depends on the relative price trajectory for renewables compared to fossil fuels and the carbon price. As the cost of renewables decrease over time so too will the transition cost less.

Currently, the LCOE price of renewable energy is less than that of fossil fuel sources of energy in

Australia and is falling rapidly.

Modelling of the costs of mitigation made conservative assumptions on technological progress and forms of carbon capture technology. This means that Australia may experience lower costs of emissions reduction than those presented. Initiatives to encourage renewable energy, changes in land-use policy that favour forests and/or biomass, more energy efficient forms of transportation and construction, and the faster development of carbon capture technologies will all influence lower emissions reduction costs.

Overall, the costs of emissions reduction are far less than the damages of inaction in all scenarios examined. This acknowledges that not all damages are included (that is, damages are underestimated) and the costs of emissions reduction may be overestimated due to conservative assumptions on technological advancement.

Objectives for state or territory intervention

A regional and national climate policy would drive the timely and effective transition of Australian businesses to a low-carbon economy so they can continue to attract investment capital and remain internationally competitive.

The objectives for state or territory intervention on climate change are to:

- avoid future damages due to climate change in line with the global economy
- position Queensland and Victoria at the forefront for low-carbon business and innovation
- smooth the transition to a low-carbon economy
- reduce financial, legal and strategic risk for state agencies and businesses in Victoria and Queensland.

A high-level business case

A strategic business case based on a cost benefit analysis (CBA) demonstrates the rationale for states and territories to invest in and implement effective climate policy.

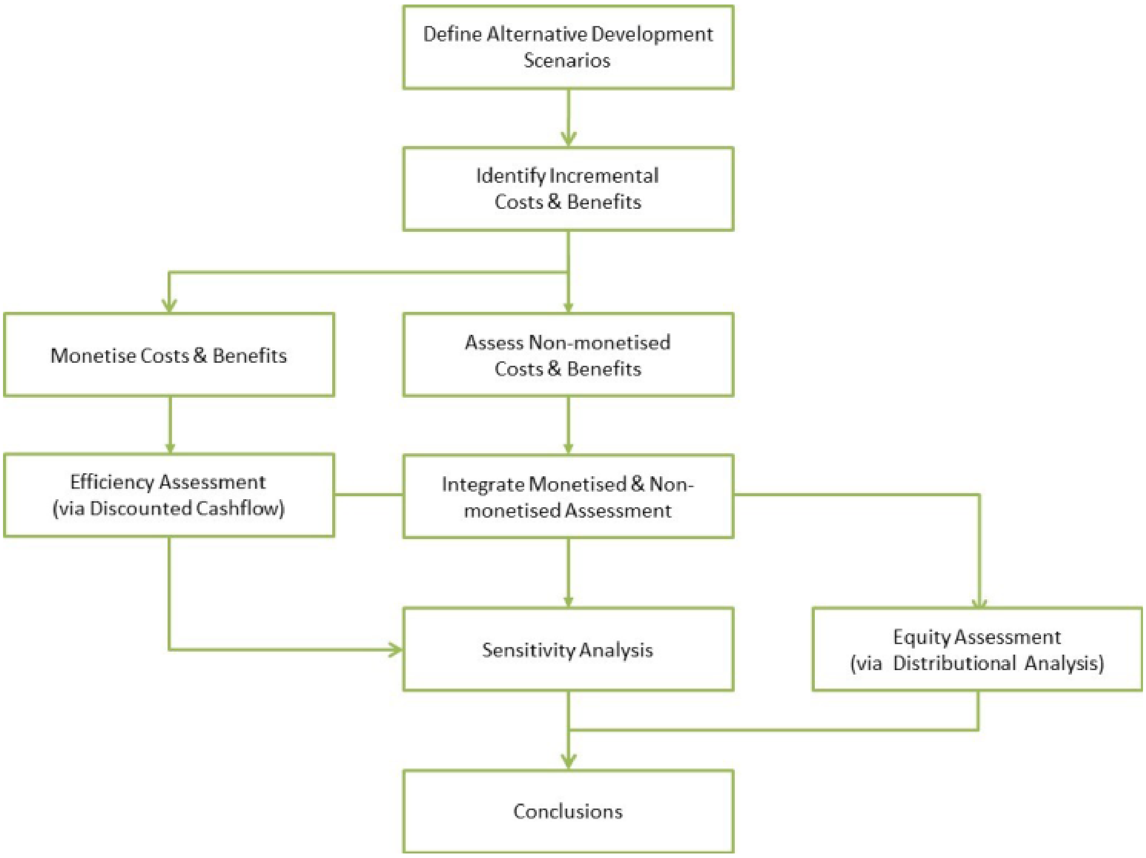
CBA method

CBAs assess broad community welfare impacts of proposed projects from an economic, social and environmental perspective. In essence, if assessed benefits outweigh costs, the project is justifiable.

However, there are some caveats:

- Not all costs and benefits can be precisely quantified and monetised (that is, expressed in dollar terms) given their inherent intangibility. This often forces decision-makers to integrate quantitative and qualitative results.
- The distribution of costs and benefits or the equity of outcomes may be unevenly experienced across the community. A potentially efficient outcome could be unworkable if those adversely affected cannot be appropriately compensated for their losses.

Figure 1: CBA Methodology



The CBA methodology used for this Issues Paper is generic and summarised in Figure 1.

This methodology is targeted to the context by:

- defining alternative project scenarios, one being business as usual (BAU), the other the state implementation of options to transition to a low-carbon economy (the project scenario), with variations that could be considered in the future
- identifying the incremental costs and benefits of moving from BAU to the project scenario/s taking a broad economic, social and environmental perspective and in doing so, a) separating the costs and benefits in general from those associated with outcomes promoted by the project scenario/s, and b) accounting for the difference between real or net costs and benefits, as opposed to transfer effects between different stakeholder groups
- quantifying then converting to dollar values the incremental costs and benefits using available monetisation techniques, which include both market and non-market valuation techniques
- assessing the efficiency of moving towards the project scenario/s using discounted cash flow analysis, which contrasts the incremental costs and benefits over the long term, reflecting the life of the low-carbon transition (say, 80 years), discounting all future cost and benefits to present day values using appropriate discount rates, then calculating appropriate performance measures, such as net present value (NPV) and benefit cost ratio (BCR), to gauge overall efficiency

- testing the sensitivity of these performance measures by varying the underlying assumptions in the discounted cash flow analysis
- assessing non-monetised costs and benefits recognising that some items are difficult to monetise due to their inherent intangibility and/or because of a lack of information/appropriate monetisation techniques
- integrating the monetised and non-monetised costs and benefits to make a fully informed conclusion about the likely efficiency of moving towards the project scenario/s
- assessing the equity of the project scenario/s by examining the distribution of who pays and who benefits and identifying any segments of the community that disproportionately win or lose as a result of project scenario.

For states and territories there are two strategic options:

- to not actively drive a transition towards a low-carbon economy but to allow market forces to move in that direction
- to actively drive the transition to a low-carbon economy.

Given that states already set emissions reductions targets in line with the Paris Agreement and have implemented initiatives to curb emissions, this Issues Paper defines:

- the BAU scenario as one where the states do not initiate any further action
- the project scenario as the states actively transitioning to a low-carbon future.

Options for states and territories

Most states and territories have followed and set targets similar to those of the Paris Agreement, with policies already being implemented. This section describes effective options for states and territories to implement and/or extend to reach the 2050 targets. These options combine to form the project scenarios.

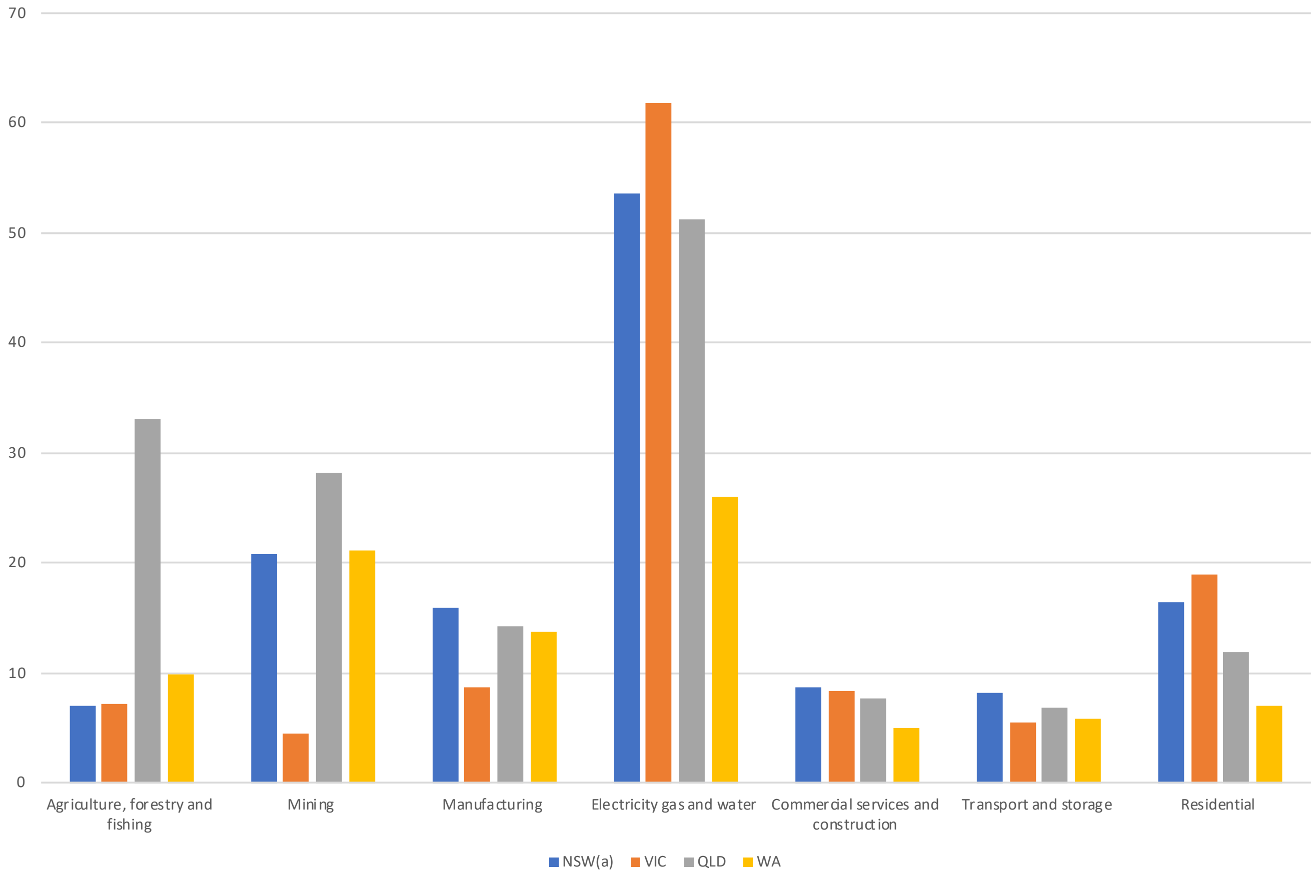
Current state targets

In December 2015, 195 countries, including Australia, agreed to the Paris Agreement, which aims to limit emissions to net zero, globally, in the second half of the century to limit global warming to well below two degrees Celsius (2°C) above pre-industrial times, and as close to 1.5°C as possible.

Australia's current emissions reduction target is 26 to 28 per cent below 2005 levels by 2030. Australia is not yet on track to meet its commitments under the Paris Agreement, but has potential to do so. Emissions are projected to rise in most sectors – specific sector support can turn this around (Climate-Works, 2018).

Victoria's *Climate Change Act 2017* set a target of net zero emissions by 2050. The Act requires five yearly interim emissions reduction targets to keep Victoria on track to meet this long-term target. The Victorian Government has also committed to reduce emissions from government operations by 30 per cent below 2015 levels by 2020 (Victorian Government, 2019).

Figure 2: State and Territory emissions by economic classification 2016 ANZIC code



Source: (Commonwealth of Australia, 2018)

The Queensland Government is aiming to power Queensland with 50 per cent renewable energy by 2030, to contribute a fair share in the global effort to arrest damaging climate change by achieving zero net emissions by 2050 and to set an interim emissions reductions target of at least 30 per cent below 2005 levels by 2030 (Queensland Government, 2019). The chart below shows current direct emissions by State and industry (as classified under the Australian and New Zealand Standard Industrial Classification (ANZSIC)).

Best practice options

A range of options for states and territories to reduce their emissions was considered based on best practice for specific sectors and across sectors:

- state-wide climate-related financial risk management
- direct investment in clean energy supply
- emissions management scheme
- emissions reduction in agriculture
- electric vehicles
- public and active transport
- energy efficient buildings
- green urban design.

After initial investigation, several options were disregarded due to limited relevance to state-level influence or limited expected net benefits.[6]

State-wide climate-related financial risk management

States and territories can work within the financial system to support a transition to a low-carbon economy, for example, by investing in low-carbon products or concessional financing of low-carbon businesses. The method quantified for this project is for states and territories to declare and manage climate-related financial risks, using the TCFD guidelines and ensure that state procurement prioritises low-carbon options.

State management of climate-related risks

Under this option, state governments, government-owned business entities (GBEs) and other state-owned or managed entities adopt the guidelines of TCFD, that is:

- adhere to the target of net zero emissions by 2050
- disclose and manage risks related to exposure to climate impacts
- transition to a low-carbon economy
- require all suppliers (and with that suppliers' suppliers) to adhere to TCFD, thereby stimulating the business community to adopt TCFD.

The emissions reduction potential of government and their related entities represents an estimated 3.1 per cent of total emissions in Queensland and Victoria (Table 1).

Table 1: Estimated emissions by state, related entities and procured providers

	Queensland	Victoria
Total emissions (Mt CO2-e, Metric megaton of carbon dioxide equivalent	153	115
Direct emissions by State and related entities (Mt CO2-e	2.87	2.73
Share of total emissions in State by State and related entities	1.9%	2.4%
Direct emissions by State procured providers	1.88	0.82
Share of total emissions in State by State procured providers	1.2%	0.7%
Share of State, related entities and procured providers emissions	3.10%	3.08%

Notes: State and entity related emissions have been calculated based on State employment numbers and direct emissions related to jobs. Procurement related emissions have been calculated based on the value of State procurement and emissions related to productivity (GVA).
Source: SGS (2019), based on (Commonwealth of Australia, 2018), (Queensland Government, 2019), (Victorian Government Purchasing Board, 2018), (ABS, 2018), (ABS, 2016), (Queensland Government, 2018), (State of Victoria (Victorian Public Sector Commission), 2018)

In addition to emissions reduction, the co-benefits of adopting TCFD throughout the economy are (AICD, 2018, Energetics, 2019):

- enhanced corporate strategy and capitalising on competitive advantage
- reduced risk of mispricing equity and better capital allocation
- potential opportunities to attract debt financing and/or insurance at lower cost
- better informed shareholders and community
- avoidance of litigation.

Businesses and governments that understand and plan for climate-related financial risks will have a healthier risk profile than those that don't. Entities with lower risk profiles have access to more affordable investment capital and debt funding. Indeed, there is growing evidence that responsible investment provides better returns and lower risk profiles.[7]

The difference in perceived risk for corporate bonds is reflected in the yield[8] and spread to swap and/or spread to Australian Government Securities (AGS).[9] Generally, the higher the risk, the higher the yield (the interest over the debt) and the higher the spread to swap/AGS.

The RBA provides data on the yields and spread to AGS for different credit ratings. Aggregate measures are reported separately for bonds with broad A (A+, A or A-) and BBB credit ratings (BBB+, BBB or BBB-), as rated by Standard and Poor's (RBA, 2019). The broad A ratings can be typified as upper medium grade risk profile, and BBB credit ratings as lower medium grade.

Analysis of the RBA data shows that the risk premium for BBB rated bonds is 0.75 percentage points over A-rated bonds[10] (see Appendix 2). This risk premium can be a modest[11] proxy for businesses and governments that do not address their climate-related financial risks compared to those that do.

Direct investment in clean energy supply

This option involves the expansion of a state-owned renewable energy generator (Queensland) and the establishment of a state-owned renewable energy generator (Victoria).

Queensland's recently established CleanCo could be extended with an additional $250 million to double the existing investment. In Victoria, this model could be replicated with a $250 million investment. Based on Queensland's model, an additional $250 million investment would save emissions equivalent to that generated by 1,000 MW of 'dirty' energy generation (Queensland Government, 2019).

The Queensland model would cost Victoria $250 million over six years, covering establishment and operating costs as well as the funding for direct investment. The investment has the potential to crowd out private sector investment[12] depending on the demand and growth in demand for renewables (as noted earlier, renewable energy prices continue to fall relative to fossil fuel, which is expected to drive demand).

The model injects cash into the renewable energy generation sector to stimulate and bring forward investment. Other benefits include:

- lower wholesale electricity prices from increased generation/competition in the national energy market
- cheaper electricity bills for households and businesses, with energy prices reduced by an average of $7 MwH
- increased electricity supply and improved energy reliability and security
- more jobs in the renewable energy sector
- renewable energy export opportunities for businesses.

This has been included in the discussion as measures that states could adopt; however, the potential for benefits, as opposed to transfers from the private to government sector, or from taxpayers to households and businesses from lower energy schemes, are unlikely to be noticeable, for the following reasons:

Private investments in new energy generation favour solar and wind due to renewable energy targets and their comparatively low cost, with major energy providers such as Origin Energy (Ludlow, 2015) and AGL (Vesey, 2017) planning to phase out coal and move into renewables.

Direct investment in renewable energy could achieve a more stable electricity supply by providing additional capacity, but there is no reason to think that private companies would not provide this.

For this reason, no explicit costs or benefits are selected for this option.

State-based emissions management schemes for the electricity sector

This option assumes states establish emissions management schemes (EMSs) for the electricity sector, in line with the NSW Greenhouse Gas Abatement scheme[13] that operated from 2003-2012. (Independent Pricing and Regulatory Tribunal, 2013).[14]

The EMS would help reduce greenhouse gas emissions[15] associated with the production and use of electricity and promote activities to offset production of greenhouse gas emissions. An EMS is technology and resource neutral[16] (i.e. minimum market distortion), has low administration and compliance costs and drives competition by placing the obligation on retailers (of which there are many) as opposed to generators.

Under the NSW EMS, the estimated operating costs were around $3 million per year, the abatement costs $15-$40 a tonne, and the increase in electricity prices one to two per cent.

The EMS is assumed to become operational about five years after announcement and operate long term to give the market confidence to invest. The EMS has immediate impact with impacts growing over time as the market gains confidence and matures.

An EMS would help to reduce greenhouse gas emissions as:

- low-emission methods of generating electricity would be comparatively cheaper
- a market-based system of emissions reduction would flow investment to the most efficient carbon reduction measures.

The impact of an EMS has been modelled at $4 million in total per year for both states resulting in abatement of 10 million tonnes of C02 each year, based on NSW results. This may need to be phased out as low emissions technology becomes cheaper than high emissions technology and carbon credit values approach zero.

Emissions reduction in agriculture

In 2018, Victoria's agricultural production was valued at $22.16 billion or 5.1 per cent of gross state product (GSP), while Queensland's was worth $21.73 billion, or 6.4 per cent of GSP (ABS, 2018). Greenhouse gas emissions (carbon dioxide equivalent) from agriculture were 13.87 million tonnes (12 per cent of total state emissions) in Victoria in 2016 and 18.3 million tonnes (12 per cent of total state emissions) in Queensland.

Emissions from agriculture come from the digestive processes of cows and sheep, clearing land for pasture and land tilling processes. Around two-thirds of Australia's agricultural emissions are from ruminant animals and mostly in the form of methane emissions. Carbon dioxide is released as a result of land clearing, pasture management and tilling, and nitrous oxide is released from soils from animal waste, soil disturbance and nitrogen fertilisers.

As an industry, agricultural production is likely to be hit hardest from climate change due to the greater risk of droughts and floods.

Reducing methane emissions from sheep and cattle

Emissions from sheep and cattle is the major emissions source in agriculture. Promising options to manage these emissions include different fodder types, dung beetles (Meat & Livestock Australia, 2017), feed supplements (CSIRO, 2019), selective breeding and vaccines. Meat & Livestock Australia (MLA) believe Australia's red meat industry could be carbon neutral by 2030 (Meat & Livestock Australia, 2017)

Research funded by MLA and undertaken by CSIRO and James Cook University developed a seaweed supplement for ruminant animals that reduces carbon emissions by over 80 per cent, while increasing meat productivity (CSIRO, 2019) This supplement has been patented and is undergoing further trials to quantify the increase in productivity. To commercialise this, a seaweed supply chain will need to be established. Other sources of methane reduction in cattle and sheep farming are also under investigation.

MLA could meet its target of zero net emissions by 2030 without state intervention, given these new technologies. States can support this goal by investing in developing and commercialising new technologies and farmer education on new technologies.

These are difficult to quantify in advance due to uncertainty around the market for new technologies, the precise levels of carbon reduction, costs of implementation and co-benefits such as boosted productivity. Based on existing research and the potential benefits from commercialisation the cost benefit analysis modelled:

- under the project scenario, state governments investing $5 million per year from 2020 to 2023 to help bring low-emission ruminant technologies to the commercialisation stage and to support their rollout, with net emissions from ruminant animals meeting the zero target by 2030
- under the base case, achieving zero net emissions from ruminant animals by 2040
- achieving a 0.1 per cent net increase in beef, lamb, wool and dairy production due to higher productivity and lower costs from adopting new methods.

Carbon farming and carbon credits

Land management practices and revegetation have multiple potential benefits beyond carbon reduction, such as:

- restoring natural habitats through re-establishing trees, shrubs and grasslands that absorb carbon and protect biodiversity
- changing methods of cropping and pasture management through no-till farming or changing crop rotations, adding carbon to the soil and increasing productivity of agricultural land
- planning trees on farmland to provide shade and windbreaks, reducing stock losses and potentially increasing the productivity of surrounding land.

With Australia's vast land areas, there is great potential for agricultural lands, degraded former agricultural lands and other public land to be harnessed for carbon sinks. The most cost-effective way to do this is through an emissions trading scheme (ETS), in which emitters pay for land projects to offset their emissions. In the absence of an ETS, governments can pay for land management and revegetation practices that absorb carbon into the soil or into plants.

In 2014 the Australian Government established the Emissions Reduction Fund. This allocated $2.55 billion to projects that reduce greenhouse gas emissions or absorb greenhouse gases. Organisations can earn Australian Carbon Credit Units (ACCUs) then sell these to the Australian Government or businesses that wish to offset emissions. In February 2019 an additional $2 billion was committed to the Fund, to deliver around another 100 million tonnes emissions reduction.

The Queensland Government has committed $8.4 million to CarbonPlus Fund. This will support greenhouse gas reduction by changing how controlled burns are conducted, reforestation and improving carbon sequestration in soils (Department of Environment and Heritage Protection, 2017).

In addition to government actions, private organisations such as CarbonNeutral (www.carbonneutral.com.au) help private organisations to reduce and offset their greenhouse gas emissions through biodiverse revegetation of marginal farmland.

Existing provisions allow for carbon farming and carbon credits, for example the Emissions Reduction Fund. These can be further supported by state governments by offsetting their own emissions or tying carbon reduction to other environmental goals, such as restoring biodiversity and protection of waterways.

The cost of carbon sinks can be difficult to quantify, with sequestration of carbon estimated to cost as little as $5 a tonne to over $100 per tonne, depending on the project (Evans, et al., 2015). Some technologies can have a cost saving, such as developing and rolling out farming practices that absorb carbon into the soil and improve crop and pasture productivity.

This measure was estimated as the benefit of both Victoria and Queensland spending an additional $2 million per year on carbon sinks, over the base case, with an estimated one tonne of carbon saved per $40 spent on average, at a modest estimate of 100 tonnes of C02e per hectare (CarbonNeutral, 2019).

Depending on the project, other benefits could include shelter and shade for livestock, reduced soil erosion, improvements in crop and pasture productivity, improvements in water quality, habitat for native animals and aesthetic improvements. As it is not possible to quantify all these benefits accurately an improvement in biodiversity of $28.62 per hectare of land used for a carbon sink is included in the model (Dumsday, 2007).

Electric vehicles

Transport is the second largest source of emissions in Australia, responsible for 18 per cent of emissions. Cars are responsible for almost half of transport emissions (Australian Government, 2017). Emissions have increased by 22 per cent since 2005 (Australian Government, 2017).[17]

Electric vehicles (EVs) will reduce transport-related emissions. This option would see 50 per cent of all new vehicles to be electric by 2030 with the roll out starting in 2020. Required infrastructure includes proper charging standards[18] and government fleets would need to be 100 per cent renewable by 2050.

The Queensland Government should continue and extend its current targets (Queensland Government, 2017) and the Victorian Government adopt similar targets to double the number of EVs in the fleet each year until fleet is fully electric.

The uptake of EVs would dramatically increase the use of electricity and require a simultaneous rapid increase in the capacity of renewable energy generation. The estimated electricity consumption of the Victorian vehicle fleet is likely to be between 21,700 and 24,100 GWh in 2046. A full EV fleet is forecast to add over 50 per cent to Victoria's total annual energy consumption in 2046 (Infrastructure Victoria, 2018). In Victoria EVs would reach cost parity with fossil fuel vehicles between 2025 and 2030 (Infrastructure Victoria, 2018). Bloomberg New Energy Finance (BNEF) recently predicted that unsubsidised EVs would reach cost parity to fossil fuel equivalents in the next five to six years.

EVs will:

- reduce emissions of $35 per tonne of CO2 abated (Electric Vehicle Council et al, 2018)
- reduce vehicles operating costs (average saving of $810 per vehicle per annum from 2018-2030 (Electric Vehicle Council et al, 2018)
- bring health benefits of $270 and $735 million per annum for Victoria by 2046, depending on size and composition of the fleet (Infrastructure Victoria, 2018).

The costs involve charging infrastructure, increased capacity of in energy generation, transmission and distribution infrastructure of between $5.2 and $9.7 billion in 2046 for Victoria alone. The net investment[19] nationally is estimated at $3.2 billion from 2018 to 2030 (Electric Vehicle Council et al, 2018), not including additional energy generation and transmission infrastructure.

This option estimates the cost of rolling out the electric vehicle fleet at the higher end of infrastructure rollout costs, based on Infrastructure Victoria estimates, with a total cost of $15.2 billion for Queensland and Victoria. This allows for the installation of additional power generation and grid capacity to support the development of sufficient electricity supply.

- Under the base case, $15.2 billion will be spent in Victoria and Queensland to roll out the electric vehicle infrastructure from 2022 to 2041. EVs will make up 25 per cent of new vehicles sold by 2030.

- Under the project scenario, $15.2 billion will be spent in Victoria and Queensland to roll out the electric vehicle infrastructure from 2022 to 2021. EVs will make up 50 per cent of new vehicles sold by 2030.
- From 2027, cost savings were estimated at $600 per additional electric vehicle under the project scenario.
- Health costs from reduction in petrol pollution, based on the Infrastructure Victoria study, were estimated at $2.7 million for each one per cent of the fleet that was electric in the project scenario compared to the base case.

Public and active transport

Increased use of public and active transport will help to curb emissions. Under the base case, planned investment in public and active transport will proceed. The project scenario assumes investments in (electrified) public transport will be brought forward and assumes increased investment in active transport (walking and cycling).

Public and active transport represent 17.5 and 11.8 per cent of journeys to work in Victoria and Queensland respectively (ABS Census, 2016).

Investments in active transport include expanding networks, improving standards, separating walking and cycling paths from other road uses, and identifying locations for grade-separated bicycle highways.

Increasing public and active transport will:

- reduce emissions
- reduce road congestion and related travel time savings
- bring health benefits, including reduced road crash costs.

The benefits of reducing urban car travel by five per cent through increased use of public transport equate to an emissions reduction of 1.6 MtCO2e (between 2010 and 2020) and net savings of $6 per tCo2e (ClimateWorks, 2010). Modelling for the Garnaut Review (2008) found that by switching from road to rail, commuters on Victoria's Regional Rail Link travelling between Wyndham Vale and the CBD would save an average of 4.7 tonnes of carbon dioxide emissions per person per year.

Due to uncertainty around the development of public and active transport rollouts, including their final costs, the number of people that will be diverted to public transport and active transport from a given unit of infrastructure investment, the outcomes of active and public transport are discussed qualitatively only.

Energy efficient buildings

This option would require all new buildings to meet at least eight-star energy ratings to reduce energy use in residential and commercial buildings by 2050.

ClimateWorks estimates emissions from buildings could reduce by 97 per cent to 2050, mostly driven by reduced energy use and a shift to renewables.[20] Achieving eight-star new build by 2050 would reduce energy use for heating and cooling by more than 80 per cent compared to current building stock (NatHERS, 2013). The required technologies are mostly available, with higher upfront costs offset by lower operating costs. Increased energy efficiency of buildings in Australia could see energy use drop by 24 per cent across the entire stock (old and new) by 2050[21] (ClimateWorks Australia, ANU, CSIRO and CoPS , 2014).

The higher construction costs and capital costs of installations, systems and appliances are typically offset by lower operating and maintenance costs. The cost of this option is therefore assumed to be net zero.

In addition to emissions reductions of 7 and 12 per cent against current levels, an important co-benefit is the enhanced living comfort; however, this benefit is difficult to quantify in dollar terms.

Table 2: Estimated reduced emissions of introducing minimum eight-star energy rating for buildings

	Queensland	Victoria
Total emissions (Mt CO2-e)	153	115
Direct and indirect emissions commercial and residential buildings	44.8	56
Total reduction in emission by 2050 due to reduced energy use	24%	24%
Emission reduction due to 8 star rating and more efficient systems and appliances	10.752	13.44
Emission reduction due to 8 star rating and more efficient systems and appliances as share of total emissions	7%	12%

Source: SGS (2019), based on (ClimateWorks Australia, ANU, CSIRO and CoPS , 2014), (Commonwealth of Australia, 2018)

Green urban design

This option would see investment in green infrastructure in cities to reduce energy use in buildings. Green infrastructure can consist of green roofs and walls, street trees, parks, grass and public open space.

Green infrastructure in cities, particularly trees, can:

- regulate temperature and improve urban amenity: reductions from 1 to 8 °C can be expected due to the presence of tree cover (Myrup, 1993)
- reduce energy use in adjacent buildings (Simpson, 1998)
- reduce stormwater run-off
- improve air quality via the absorption of air pollutants (Nowak, 1999)
- improve property value due to enhanced aesthetics of the area
- reduce maintenance costs of footpaths
- Benefits per tree were determined in a study for Adelaide in 2002 and from Moore (2009). These benefits were indexed to 2019 values (Table 3).

Table 3: Benefits of urban trees, per tree

Benefit category	Benefits	GHG emissions saved/sequestered (kg)
Benefits per tree - one off		
Carbon sequestered in trees	$250.00	12,500
Water saving from electricity generation	$0.45	
Prolonged life of bitumen paths	$472.50	
Benefits per tree - annual		
Street tree value	$150.00	
Electricity saving	$5.10	
Carbon emissions saved (kg)	$0.72	1.2
Reduction in air pollution	$50.98	

Note: values updated to 2019 $ value. Source: (Treenet, 2019)

Costs of establishing and maintaining trees can vary by tree type and its life expectancy, with jacarandas costing $3650 for a 90-year lifespan and blue gums $2877 for a 60 year lifespan (City of Mitcham, 2014). For trees to last the expected 56-year duration of the cost benefit analysis, an upfront cost of $3000 per tree was estimated.

Cost benefit analysis

A cost benefit analysis (CBA) was undertaken of the best practice options. The CBA applies to Queensland and Victoria specifically, but the results are broadly also applicable to other states and territories.

This cost benefit analysis (CBA) has been conducted in line with Victorian and Queensland Government Treasury guidelines for cost benefit analyses, with some methods varying due to differences in requirements (for example, with respect to discount rates).

The CBA has been conducted over the period from 2019 to 2075 in 2019 Australian dollars, with results tested at five per cent and seven per cent discount rates. The benefits of saving one tonne of carbon dioxide have been estimated at $35/tonne, which is independent of market prices on carbon reduction.

Analysis of options and comparison to the base case

The base case and the project scenario are based on what the Victorian and Queensland governments can do to reach zero net emissions in both states by 2050. In some cases, this involves bringing forward actions that may have occurred through the free market or other state expenditure and planning patterns; in other cases it involves investing in emissions reduction that may not otherwise occur.

Key findings

This CBA estimates the value of social, economic and environmental benefits that will come if state governments act to reduce climate change impacts. As noted in the discussion, there are several co-benefits of action by state governments, which include:

- lower interest on debt due to lower perceived risk
- increases in agricultural productivity
- lower costs for households and businesses from low-emission technologies
- improvements in biodiversity
- improved urban air quality
- improved comfort and lower health risks
- commercial benefits from developing and selling emissions reduction technology.

Where possible, these co-benefits have been quantified in the CBA.

These options, as modelled, will reduce greenhouse gas emissions over the base case of 627 million tonnes from 2020 to 2075, at a total cost of $3.6 billion under the base case at a seven per cent discount rate. This investment also results in $16.2 billion of benefits, and a benefit to cost ratio of 5.5 to 1.

The greatest net benefit comes from cost savings from EVs. Since this option allows for over 2 million more EVs on the road compared to the base case, at a cost saving of $600 per vehicle, further benefits flow from of rolling out the infrastructure to allow citizens to receive cheaper technology more quickly. The results of the CBA are shown in Table 4.

As mentioned earlier, mitigation of climate change is determined at the global level and emissions reductions in Australia have a marginal impact.

Even when the benefit of reduced emissions ($7.5 billion) is excluded, the analysis shows that the transition to a low-carbon economy is a sound strategic objective generating (co-)benefits that outweigh the costs at 2.8 to 1.

Table 4: Cost Benefit Analysis results

Discount rate	3%	5%	7%	10%
Costs of investment ($m)				
Agriculture	$18	$17	$16	$14
Carbon sinks	$74	$58	$43	$31
Electric vehicles	$2,250	$3,009	$3,419	$3,645
Street trees	$58	$45	$35	$26
Energy efficient buildings	$0.00	$0.00	$0.00	$0.00
Emissions management scheme	$78	$59	$47	$34
TCFD	$58	$49	$43	$35
Total costs	**$2,536**	**$3,235**	**$3,603**	**$3,785**
Benefits ($m)				
Reduction in CO2e (Mt)	627	627	627	627
Value of C02e saved	$13,218	$9,805	$7,487	$5,243
Increase in agricultural production	$148	$116	$92	$66
Biodiversity benefits	$7	$5	$3	$2
Improved air quality	$907	$605	$413	$242
Cost savings from electric vehicles	$23,782	$15,658	$10,508	$5,979
Savings from adopting TCFD	$2,209	$1,698	$1,322	$927
Total benefits	**$40,271**	**$27,887**	**$19,825**	**$12,460**
Net present value ($m)	$37,735	$24,652	$16,222	$8,674
Benefit cost ratio	15.9	8.6	5.5	3.3

Sensitivity analysis

To test the sensitivity of the results to these assumptions, the CBA was recalculated using more conservative assumptions:

- value of carbon emissions savings reduced from $35/tonne to $20/tonne
- interest rate savings reduced to 0.5 per cent
- increased costs of implementing programs by 20 per cent
- a halving of the increase in agricultural production.

Even under these unfavourable conditions, the benefit cost ratio remains positive at 3.8 with a discount rate of seven per cent.

Table 5: Sensitivity analysis results

Discount rate	3%	5%	7%	10%
Costs of investment ($m)				
Agriculture	$22	$20	$19	$17
Carbon sinks	$87	$67	$52	$37
Electric vehicles	$2,700	$3,611	$4,103	$4,374
Street trees	$70	$53	$42	$31
Energy efficient buildings	$0.00	$0.00	$0.00	$0.00
Emissions management scheme	$93	$71	$56	$41
TCFD	$70	$59	$51	$41
Total costs	**$3,043**	**$3,882**	**$4,324**	**$4,542**
Benefits ($m)				
Reduction in CO2e (Mt)	627	627	627	627
Value of C02e saved	$7,547	$5,599	$4,276	$2,995
Increase in agricultural production	$74	$58	$46	$33
Biodiversity benefits	$7	$5	$3	$2
Improved air quality	$907	$605	$413	$242
Cost savings from electric vehicles	$23,782	$15,658	$10,508	$5,979
Savings from adopting TCFD	$1,578	$1,213	$944	$662
Total benefits	**$33,895**	**$23,138**	**$16,191**	**$9,913**
Net present value ($m)	$30,851	$19,256	$11,867	$5,371
Benefit cost ratio	11.1	6.0	3.7	2.2

Recommendations

The benefits of mitigating the impacts of climate change and its damages far outweigh the costs. Even when disregarding the benefits of emissions reductions from a climate mitigation point of view, the economic benefits of the transition generously outweigh the cost.

While this business case is specific to Queensland and Victoria, it highlights that all Australian states and territories have many options at their disposal to support the transition. Boosting renewable power generation and use should be a priority. A state-based EMS for the energy sector could enable sectors throughout the economy to transition effectively.

Sector-specific options targeting transport, agriculture and land use will drive change and employment opportunities, especially as these sectors undergo drastic change.

Disclosing and planning for climate-related financial risk is elementary not only to government but also to business. It will enhance the risk profile and open up access to affordable investment capital in the long term.

This business case has only quantified the benefits of climate-related disclosure for the Queensland and Victorian governments and related entities. As state-level procurement will require climate-related risk disclosure, the benefits will ripple through the economy, thereby enhancing the risk profile of the entire investment climate of Queensland and Victoria.

While this section considers the costs and benefits of the options for Queensland and Victoria specifically, it is expected similar outcomes would apply to other states and territories.

Next steps

This Issues Paper provides insight into the costs and benefits of transitioning to a low-carbon economy at the state level. The results are high-level in line with the available time and resources. Ideally, next steps would:

- undertake detailed regional economic analysis on the optimum set of policy options and nuances by each state and territory that reflects regional specific circumstances
- quantify the economy-wide benefits of climate-related risk disclosure and planning to the investment climate of Queensland and Victoria
- monetise benefits that were not quantified in this paper
- extend the econometric GTAP-IAM model to directly calculate damages and allow for more seamless comparison of damages to the costs of emissions reduction at various temperature levels
- provide an in-depth business case to inform policies to achieve a low-carbon future.

[1] Including community, stakeholder and investor expectations

[2] Corporations Act 2011 s297 (note re true and fair view of performance and prospects) and s299A (need to report on information reasonably required by shareholders to make an informed assessment on position, strategy and prospects)

[3] Which means assuming an increase in global temperatures of roughly 3.6 to 4 degrees Celsius

[4] Based on an assessment of 15 million addresses in Australia, tested against six extreme hazards – flood, coastal inundation, bushfire, wind storms, heat-waves and soil subsidence

[5] This issues paper considered one scenario only. Variations may be tested in the future.

[6] For example, the elimination of subsidies for fossil fuel use was eliminated because most subsidies are determined at the national level, and State subsidies were neutral regarding source of energy or were supporting affordable energy in remote areas or to disadvantaged community members. Elimination of such subsidies would adversely affect vulnerable community members.

[7] The following sources confirm that sustainable businesses, and businesses taking environmental risks into account perform better: (RIAA, 2018), (ACFS, 2019), (Verheyden, 2016) and (Kotsantonis, 2016)

[8] Is the return an investor realises on a bond. The yield is a function of the bond's price and its interest payment.

[9] A swap spread is the difference between the fixed component of a given swap and the yield on a sovereign debt security (like Australian Government Securities) with a similar maturity. Because a Treasury bond is often used as a benchmark and its rate is considered to be default risk-free, the swap spread on a given contract is determined by the perceived risk of the parties engaging in the swap. As perceived risk increases, so does the swap spread. In this way, swap spreads can be used to assess the creditworthiness of participating parties

[10] Average risk premium from 2005 to 2019 and for bonds with tenors ranging from 3 to 10 years

[11] More extreme proxies would for instance be comparing Prime to Speculative rated bond yields.

[12] The direct investment model has been criticised as a model to enhance power reliability due to the possible crowding out effect (Grattan Institute, 2019). The criticism does not address the suitability of the model as a tool transition to a low-carbon economy. The ACCC has concerns about state owned generators from a competition perspective with previous state owned generators resulting in higher prices for customers. (Financial Review, 2017) The ACCC also notes that CleanCo is unlikely to drive competition in the market. (Brisbane Times, 2018)

[13] This successful model was ended with the expectation it would be replaced by a national ETS or an ETS scheme covering the National Electricity Market

[14] There is potential for States to set up a joined ETS scheme. In this option it is assumed Queensland and Victoria both set up an ETS for the electricity sector.

[15] The NSW scheme achieved abatement of around 5-8 million tCO_2 a year. (Grattan Institute, 2011)

[16] Types of abatement outcomes (based on NSW scheme) include: the building of new low-emissions-intensive generation plant, the greater use of existing low-emissions power plant, and efficiency improvements to existing power stations, the building of smaller generation and cogeneration plant fuelled by waste methane from landfill, sewerage and putrescible waste, the capture and combustion of waste coal mine gas, to convert it from methane (which has a high global warming potential) to carbon dioxide (which has a much lower global warming potential) before venting it to the atmosphere, improvements in fuel efficiency and production processes at large industrial sites, tree planting and maintenance projects on farming land, small scale projects such as replacing energy inefficient appliances and technologies (globes etc) in households.

[17] Climate Council of Australia (2018) Australia's Rising Greenhouse Gas Emissions https://www.climatecouncil.org.au/wp-content/uploads/2018/06/CC_MVSA0143-Briefing-Paper-Australias-Rising-Emissions_V8-FA_Low-Res_Single-Pages3.pdf

[18] Federal Chamber of Automotive Industries recommends introduction of standards

[19] Net investment refers to the increased investment in EV charging infrastructure and the reduced investment in areas such as fuel infrastructure

[20] The shift to renewables is addressed separately

[21] This includes growth of the residential and commercial stock

References

Australian Bureau of Statistics (ABS), 2016, Census of Population and Housing. Commonwealth Government of Australia.

Australian Centre for Financial Studies (ACFS), 2018. 5220.0 Australian National Accounts: State Accounts. Commonwealth of Australia. *Socially Responsible Investing in Australia*. Viewed on: https://australiancentre.com.au/publication/socially-responsible-investing-australia-2/

Australian Institute of Company Directors (AICD), 2018, *Climate change and your Board's Risk Strategy* (Webinar) Viewed on May 2019 https://www.cahootlearning.com/webinars/aicd/seminars5/7856/preview.html.

Barret, C. & Skarbek, A., 2019. *Climate Risk and the Financial System: Lessons for Australia from the international experience*, Monash Sustainable Development Institute, Melbourne.

Caldwell, F. 2018. LNP rejects recommendation to sell Queensland energy assets, Viewed 22 May 2019 https://www.brisbanetimes.com.au/politics/queensland/lnp-rejects-recommendation-to-sell-queensland-energy-assets-20180711-p4zqsr.html

CarbonNeutral, 2019. Carbon Neutral FAQs. Viewed on: https://carbonneutral.com.au/faqs/

Chapman, R. e. a., 2018. 'Cost Benefit Analysis of an Active Travel Intervention with Health and Carbon Reduction Benefits', *International Journal of Environmental Research and Public Health,* Vol. 15, no. 5, pp. 962.

City of Mitcham, 2014. Tree Strategy 2016-2025, Viewed 22 May 2019 http://www.mitchamcouncil.sa.gov.au/treestrategy.

ClimateWorks, 2018. *Tracking progress to net zero emissions. September 2018. National progress on reducing emissions across the Australian economy and outlook to 2030*, ClimateWorks Australia, Melbourne.

ClimateWorks Australia, ANU, CSIRO and CoPS, 2014. *Pathways to Deep Decarbonisation in 2050: How Australia can prosper in a low carbon world: Technical report*, ClimateWorks, Melbourne.

ClimateWorks, 2010. *Low Carbon Growth Plan for Australia*, ClimateWorks, Melbourne.

Commonwealth of Australia, 2018. *National Inventory by Economic Sector*, Commonwealth of Australia, Canberra.

CSIRO, 2019. Futurefeed, Viewed 22 May 2019 https://research.csiro.au/futurefeed/

Debelle, G. 2019, Climate Change and the Economy (Speech to Public Forum hosted by the Centre for Policy Development). Viewed 22 May 2019 https://www.rba.gov.au/speeches/2019/sp-dg-2019-03-12.html

Department of Environment and Heritage Protection, 2017. *Pathways to a clean growth economy - Queensland*

Climate Transition Strategy, Queensland Government, Brisbane.

Dumsday, R., 2007. *Employing Benefit Transfer in Environmental Applications - The View from the Real World*. Australian National University, Canberra.

Electric Vehicle Council et al, 2018. Recharging the Economy: The economic impact of accelerating electric vehicle adoption. Viewed on 22 May 2019 http://electricvehiclecouncil.com.au/wp-content/uploads/2015/05/Recharging-the-economy.pdf.

Energetics, 2019. Insights into the recommendations of the FSB on climate-related financial risks. Viewed on 22 May 2019 https://www.energetics.com.au/insights/thought-leadership/insights-into-the-recommendations-of-the-fsb-on-climate-related-financial-risks.

Evans, M. C. et al., 2015. Carbon farming via assisted natural regeneration as a cost-effective mechanism for restoring biodiversity in agricultural landscapes. *Environmental Science & Policy*, Vol. 50, pp. 114-129.

Grattan Institute, 2011. Learning the hard way: Policies to reduce emissions. Viewed on 22 May 2019 https://grattan.edu.au/report/learning-the-hard-way-australias-policies-to-reduce-emissions/

Grattan Institute, 2019. Keep calm and carry on: Managing electricity reliability. Viewed on 22 May 2019 https://grattan.edu.au/report/keep-calm-and-carry-on/

Hartcher, P. 2019 'Australia can be 'superpower of post carbon world', says Ross Garnaut', *Sydney Morning Herald*, 15 May, https://www.smh.com.au/federal-election-2019/australia-can-be-superpower-of-post-carbon-world-says-ross-garnaut-20190515-p51nsb.html

Hutley, N. and Hartford Davis, S. 2019, 'Climate change and directors' duties', The Centre for Policy Development, https://cpd.org.au/wp-content/uploads/2019/03/Noel-Hutley-SC-and-Sebastian-Hartford-Davis-Opinion-2019-and-2016_pdf.pdf

Investor Group on Climate Change (IGCC), 2018. *Scaling Up: Investing for low carbon solutions*, Accessed 18 May 2019 https://igcc.org.au/wp-content/uploads/2018/08/IGCC_Report-low-carbon-solutions_Aug2018.pdf

Independent Pricing and Regulatory Tribunal, 2013. NSW Greenhouse Reduction Scheme: Strengths, weaknesses and lessons learned. Viewed 15 May 2019 https://www.ipart.nsw.gov.au/Home/Industries/Greenhouse-Gas-Reduction-Scheme/NSW-Greenhouse-Gas-Reduction-Scheme-Strengths-weaknesses-and-lessons-learned-Final-Report-July-2013

Infrastructure Victoria, 2018. *Advice on Automated and Zero Emissions Vehicles Infrastructure*, Infrastructure Victoria, Melbourne.

Kotsantonis, S. et al, 2016. 'ESG Integration in Investment Management: Myths and Realities'. *Journal of Applied Corporate Finance,* Vol. 28, No. 2, pp. 10-16.

Ludlow, M., 2015. 'Origin Energy to ditch coal assets'. *Australian Financial Review*. Viewed 25 May 2019, https://www.afr.com/business/energy/origin-energy-to-ditch-coal-assets-20151020-gkdwam

Ludlow, M. 2017 'State-owned power companies entrench high prices, says Australian Energy Regulator', *Australian Financial Review*, 17 July. Viewed 25 May 2019 https://www.afr.com/news/politics/stateowned-power-companies-entrench-high-prices-says-australian-energy-regulator-20170718-gxdd1z

Meat & Livestock Australia, 2017. *Red meat industry can be carbon neutral by 2030*. Viewed 22 May 2019 https://www.mla.com.au/news-and-events/industry-news/red-meat-industry-can-be-carbon-neutral-by-2030/

Moore, G. M., 2009. *Urban Trees: Worth More than they Cost*, University of Melbourne.

Myrup, L.O. et al., 1993. 'An Analysis of Microclimatic Variation in a Suburban Environment.' *Atmospheric Environment*, 27B, pp. 129-156.

Nowak, D., 1999. *The Effects Of Urban Trees On Air Quality*, USDA Forest Service, Syracuse, NY.

Premier of Victoria, 2016. Victorian Green Bonds An Australian And World First. Viewed 22 May 2019 https://www.premier.vic.gov.au/victorian-green-bonds-an-australian-and-world-first/

Queensland Government, 2017. *Electric Vehicles Strategy*, Queensland Government., Brisbane.

Queensland Government, 2019. CleanCo Fact Sheet. Viewed on https://s3.treasury.qld.gov.au/files/18-118_FG-CleanCo-A4-Fact-Sheetv2.pdf

Queensland Government, 2018. Queensland public service workforce statistics, *December Quarterly Workforce Profile*. Viewed on https://www.forgov.qld.gov.au/queensland-public-service-workforce-statistics

Queensland Government, 2019. Transition to a zero carbon economy. Viewed on 22 May 2019 https://www.qld.gov.au/environment/climate/climate-change/transition

Queensland Government, 2019. Queensland contracts directory awarded contracts, Viewed on 15 May 2019 https://data.qld.gov.au/dataset/queensland-government-contracts-directory-awarded-contracts

Reserve Bank of Australia (RBA), 2019, Reserve Bank of Australia - Statistical Tables. Viewed on https://www.rba.gov.au/statistics/tables/?v=2019-05-15-12-15-48#interest-rates

Responsible Investment Association Australia, 2018. Responsible Investment Benchmark Report, 2018 Australia. Viewed on https://responsibleinvestment.org/wp-content/uploads/2018/08/RIAA_RI_Renchmark_Report_AUS_2018v8.pdf

Satori, R., 2016. 'Estimation of climate change damage functions for 140 regions in the GTAP 9 database'. *Journal of Global Economic Analysis,* Vol 1, no. 2, pp. 78-115.

Simpson, J.R. & McPherson, E.G., 1998. 'Simulation of tree shade impacts on residential energy use for space conditioning in Sacramento'. *Atmospheric Environment: Urban Atmospheres*, Vol 32, pp. 69-74.

State of Victoria (Victorian Public Sector Commission), 2018. *State of the Public Sector in Victoria 2017-18*, State of Victoria, Melbourne.

Steffen, W., Mallon, K., Kompas, T., Dean, A., and Rice, M., 2019. *Compound Costs: How climate change is damaging Australia's Economy*, Climate Council of Australia, Sydney.

Task Force on Climate-Related Financial Disclosures (TCFD), 2017. Final Report: Recommendations of the Task Force on Climate-related Financial Disclosures. Viewed 22 May 2019 https://www.fsb-tcfd.org/wp-content/uploads/2017/06/FINAL-TCFD-Report-062817.pdf

Task Force on Climate-Related Financial Disclosures (TCFD), 2019. *supportive quotes*. Viewed on https://www.fsb-tcfd.org/supportive-quotes/

Treenet, 2019. Treenet. Viewed on 20 May 2019 https://treenet.org/resources/the-benefits-of-adelaides-street-trees-revisited/

United Nations Environment Programme (UNEP), 2019. *Climate change*. Viewed on https://www.unepfi.org/climate-change/climate-change/

Verheyden, T., Eccles, R. G., & Feiner, A, 2016. 'ESG for All? The Impact of ESG Screening on Return, Risk and Diversification'. *Journal for Applied Corporate Finance*, Vol 28, no 2, pp. 47-55.

Vesey, A., 2017. Getting out of coal is a simple message, but a challenging task. Viewed 2 May 2019 agl.com.au

Victorian Government Purchasing Board, 2018. *VGPB Annual report 2017-18*, Victorian Government, Melbourne.

Victorian Government, 2019. Emissions reduction targets. Viewed on https://www.climatechange.vic.gov.au/reducing-emissions/emissions-targets

Appendix 1

Economic damages from climate change and the costs of emissions reduction

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Summary

Extending two different intertemporal and optimal global trade models, based on Kompas et. al., (2018a, 2018b), and recent work contained in Steffen et al., (2019), this paper provides cumulative measures of the damages from climate change out to 2100 for Australia and compares the costs of emissions reduction relative to potential damages, without significant action to reduce emissions, to 2030.

From 2019 forward, we first calculate the potential damages from climate change for 139 countries for the 4 degree scenario for global warming at 2100. The cumulative damages for Australia, drawn from this framework, and hence the potential avoided costs from emissions reduction, are $584.5 billion in 2030, $762 billion in 2050, and over $5 trillion in 2100 (see Steffen et al. 2019 and Appendix 1).

The damage functions themselves are very limited, focusing on losses in agricultural and labour productivity, limited human health effects and infrastructure damage. In other words, the cost of damages to environmental assets, a large portion of fire and flood events (other than those generating the infrastructure damage accounted for in the estimates), the effects of pollution and losses in biodiversity that go with temperature increases are not included.

It's also important to emphasise that the cumulative losses to 2030 of $584.5 billion do not account for recent damages from fire and drought in Australia.

The $5 trillion in cumulative losses to 2100, given our projections for economic growth (Kompas, 2018b), with 4 degree warming, are roughly 1.3 per cent of cumulative GDP from now until 2100. Annual damages from 2100, going forward, are 2.4 per cent of GDP per year for Australia. These damages are significant, keeping in mind that the damage functions are very limited. Indeed, national averages can also be misleading. Much like in the global context, across countries, they hide regional and often considerable variation in damages.

In this work, neighbouring countries, many of whom are major trading partners with Australia, experience much more severe damages. Losses in GDP in the region in 2100, again annually, and underscoring the importance of the possible variation in damages, range from 12-24 per cent of GDP. These figures are comparable if not exceeding country losses in GDP in the Great Depression of the 1930s.

Next, we calculate the costs of emissions reduction in Australia using either a price on carbon or a (model-equivalent) renewables target. As yet, we are not able to extend the emissions reduction model to 2100 for the two degree target. In this preliminary version of the work, we instead report only to 2030 using an SSP2 scenario (IASSA, 2019) and construct a baseline case for emissions reduction in a global model across 20 regions/countries and 30 commodity groups.

We assume that Australia meets its minimum Paris Accord commitment in 2030 with at least a 26 per cent reduction in emissions compared to 2005 (DEE, 2018), and all other regions/countries reduce

emissions by more than double the current unconditional 'Nationally Determined Contribution' in the Paris Accord (UNEP, 2018), or a 12 per cent reduction in emissions on average.

These reductions are considerably less than current policy and 'business as usual', either for Australia or for the global average, and far less than the reductions needed to reach a two degree target in 2100.

By this calculation, the cumulative costs of emissions reduction for Australia are $35.5 billion from 2019-2030, or roughly 0.14 per cent (.0014) of cumulative GDP over this period. In other words, GDP going forward to 2030 would only be marginally smaller. Indeed, on this modelling, using baseline prices, cumulative GDP from 2019 rises throughout and reaches $25.4 trillion in 2030, with negligible impact from emissions reduction. The cost of emissions reduction include any losses in net exports due to falls in emissions globally. To meet the 26 per cent emissions reduction target, model results indicate that Australia needs to gradually increase the price on carbon to $40/tco2 (2011 prices).

In this baseline scenario there will still be damages from climate change going forward, given the 26 per cent target, although they are much less. Since we do not have results for infrastructure damages in 2030, under the 26 per cent target, we are (as yet) unable to give precise estimates.

Model results thus far, up to 2030, are generated mostly in terms of a substitution effect or a change in the composition of demand between fossil fuel sources of energy relative to renewables, compared to the baseline scenario. We make very little assumptions on technological progress, save for a technology equivalent change in the price and output response of renewable energy, given that renewable prices are falling rapidly (IRENA, 2018), along with projected increases in resource efficiency.

As a result, the estimates for the costs of emissions reduction will be larger than will likely occur in practice. In other words, 2030 mitigation costs, if anything, are likely to be overstated in this model context, given the rapid rise in renewables competitiveness. There are always limitations in economy-wide modelling in representing, in particular, the turnover of high-emissions to low-emissions capital equipment – replacement of ageing high-emissions equipment in reality may happen more quickly and at lower cost than in this economic model, or even at zero cost.

The implication here, given that the target is conservative and clearly achievable, is that Australia should be able to do even better in terms of lowering the costs of emissions reduction than indicated in the baseline scenario. Government subsidies to encourage renewable energy and needed infrastructure, changes in land-use policy that favour forests, more energy efficient forms of transportation and the faster and more efficient development of carbon capture and offsetting technologies will all generate substantial falls in the cost of emissions reduction, even with more aggressive emissions reduction targets.

Overall, the costs of emissions reduction are far less than the damages of inaction in all scenarios that we have examined, knowing that we have badly underestimated damages from climate change and likely overestimated the costs of emissions reduction.

All technical details and some of these additional effects will be captured in the '2 degree at 2100' technical report that supports the baseline estimates given here and extends them to zero net emissions globally in 2050. The effects of variations in assumptions, across different scenarios, most importantly, will also be included. The costs of emissions reduction reported here are also supported by third model, a 30 region/country, 30 commodity, dynamic adaptive version of the GTAP power and energy model.

Introduction

Economists have largely underestimated the potential damages from climate change, owing in part to the use of dimensionally small computational models that aggregate commodities and countries into a few regions and/or commodities, with substantial averaging. Some intertemporal models have as few as 12 regions, and even more limited numbers of commodities. This averaging systematically misses the effects of extreme damages, and changes in these damages that occur at the 'tails' of the distribution. This averaging also makes it impossible to accurately capture the costs of emissions reduction relative to the avoided damages (i.e., the benefits) that go with falls in emissions.

Much of the current debate on climate change, indeed, focuses only on the costs of mitigation, which can be large, depending on how quickly an economy transitions from fossil to renewables in its energy mix. **But the question is how large those costs are relative to the damages we avoid as a result of a transition from fossil fuels.**

This component of the project draws on two intertemporal model results, with optimizing behaviour by producers and consumers. Both models have a large dimensional platform, using parallel processing techniques, which allows specific information for Australia, at the national level, to be obtained, or 'backed-out', while still capturing global trading relationships and emissions trends.

The first model, GTAP-INT, builds on recent studies (Kompas et al., 2018a, 2018b), which have been highlighted in Steffen et al., (2019), to account for cumulative damages from climate change for 139 countries in a global trade model, across more than 50 sectors or commodity groups, from 2019 to 2100. Results are obtained at various global temperature increases. Although Australia suffers relatively less harm in this modelling compared to its neighbours in the region, the damages are still substantial.

The second model, GTAP-IAM, draws on preliminary work to determine the relative costs of emissions reduction for Australia in a 20 region/country, 30 commodity model, as an extension of Kompas (et al., 2018a), in the form of an 'integrated assessment model'.

The comparison of the two models allows for a determination of the costs of emissions reduction compared to the benefits in terms of avoided damages with current policy. The GTAP-IAM model uses SSP2 (IASSA, 2019) as its baseline, for projections on population and economic growth. The cost of mitigation depends very much on the relative price trajectory for renewables compared to fossil fuels and the size of the price on carbon. The less expensive renewables become over time the less costly the transition.

The transition itself from fossil fuels to renewables can be obtained either through setting a price on carbon or by setting renewable targets, as a proportion of the total energy mix, at certain points in time. There are differences in the use of both instruments, but in a model context they are directly comparable. The costs of emissions reduction are taken as losses in GDP from baseline as a result of the price on carbon.

Damages

The damages from climate change are also the avoided costs from the successful mitigation of greenhouse gas emissions. In this model, damages are expressed in 'real terms' using a five per cent discount rate (endogenously determined in the model) to convert future losses into current dollars. The estimates follow a (roughly) four degree increase in global temperatures in 2100.

The data and parameter values (e.g., elasticities of substitution between fossil fuels and renewables) for the models are drawn from a publicly available source, the Global Trade Analysis Project (GTAP), and published damage functions for the effects of climate change (GTAP, 2019 and Roson and Satori, 2016). GTAP, itself, is the current and most comprehensive global general equilibrium and trade model, which can simulate the trade interactions between 140 countries/regions in the world and more than 50 commodity groups. At its core, GTAP, along with government, consists of two broad agents: regional households and producers. Producers produce and sell commodities to households. They use revenue from sold output to pay for productive inputs, which includes intermediate commodities and primary production factors, or land, natural resources, different kind of labour, and capital. Regional households receive income from owning productive factors to form income, which they divide into three expenditure categories: government expenditure (through taxes), private expenditure, and savings. In the GTAP model, saving is used to finance investment, which adds to the capital stock. The investment process in GTAP is modelled in a way similar to that of other normal commodities. The producers use inputs to produce a capital good, which can be added to the current capital stock (less depreciation) to form the next period's capital stock. As the capital stock accumulates over time, the GTAP model can be used to simulate the dynamic evolution of the world economy, across all countries/regions, subject to expected rates of return on capital. All commodities can be sold or exchanged, and consumers and producers can buy goods either domestically or internationally.

In terms of damages, setting aside losses from infrastructure for the moment, and following, again, Roson and Satori (2016), potential damages from climate change in the modelling are limited to reduced agricultural and labour productivity, loss of arable land due to sea level rise and some health impacts. Reduced agricultural productivity arises from a combination of variables, including increasing average temperature, shifting precipitation patterns, rising atmospheric carbon concentrations and sea level rise (through reduced supply of arable land). Reduced labour productivity arises from increased heat stress, measured using a heat stress index that takes both temperature and humidity into consideration (Kompas et al., 2018b and Steffen, et al., 2019).

Infrastructure damages are drawn directly from Steffen et al., (2019), based on an assessment of 15 million addresses in Australia, tested against six extreme hazards – flood, coastal inundation, bushfire, wind storms, heat-waves and soil subsidence (the sinking or settlement of soil). The financial impacts were based on the projected probability of damage to each property and their replacement costs for each of the hazards and for each year to 2100.

In terms of the time trend, total cumulative damages for the 4 degree case increase dramatically from 2050, stressing the importance of acting quickly to reduce emissions now. In 2050, infrastructure damages are $611 billion and losses in agricultural and labour productivity are $151 billion, or $762 billion in total. In 2030, the cumulative damages to infrastructure are $571 billion and agricultural and labour productivity losses are $13.5 billion (Steffen et al. 2019; Kompas et al., 2018b), for a total of $584.5 billion, noting (again) that all amounts are in AUD dollars and the discount rate is five per cent.

Costs of emissions reduction

The cost of emissions reduction model again uses the GTAP data base and modelling approach, now extended for energy flows and power mix – a combined GTAP E (Energy) and P (Power) model (Burniaux and Truong, 2002; Peters, 2016a,b), with a climate model module following the core equations in Glotter et al. (2014) and Manne et al. (1995).

The model includes specific country and regional categories: China, Australia, Japan, Korea, USA, France, Germany, UK, India, Middle East and North Africa, Sub-Saharan Africa, Latin America, Italy, Southeast Asia, Korea, Canada and Mexico, East Asia, Rest of the European Union, the Russian Federation, North America, and the Rest of the World. Commodities include oil, gas, coal, oil products, renewables, electricity generated from fossil fuels, electrical energy generated from renewables, construction, transport, services, forestry and fishing, and other manufacturing and agricultural goods.

In total, there are 20 countries/regions and 30 commodity sectors. We designate possible paths for future growth in GDP and population, given a SSP2 scenario, and will ultimately concentrate on the two degree case in 2100 in the full technical report. The preliminary baseline case to 2030, as indicated, estimates the costs for emissions reduction in Australia assuming it meets its Paris Accord minimum commitment of a 26 per cent reduction by 2030. We also assume in the base case that the rest of the world reduces global emissions by 12 per cent on average or double the unconditional Paris Accord target (UNEP, 2018).

The concept of a Levelized Cost of Energy (LCOE) is also applied for the analysis of future renewable prices in Australia and around the world (IRENA, 2018) to generate a technology equivalent for the fall in renewable prices. LCOE measures the cost of producing one extra unit of electricity with a newly constructed electricity generation plant. As a result, it is equivalent to the long-run marginal cost of power at a given point in time. The formula for calculating LCOE is based on investment costs, operation and maintenance expenditures, fuel expenditures, and the discount rate over a given number of years. The volume metric is normally expressed as 'million tonnes of oil equivalent' (MTOE). The model also includes resource efficiency changes over time but, at the moment, excludes a land-use component or any potential gains from enhanced forestry practices. Currently, the LCOE price of renewables is less than that of fossil fuel sources of energy in Australia and is falling rapidly. Changes in the price of renewables are handled in the model by a technology shift/shock parameter to mimic the price reduction and output response — with the price of renewables less than fossil-sourced energy going forward.

The costs of emissions reduction are measured by the fall in GDP as a result of placing a price on carbon and the losses in net exports as a result of reductions in emissions globally. A renewables target as a percentage of the energy mix would give a similar outcome in the model. The price on carbon represents a shift of revenues to the government budget which can be redistributed to households through lower income taxes, for example, or through other mechanisms (e.g., subsidies to renewables). It follows that the only real cost of the price on carbon is the efficiency loss, the so-called deadweight loss, that goes with a price instrument. We measure this loss in the model through incremental falls in GDP, knowing that the switch from fossil fuels to renewables will also recover GDP as the energy mix changes.

As indicated, we make very little assumptions on technological progress, save for projected increases in resource efficiency and a technology-equivalent change in the price and output response for renewable energy, given that these prices are falling rapidly (IRENA, 2018).

Next steps

This is a 20-region/country, 30 commodity global trade model, so results for Australia are at a national scale, obtained in a so-called 'top-down' manner. It would be ideal, given the global results, to build a 'bottom-up' model to allow for regional variation in Australia and capture all of the detail of the local electricity and overall energy markets. It would also be valuable to add in a land-use component to account for changes in forestry and land-use policy and other government initiatives to lower the costs of emissions reduction.

An extension that directly calculates the damages from climate change could be added directly to the GTAP-IAM model, allowing for a more seamless comparison of damages to the costs of emissions reduction at various temperature levels. This is possible and may be captured in the '2 degree at 2100' technical report to follow.

References

Burniaux, J. M. and Truong, T. 2002, 'GTAP-E: An energy-environmental version of the GTAP model', GTAP Technical Paper no.16.

Department of Environment and Energy, 2018, *Australia's emissions projections 2018*, Commonwealth of Australia, Canberra.

Global Trade Analysis Project (GTAP), 2019. Accessed on 19 May 2019, https://www.gtap.agecon.purdue.edu/

Global Energy Transformation: A Roadmap to 2050, 2019, International Renewable Energy Agency (IRENA), Abu Dhabi.

Glotter, M. J., Pierrehumbert, R. T., Elliott, J. W., Matteson, N. J. and Moyer, E. J. 2014, 'A simple carbon cycle representation for economic and policy analyses', *Climatic Change*, Vol 126, no. 3, pp. 319-335

International Institute for Applied Systems Analysis (IASSA), 2019, 'SSP database (shared socio-economic pathways), version 2.0', Viewed on 12 March 2019, https://tntcat.iiasa.ac.at/SspDb

International Renewable Energy Agency (IRENA), 2018, *Renewable Power Generation Costs*, International Renewable Energy Agency, Dubai.

Kompas, T. and Pham Van Ha, 2018a, 'The Curse of Dimensionality' Resolved: The effects of climate change and trade in large dimensional modelling,' *Economic Modelling*, in press.

Kompas, T., Pham Van Ha and Tuong Nhu Che, 2018b, 'The Effects of Climate Change on GDP by Country and the Global Gains from Complying with the Paris Climate Accord', *Earth's Future*, 6, 1153-1173.

Manne, A., Mendelsohn, R. and Richels, R. 1995, 'MERGE: A model for evaluating regional and global effects of GHG reduction policies', *Energy Policy*, Vol 23, no. 1,pp. 17 – 34.

Peters, J. 2016a, 'GTAP-E-Power: An electricity-detailed economy-wide model', *Journal of Global Economic Analysis* Vol. 1, no. 2, pp. 209–250.

Peters, J. 2016b, 'The GTAP-Power data base: Disaggregating the electricity sector in the GTAP data base', *Journal of Global Economic Analysis,* Vol 1, no. 1, pp, 209–250.

Roson, R. and Sartori, M. 2016, 'Estimation of climate change damage functions for 140 regions in the gtap 9 database', *Journal of Global Economic Analysis, Vol 1. no. 2, pp* 78–115.

Steffen, W., Mallon, K., Kompas, T., Dean, A and Rice, M. 2019, *Compound Costs: How Climate Change is Damaging Australia's Economy*, Climate Council of Australia, Sydney.

United Nations Environment Programme 2018, *Emissions Gap Report 2018*, United Nations Environment Programme, Nairobi.

Appendix 2

Table 6: Comparison of Australian corporate bond spreads and yields.

Tenor	Yield	Spread to AGS	Yield	Spread to AGS	Risk premium (yield difference)
3	4.86	128	5.61	204	0.75
5	5.17	144	5.97	223	0.8
7	5.49	163	6.20	234	0.71
10	5.81	176	6.53	248	0.72
Average	5.33	153	6.08	227	0.75

Notes: Non-financial corporate bonds. Averages from 2005 to 2019

Appendix 3

Apportionment methodology

Modelling by Kompas et al (2019) calculates the cumulative damages for Australia.

To apportion these costs to the states, and to Queensland and Victoria in particular, SGS considered and weighed equally three factors: assets and infrastructure at risk, the size of each State's agricultural sector and exposure of population to extreme heat. The associated indicators are historic losses due to natural perils (Productivity Commission 2014); value of agricultural production (ABS 2016); and future occurrence of extreme heat days by population (Loughnan et al 2013).

This allows a consideration of the infrastructure and agricultural impacts of climate change as well as the health and labour productivity implications of increased occurrences of extreme heat. Consideration of these three impacts recognises that the effects of climate change and the severity of these effects will be felt differently across the States. The inputs and the calculated apportionment are shown in Table 7 with a more detailed source and data description provided in Table 8.

Table 7: Apportionment inputs and weighting

	Historic asset losses	Value of agricultural production	Vulnerability to future extreme heat	Apportionment
NSW	37%	23%	33%	31%
Vic	16%	23%	20%	20%
Queensland	32%	24%	33%	29%
SA	1%	11%	2%	5%
WA	6%	15%	6%	9%
Tas	1%	3%	1%	1%
NT	6%	1%	1%	3%
ACT	1%	0%	5%	2%
Total	100%	100%	100%	100%

Table 8: Inputs and sources for apportionment

Input	Source	Description
Historic insurance losses	Productivity Commission (2014) Natural Disaster Funding Arrangements, Inquiry Report no. 74, Canberra as in SGS Economics and Planning (2016) At what cost? Mapping where natural perils impact on economic growth and communities. Prepared for IAG, November 2016.	Insurance losses by natural perils 1970-2013 includes impacts of bushfire, tropical cyclone, flood, storm, hail, earthquake.
Vulnerability to future extreme heat	Loughnan, ME, Tapper, NJ, Phan, T, Lynch, K, McInnes, JA 2013, A spatial vulnerability analysis of urban populations during extreme heat events in Australian capital cities, National Climate Change Adaptation Research Facility, Gold Coast, 128 pp.	Average number of days per year when temperature exceeds the threshold for maximum temperature (Tmax) [The first period of data (1990-2010) is taken from BoM observations and CCAM projections and future periods (2020-2040 and 2060-2090) are BoM observations added to the CCAM projections.]
Value of agricultural production	ABS 7503.0 - Value of Agricultural Commodities Produced, Australia, 2015-16	Proportion of agriculture production by value

Based on this indicative apportionment method, the possible damages by State are as follows.

Table 9: Indicative apportionment of possible damages due to climate change by State and Territory, in $B

	Apportionment indicator	2030		2050		2100	
NSW	31%	$	182	$	237	$	1,555
Vic	20%	$	115	$	150	$	986
Queensland	29%	$	171	$	223	$	1,465
SA	5%	$	27	$	36	$	235
WA	9%	$	53	$	69	$	450
Tas	1%	$	8	$	11	$	69
NT	3%	$	15	$	20	$	132
ACT	2%	$	13	$	17	$	109
Total	100%	$	585	$	762	$	5,000

Appendix 4

Summary of options and key assumptions

Table 10: Summary of options

	Base case	Project scenario	Impact of project case
Statewide adoption of TCFD	No State adoption of TCFD	State adoption of TCFD	Reduction in interest on State government debt Reduction in State emissions
Direct investment in clean energy supply	$250m investment from CleanCo	$500m investment from CleanCo $250m investment from Victoria in clean energy	No express impacts due to crowding out effects
Emissions Management Scheme for the energy sector	No EMS	EMS for Victoria, Queensland and other Operating costs of $5m per year	Costs from purchasing offsets Benefits from carbon abatement projects
Support for reducing methane emissions from ruminant animals	Industry carbon neutral by 2040	Industry carbon neutral by 2030 $5m investment from State governments	Increase in animal productivity of 0.1%
Carbon farming/carbon credits	No change	Additional $2m per year per state into carbon farming each year	100,000 tonnes of carbon sequestered Biodiversity improvements at $28.62/ha
Electric vehicles	$15b spent from 2022 – 2041 to roll out electric vehicle infrastructure 25% of new vehicles electric by 2030	$15b spent from 2020 – 2029 to roll out electric vehicle infrastructure 50% of new vehicles electric by 2030	Bringing forward benefits of electric vehicle adoption – cost reductions, health and GHG emissions reduction
Public and active transport		Bringing forward planned investments in public and active transport infrastructure	Not quantified
Energy efficient buildings	Minimum energy efficiency rating of 5 or 6 star	Minimum energy efficiency rating of 8 star Net zero costs	Energy and C02 savings Greater availability of electricity for electric cars Reduction in energy use of 24% by 2050
Urban trees		Additional 1000 trees planted in urban and suburban areas in Victoria and Queensland each year at $3000 each	Energy savings, reduction in air pollution, stormwater savings and improved aesthetics

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