AU 2050 Report

pathways to

deep decarbonization

in Australia

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SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS
Australian National University
ClimateWorks AUSTRALIA

This report was written by

ClimateWorks Australia

Five years ago, The Myer Foundation and Monash University realised that Australia needed a new approach to drive action on climate change. One that understood the interests of business, government and investors and was trusted to be an independent, credible advisor in Australia's transition to a prosperous low carbon future.

That's why they partnered to create ClimateWorks Australia – an independent, research-based, non-profit organisation committed to catalysing reductions in greenhouse gas emissions in Australia.

Since then, ClimateWorks has built a reputation as a trusted, credible and fact-based broker by working in partnership with leaders from the private, public and non-profit sectors.

With strong links to the US-based ClimateWorks Foundation, ClimateWorks Australia also benefits from an international network of affiliated organisations that support effective policies for greenhouse gas reduction.

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Australian National University

The Australian National University (ANU) is a research-intensive university with an emphasis on policy engagement. Crawford School serves and influences Australia, Asia and the Pacific through advanced policy research, graduate and executive education and policy impact. Crawford School combines research, education and policy impact from disciplinary excellence in the core research areas of economics, governance, environment and development.

The Centre for Climate Economics and Policy at ANU Crawford School is a network of researchers and experts working on climate change and energy economics and policy.

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With technical input from

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We are very grateful to the many experts who have provided their time and expertise during the scoping and development of the project, as well as during the review of preliminary results. Contributors are named at the end of this report.

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This financial support assists with undertaking the research, analysis and stakeholder engagement for the Pathways to Deep Decarbonisation in 2050 project. It is provided on the basis that ClimateWorks Australia and ANU retain strict independence and that final decisions on content and publication of the research and findings rest with ClimateWorks Australia and ANU.

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The Australian project page and original publication are available at:

http://climateworksaustralia.org/project/current-project/pathways-deep-decarbonisation-2050-how-australia-can-prosper-low-carbon

The methodology and assumptions of the modelling for the Australian deep decarbonisation pathways project is available in the technical report published at:

http://climateworksaustralia.org/sites/default/files/documents/publications/climateworks_pdd2050_technicalreport_20140923.pdf

This October report is the first printed edition of the report published on-line on September 23rd, 2014. Minor changes have been made to eliminate typographic errors, improve grammatical consistency, improve the flow of text and refine stylistic elements. There is no material difference between the September and October reports.

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How Australia can pros

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Countries have agreed that to avoid dangerous climate change, global warming must be kept below 2 degrees. For this to happen all countries, including Australia must increase their emissions reduction efforts.

SUSTAINABLE DEVELOPMENT SOLUTIONS NETWORK
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The Deep Decarbonization Pathways Project (DDPP) is a collaborative initiative to understand how 15 countries, representing 70% of global CO_2 emissions, can transition to low carbon economies.

ClimateWorks Australia and the Australian National University are leading Australia's participation in the DDPP.

This report is the first milestone in the Australian project and further work is being undertaken. Broad participation in the identification of the challenges and their solutions is invited.

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Ambitious Energy Efficiency

in all sectors leads to a halving of the energy intensity of the economy.

Low Carbon Electricity

is supplied by renewable energy or a mix of renewable energy and either CCS or nuclear power at similar costs.

Electrification and Fuel Switching

from fossil fuels to bioenergy and from coal and oil to gas reduces emissions from transport, industry and buildings.

Non-Energy Emissions

are reduced through process improvements and CCS in industry, while a profitable shift from livestock grazing to carbon forestry offsets any remaining emissions.

How can business and Government prepare?

1) Accelerate emissions reductions activities that are already profitable.

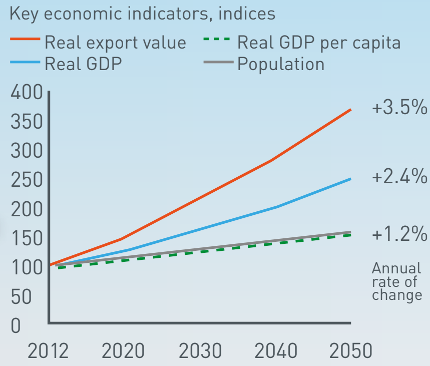
2) Take the long-term into account for investment decisions, to avoid lock-in of carbon-intensive assets.

3) Invest in research and development to prepare for technologies that will be needed in the future.

rbonisation in 2050:
per in a low carbon world

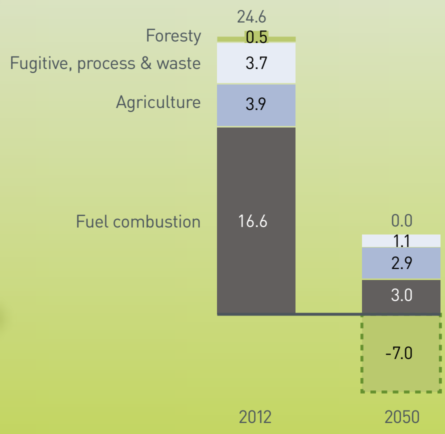
Economic growth to 2050

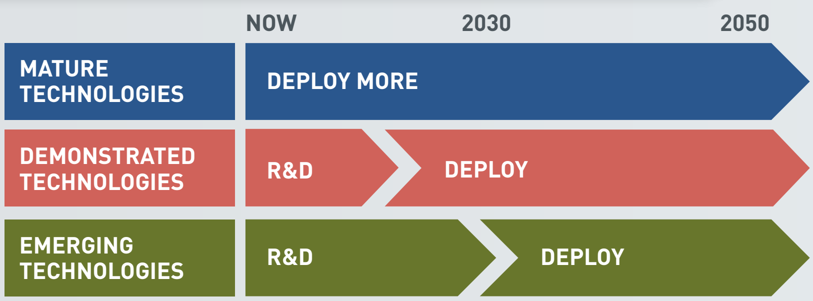
Australia can decarbonise whilst maintaining economic prosperity. This study shows that real GDP grows at 2.4% per annum, a similar rate to the past 5 years.



Emissions in 2050

Australia can reach net zero emissions by 2050 and live within the global carbon budget.





The development and ongoing review of deep decarbonisation pathways are fundamental to long-term planning for a low carbon future.

Executive summary

This report is part of the global Deep Decarbonization Pathways Project (DDPP), which aims to understand and show how countries can transition to a very low carbon economy. The project comprises 15 countries representing more than 70% of global greenhouse gas emissions and is convened under the auspices of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI).

The report presents an illustrative deep decarbonisation pathway for Australia – just one of many possible pathways – developed using a combination of well-established modelling tools to identify feasible and least-cost options. The frame of reference for the analysis is that all countries decarbonise by 2050, consistent with the objective of limiting the increase in global mean surface temperature to 2°C in order to avoid dangerous climate change.

This work finds that Australia can achieve net zero emissions by 2050 and live within its recommended carbon budget, using technologies that exist today, while maintaining economic prosperity. Major technological transitions are needed in some industries and many activities, but no fundamental change to Australia's economy is required. Economic activity and Australian incomes keep rising. The economy grows by 150% to 2050, while net emissions fall to zero and energy sector emissions are reduced by more than four fifths.

Decarbonisation of energy systems in all countries relies on three pillars: ambitious energy efficiency; low carbon electricity; and electrification and fuel switching. For Australia there is a fourth pillar: reducing non-energy emissions in industry and agriculture.

In the illustrative pathway, ambitious energy efficiency in all sectors leads to a halving of the final energy intensity of the economy between now and 2050. Low carbon electricity is supplied by renewable energy or a mix of renewable energy and either CCS or nuclear power. Electricity prices increase at moderate rates and then stabilise and are more than offset by the savings in electricity from energy efficiency, so average household electricity bills decline over time (not taking into account switching cars and heating to electricity).

Emissions from transport, industry and buildings are hugely reduced through energy efficiency and switching from fossil fuels to carbon-free electricity and biofuels or gas. Remaining energy emissions are 3.0 tonnes of carbon dioxide equivalent per person at 2050, with about half of this attributable to production for export.

Non-energy emissions from industry are reduced through substitution with less emissions-intensive materials, process improvements and carbon capture and storage in some applications. Agriculture emissions are reduced through best practice farming and increased carbon forestry compensates for all remaining emissions at 2050. The agriculture and forestry sector maintains a similar share of GDP as today, as do the mining and manufacturing industries, with the exception of coal, oil and petroleum.

The technologies required for decarbonisation are currently available or under development. Ongoing commercialisation, enhancement and integration will improve their cost-competitiveness and performance. Experience with technological change, such as the rapid fall in costs of solar cells seen in recent years, suggests that there will be positive surprises along the way.

The analysis shows that deep decarbonisation requires neither substantial lifestyle changes nor large changes in Australia's economic structure. Australia retains its international advantage in primary industries, including mining and agriculture. While some technologies and activities decline, others expand and contribute to continued economic growth. The largest changes occur in the energy and land sectors. Australia's rich renewable energy resources could make it an energy superpower in a world where clean energy dominates. Together with substantial potential for geological sequestration and vast land available for carbon forestry, this creates economic opportunities for Australia in a decarbonised world.

Achieving deep decarbonisation in this way by mid-century as outlined in this report – within the timeframe required to limit global warming to 2°C – would be a significant transition for Australia, and such a transition needs to be well managed. The experience with previous episodes of far-reaching economic change – such as the transition from agriculture to mining as a dominant factor in exports, as well as the rise of Australia's service industry – has shown the flexibility, adaptability and resilience of Australia's economy.

A successful low carbon transition requires a thorough understanding of the options, opportunities and challenges. It also needs long-term policy signals to encourage the investment decisions needed for a decarbonised economy. Australia would not be alone in such an effort; a global effort is a fundamental prerequisite to enable decarbonisation with prosperity.

The Australian project is led by ClimateWorks Australia and the ANU and is supported with modelling conducted by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Centre of Policy Studies (CoPS) at Victoria University. The analysis draws on new data and research, using the same modelling tools as previous analyses by Treasury, the Garnaut Review and other studies.

This report is accompanied by a technical report, which provides details on assumptions, data, modelling tools and results. Together, these reports elaborate on the Australian chapter of the *Pathways to deep decarbonization 2014 report* (UN SDSN & IDDRI 2014) presented to United Nations Secretary-General Ban Ki-moon in support of the UN Climate Summit in New York on September 23, 2014.

ClimateWorks and ANU will continue to lead Australia's participation in the global DDPP, with ongoing analysis and consultations planned on alternative pathways and enabling factors for transitions. It is hoped that this report will advance the national debate on longer-term emissions reduction strategies. Broad participation in the conversation about Australia's options to prosper in a low carbon world is encouraged.

1 Introduction

The Pathways to Deep Decarbonization in 2050 project is part of a globally coordinated project to identify pathways to a low carbon future.

The Deep Decarbonization Pathways Project (DDPP) is a collaborative initiative, convened by the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI). Its objective is to understand and show how individual countries can transition to a very low carbon economy, a process referred to as 'deep decarbonisation', in order to illustrate how the world can meet the internationally agreed target of limiting the increase in global mean surface temperature to 2 degrees Celsius (°C).

Led by Professor Jeffrey Sachs, Director of the SDSN and Special Advisor to the United Nations (UN) Secretary General, the DDPP currently comprises 15 country research teams composed of leading researchers and research institutions from countries representing 70% of global greenhouse gas (GHG) emissions and different stages of development.

Working within a common global framework, country research teams have developed deep decarbonisation pathways, consistent with the objective of limiting the increase in global mean surface temperature to 2°C. These pathways take into account national socio-economic conditions, development aspirations, infrastructure stocks, resource endowments and other relevant factors.

ClimateWorks Australia and the ANU were appointed to lead the Australian research team and are supported by modelling undertaken by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Centre of Policy Studies (CoPS) at Victoria University. Other participating countries include: Brazil, Canada, China, France, Germany, India, Indonesia, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom and the United States.

The deep decarbonisation pathways developed by country research teams informed the Australian chapter of the *Pathways to Deep Decarbonization 2014* report (UN SDSN and IDDRI 2014), which was developed for the UN Secretary-General Ban Ki-moon in support of the Climate Summit at the United Nations on September 23, 2014. This report can be viewed at www.deepdecarbonization.org, along with all of the country-specific chapters.

This report and the associated technical report (CWA et al. 2014) elaborate on the work undertaken to prepare the Australian chapter of the DDPP 2014 report. They provide additional Australian context and technical detail about the modelling and analysis. The accompanying technical report provides more information on the modelling framework, assumptions and results of the sectoral analysis. The analysis presents an illustrative deep decarbonisation pathway for Australia; just one of many possible pathways and has been developed using a combination of well-established modelling tools with a prominent role for least-cost economic modelling methodology.

The frame of reference for the analysis is that all countries decarbonise by 2050, consistent with the objective of limiting the increase in global mean surface temperature to 2°C.

The purpose of this report is to help focus the national climate change debate on the importance of 2050 deep decarbonisation pathways.

The analysis presented in this report demonstrates that in a low carbon world, Australia can decarbonise via a range of pathways while at the same time maintaining prosperity. To support such an outcome, backcasting analysis from a 2050 time horizon can help to identify technological pathways and the actions required to achieve them.

Government and industry can help focus the national climate debate on this 2050 time horizon by participating in the development and ongoing review of deep decarbonisation pathways and by preparing for their implementation.

Previous Australian modelling studies on long-term emissions scenarios

Several previous modelling exercises have modelled emissions reductions scenarios to 2050. The main exercises to note are the Garnaut Review (2008), the modelling by the Treasury (2011) and modelling undertaken for the Climate Change Authority (2014). The modelling undertaken for this report uses a similar suite of modelling tools (drawing on CSIRO and CoPS models), yet shows deeper reductions in emissions levels than any of the scenarios in these previous studies. The analysis for this report uses updated information about technology availability and costs, as well as new research on emissions reductions opportunities, in particular in industrial production and land-based carbon sequestration.

The role of deep decarbonisation studies for the climate negotiations

For the first time, emissions commitments for beyond 2020 are on the agenda of the global climate negotiations. All countries are required to submit their national pledges for emissions levels in the 2020s in early 2015. As a result, attention is shifting from short-term targets to medium-term emissions reductions trajectories.

Countries will also need to address the more fundamental question of how to get to very low emissions levels implicit in a high-level commitment to 2°C. This requires a consideration of how much carbon can be safely emitted to 2050 and beyond – the so-called 'carbon budget'. The global Deep Decarbonization Pathways Project is a step in this direction. The project informs national governments and business communities, with the analysis to flow into the negotiation process towards the 21st Conference of the Parties on Climate Change (COP21) in Paris at the end of 2015.

Countries may take inspiration to conduct extensive decarbonisation studies to inform their domestic strategies and to facilitate dialogue between countries, both within and outside the negotiations.

This study aims to help focus the conversation amongst business, government and civil society concerning longer-term climate change policy.

Sustainable Development Goals to help drive global action to 2030 (Adapted from SDSN 2013)

At the Rio+20 United Nations Conference on Sustainable Development the world's governments agreed to adopt the Sustainable Development Goals (SDGs), to take over from the existing Millennium Development Goals, which applied to developing countries from 2000–2015. The UN Secretary-General is coordinating preparation of the SDGs by the year 2015. These goals are in response to recognition by the global community that sustainable development is a worldwide priority, but that more effort and coordination is needed to achieve it.

The SDGs are targeting key challenges to address by 2030, including extreme poverty and hunger, health and wellbeing, sustainable agricultural production, natural resource management and curbing human-induced climate change with sustainable energy.

With support from the global community, these SDGs can help drive coordinated global action and provide further impetus for addressing climate change.

Countries have agreed that to avoid dangerous climate change, global warming must be limited to 2°C. To achieve this all countries, including Australia, must significantly strengthen their emissions reduction efforts.

To avoid unacceptable risks of dangerous climate change, the increase in global mean surface temperature must be limited. Limiting temperature rise to 2°C has been agreed to by 141 countries since 2009 and is the focal point of the international climate negotiations (UNFCCC 2014).

The scale of emissions reductions required to achieve the 2°C limit means that energy and industrial emissions must more than halve by 2050, and net GHG emissions must then approach zero during the second half of this century (Bruckner et al. 2014; SDSN & IDDRI 2014). At the same time, the global population is expected to grow by 33% (UN DESA 2013) and the global economy is expected to grow to almost four times its current size.

Global CO_2 emissions from today's energy systems and industry are around 34 billion tonnes per year (Edenhofer et al. 2014; SDSN & IDDRI 2014). This needs to decrease to around 15 billion tonnes by 2050 to have a 50% chance of achieving the 2°C limit and to around 11 billion tonnes to have a greater than two-thirds chance (Bruckner et al. 2014; IEA 2014a; SDSN & IDDRI 2014). If the higher figure is apportioned equally across the global population, it equates to 1.6 tonnes per capita by 2050[1]. This will require a profound transformation of energy systems through steep declines in carbon emissions from all sectors of the economy.

1 Assuming a global population of 9.6 billion in 2050, in line with the medium fertility projection of the UN Population Division (UN DESA 2013).

The importance of the 2°C target

Through the agreement reached at the 15th session of the Conference of the Parties (COP15) in Copenhagen in 2009, the international community recognised the need to limit global average temperature rise to 2°C in order to avoid the more dangerous impacts of climate change (UNFCCC 2010a).

Various studies have shown that the risk of crossing tipping points in the Earth's climate system increases as the 2°C limit is approached and exceeded. The effects of these impacts, such as sea level rise and increased extreme weather events, will not be evenly distributed across the world, nor would they be linear in moving from 2°C to 4°C (The World Bank 2012a).

Within Australia, modelling undertaken as part of the Garnaut Climate Change Review in 2008 investigated the potential impacts of climate change on Australia under a range of scenarios, which saw temperatures rise by different levels up to 5°C by the end of the century. The review found that the impacts on a number of areas in Australia's interest increase in severity as climate change moves beyond 2°C, as shown in Table 1.

Table 1: Potential impacts of moving beyond 2°C (adapted from Garnaut 2008)

Area of impact	Potential impacts of moving beyond 2°C
Murray-Darling Basin irrigated agriculture	Significant decline in agricultural production, possible cessation of the large majority of agriculture in the Murray-Darling Basin
Tourism and iconic ecosystems	Catastrophic destruction of the Great Barrier Reef
Water supply infrastructure	Significant increase in the cost of supplying urban water
Human health	Significant increase in heat-related deaths, increased incidence of vector-borne disease
Geopolitical stability in the Asia-Pacific region and effects on trade	Major dislocation in coastal megacities of south Asia, south-east Asia and China and displacement of people in islands adjacent to Australia. Possible adverse effects for Australia's trade.

Australia's emissions profile

Australia's per capita GHG emissions are amongst the highest in the world (Figure 1). The high emissions intensity of our economy is primarily due to:

> the predominance of coal-fired generation in Australia's electricity supply

> the relatively large role of energy and emissions-intensive industrial activity in Australia's economy

> the relatively low cost of energy historically and, as a result, resultant relatively slow progress in improved energy efficiency in many parts of the economy

> the relatively large role of agriculture in the economy, including beef production, and

> the long distance transport requirements, due to large distances between urban centres.

Between 1990 and 2010 Australia's greenhouse gas emissions, excluding land use and forestry, have grown by approximately 30%. Electricity sector emissions grew by nearly 60% between 1990 and 2009 but fell 18% between 2009 and 2013. Emissions from stationary energy (other than electricity), transport, industrial processes and fugitive emissions have all risen substantially since 1990. Emissions from agriculture have risen slightly and emissions from waste have declined. Reductions in forestry emissions are the main reason why overall emissions, including land use, did not greatly increase. Increasing emissions from energy use between 1990 and 2010 were roughly offset by reduced deforestation and increased plantation forestry (DOE 2014).

Since 1990, the overall emissions intensity of Australia's economy has almost halved and emissions per capita have decreased by approximately 25% over this period (ABS 2012; 2013a; DOE 2014). Near-term business-as-usual projections see emissions rising over the rest of the decade, as large-scale resources projects (in particular natural gas extraction and liquefaction) come online and the outlook for further reductions in deforestation is limited (CWA 2013a). However falling electricity demand may temper increases in emissions from the electricity sector.

Figure 1: Australia's greenhouse gas emissions in 2012 (ABS 2012; BREE 2013a; DOE 2014)

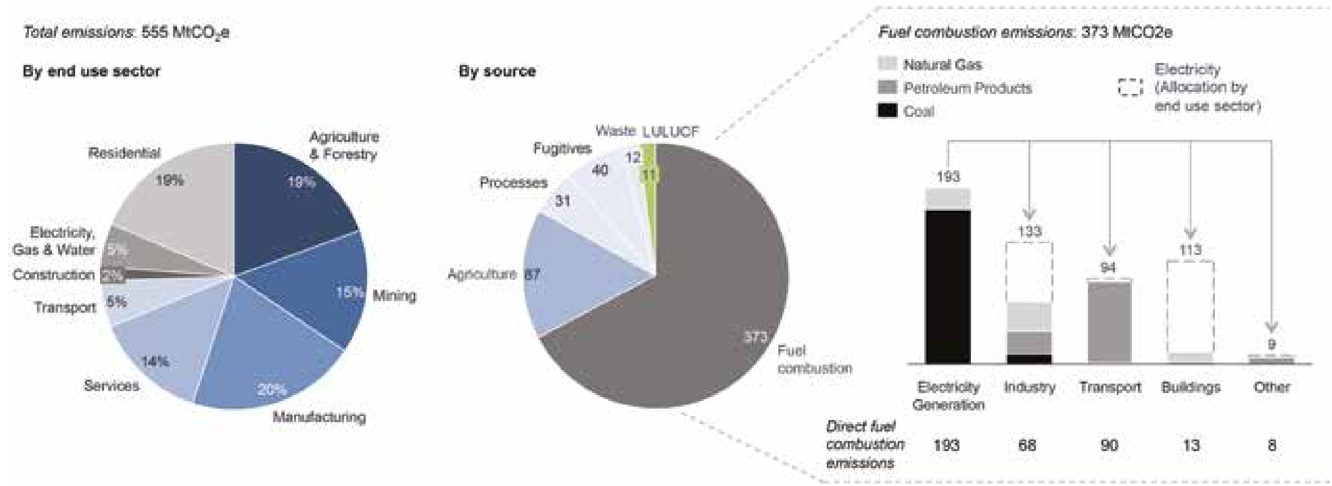
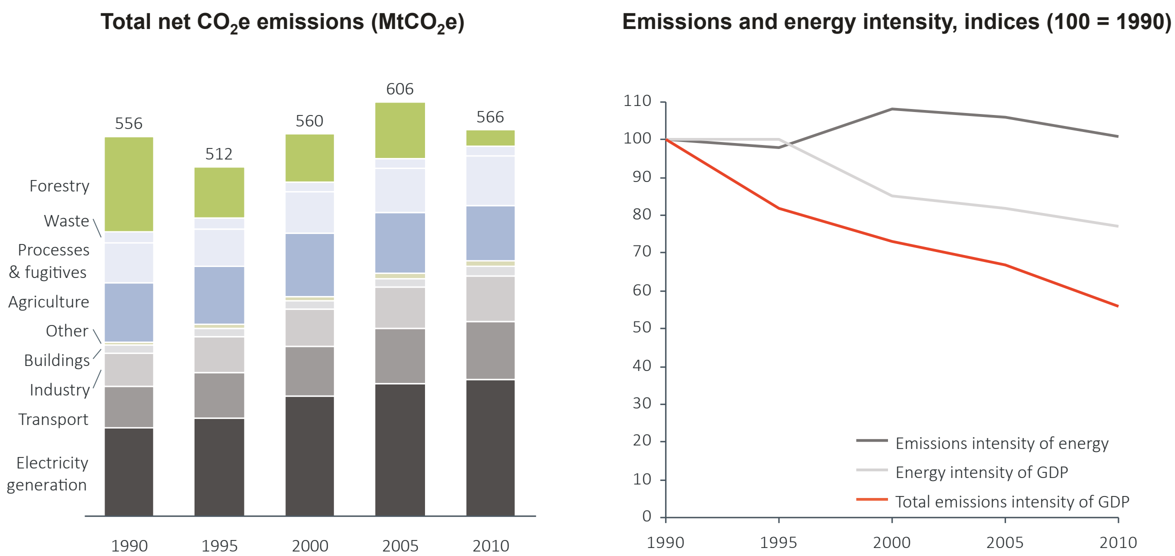


Figure 2: Australia's historical emissions trajectory and intensity (ABS 2012; BREE 2013a; DOE 2014)



2 Reducing emissions while maintaining economic growth

The illustrative pathway shows that Australia could reach net zero emissions by 2050 and achieve its share of the global carbon budget.

For Australia to contribute commensurately to the objective of limiting global temperature to less than 2°C, our energy-related emissions need to decrease by an order of magnitude by 2050. This report presents an illustrative deep decarbonisation pathway by which these emissions are reduced by more than 80% on 2012 levels (17 tCO_2 per capita) to 3.0 tCO_2 per capita in 2050[2]; and further reduced to 1.6 tCO_2 per capita if emissions directly attributable to the production of exports are excluded. The following sections outline the technology transitions that enable Australia's emissions to be reduced by these magnitudes by 2050.

Australia has substantial potential to offset emissions via land sector sequestration. The illustrative pathway includes a shift in land use toward carbon forestry, where profitable for landholders under carbon abatement incentives, but it does not include the sale of permits into overseas markets, nor the purchase of permits from other countries. The analysis finds that there is more than enough economic potential to shift land use to carbon forestry to offset all residual emissions to 2050, allowing Australia to reach net zero emissions by 2050.

In this pathway, the cumulative emissions to 2050 are compatible with Australia's carbon budget recommended by Australia's Climate Change Authority (2014), an independent body established under the Climate Change Authority Act 2011. This requires strong mitigation action in all sectors of the economy, in the context of a strong global decarbonisation effort.

Figure 3: Energy emissions per capita by sector, tCO_2 per capita, 2012 and 2050

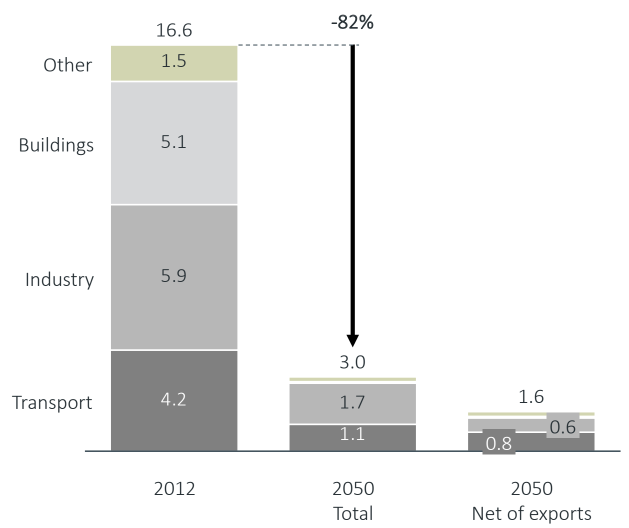
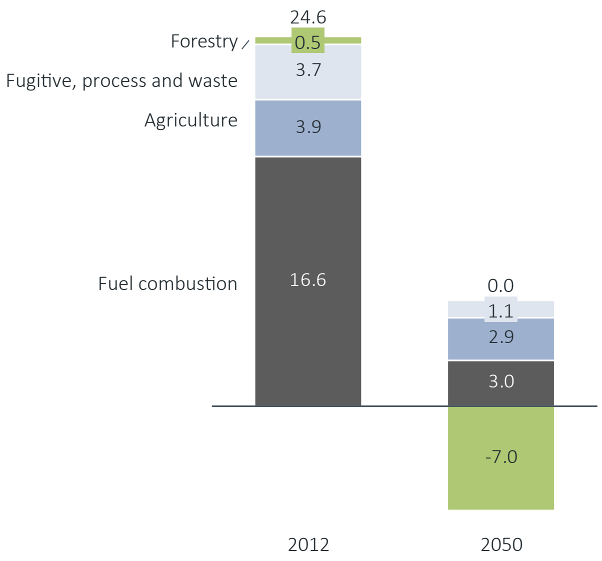


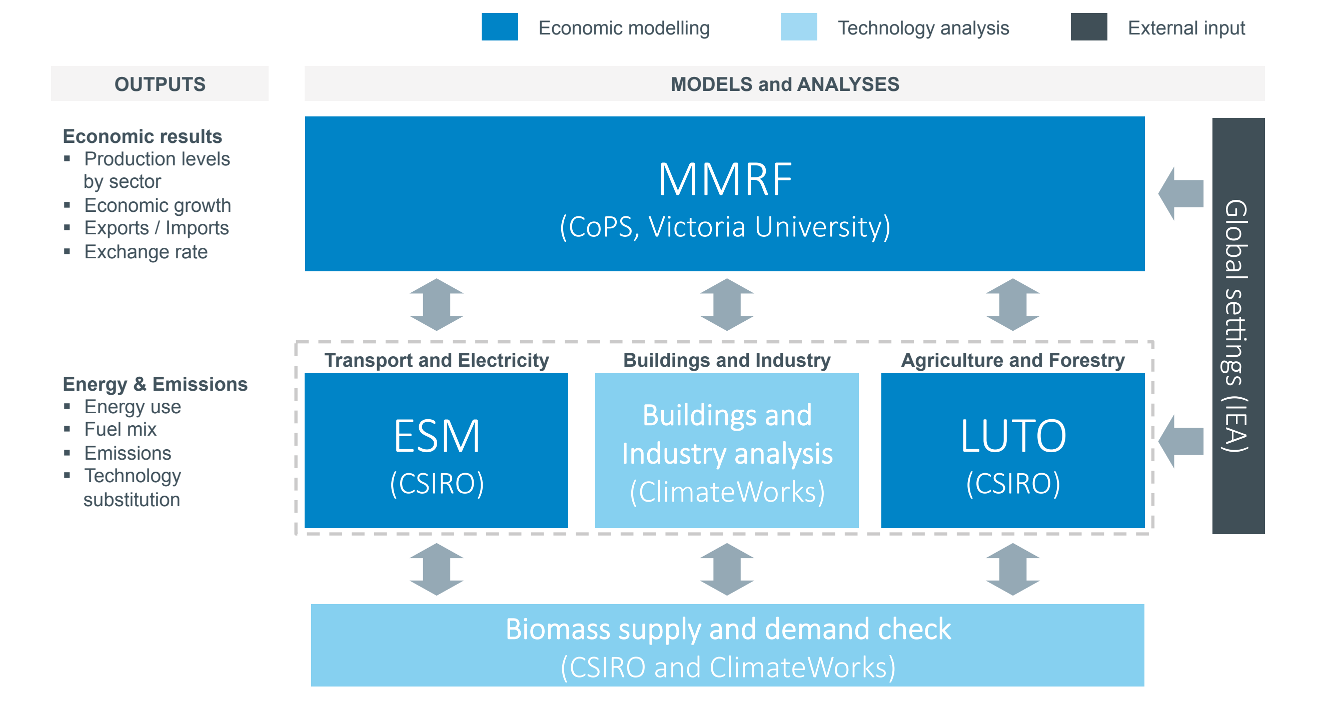
Figure 4: Greenhouse gas emissions per capita by source, tCO_2e per capita, 2012 and 2050



2 This result corresponds to the *100% renewable grid* scenario. In the *CCS* or *Nuclear* scenario, energy emissions reduce to 3.2 tCO_2e per capita. Refer to section 3, under the heading 'Low carbon electricity' for more detail about the scenarios.

The model is grounded in economic modelling, supported by sectoral analysis of technical emissions reduction potential

Figure 5: The modelling framework



The analysis uses a combination of bottom-up sectoral models brought together in a national economic model. The models are well established and have been used in similar exercises before. Figure 5 shows a schematic diagram of the main models, processes and data.

Modelling of the Australian economy was carried out by the Centre of Policy Studies (CoPS) using the Monash Multi-Regional Forecasting (MMRF) multi-sector general equilibrium model. In line with best practice, this general equilibrium model was run in conjunction with detailed sectoral analysis of the technical and economical potential for emissions reduction.This is widely viewed as the benchmark approach in Australia and internationally, and has been the norm in recent Australian climate policy analysis, such as Treasury (2011) and Garnaut (2008).

The sectoral analyses and modelling includes:

> **Economic modelling of the electricity and transport sectors**. The CSIRO Energy Sector Model (ESM) provides least-cost solutions for meeting electricity and transport demand trajectories under given abatement incentive. It builds upon an assessment of the resources and technologies available, as well as the physical constraints applying to those technologies. The results of the modelling were used to inform the MMRF about fuel demand, technology mix and the activity growth in electricity generation and transport subsectors. Projected emissions trajectories for those sectors were taken directly from the ESM results.

> **Detailed analysis of the emissions reduction opportunities in the buildings and industry sector**. ClimateWorks conducted a detailed bottom-up analysis of the potential for energy efficiency, fuel switching (e.g. from coal/oil to gas and gas to biogas/biofuel or electricity), direct emissions reduction opportunities and deployment of carbon capture and storage in buildings and industry. The findings from this analysis were used as inputs to the MMRF analysis; and to calibrate the energy and emissions results from the model.

> **Economic modelling of the carbon forestry potential.** The CSIRO Land Use Trade-Offs (LUTO) model was used to develop the potential for land sector sequestration of carbon from non-harvest carbon plantings (including single species eucalypt plantations and mixed species plantings providing carbon and biodiversity benefits), where this would be more profitable than traditional agricultural activities (crops, livestock) under projected future input and output prices, carbon abatement incentives and associated impacts on agricultural production. These results were used to inform the MMRF about changes in land use and forestry activity, as well as the supply of land sector offsets.

- **Check on biomass supply and use.** Finally, ClimateWorks and CSIRO collaborated to ensure that the volume of biomass use across the Australian economy was consistent with available resources. The ESM is able to resolve competition for biomass resources between the electricity and transport sectors. Existing CSIRO modelling was also called upon to determine whether biomass volumes were consistent with projected agricultural and carbon forestry activities (Bryan et al., forthcoming).

The UN SDSN and IDDRI provided a number of global settings for the modelling, such as global demand for energy, population and economic growth, technology costs and fuel prices, drawn primarily from the work of their project partner, the International Energy Agency (IEA). A number of features of the modelling framework are new compared to previous domestic modelling exercises. In particular, it is the first time that:

- the updated carbon forestry LUTO model has been used for a whole of economy analysis
- a much more thorough investigation of mitigation potential from industrial production, buildings and transport was used to calibrate the results of the MMRF model in terms of energy use and emissions associated with those sectors
- a strong shift to electrification in industry and buildings was modelled in Australia
- modelling of an Australian emissions reduction pathway occurred in the context of a harmonised international modelling exercise.

In addition, many assumptions have been updated since similar modelling was conducted by Garnaut and Treasury, such as the following examples.

- The costs associated with of many renewable generation technologies have decreased significantly, for example solar PV already costs close to half of what previous studies estimated its cost would be in 2030 (IEA-PVPS 2013; SKM MMA 2011 as used by Treasury 2011).
- The cost of technologies used to manage variable electricity supply has decreased significantly, in particular the cost of batteries.
- Biofuels for aviation were thought infeasible in the original modelling by Garnaut (2008), yet the first fully biofuel-powered commercial, international flight was completed in 2014 (Amyris 2014).

Further detail on the modelling framework, including a discussion of its limitations, is provided in the technical report.

This report presents a possible pathway, not a prescription

This report presents just one of many possible pathways, illustrating a pathway to deep decarbonisation for Australia. It was developed using a combination of well-established modelling tools with a prominent role for least-cost economic modelling methodology.

The illustrative pathway explores the types of technology transitions that could occur in each sector of the Australian economy as it decarbonises and the potential associated economic impacts, based on technologies known today. It does not assume major technological breakthroughs, major structural changes in the economy or substantial lifestyle changes.

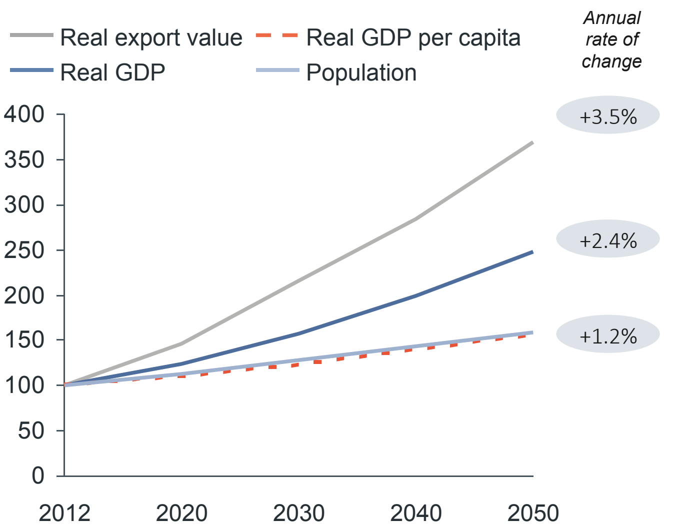
Three electricity generation scenarios and various options for the land use sector are modelled. A range of other technology options from across all sectors of the Australian economy are explored qualitatively.

Like all such modelling exercises, this study does not attempt to predict the future or claim that the results represent the most likely outcome. This study does not advocate a particular scenario as the most desirable course of action.

Deep decarbonisation can be achieved while maintaining prosperity.

The modelling results show that deep decarbonisation can be achieved while real GDP grows at 2.4% per year on average, resulting in an economy nearly 150% larger in 2050[3] than today. Trade is also predicted to continue to grow, with exports growing at 3.5% per annum. This result is consistent with the findings of many other reports that show that decoupling GDP growth from CO_2 emissions growth is achievable (Edenhofer et al. 2014; Garnaut 2008; PwC 2013; Stern 2006).

Figure 6: Key economic indicators, indices



This study explores the feasibility of Australia achieving deep decarbonisation, in the context of international action to limit global warming to 2°C.

Cost comparisons with a 'no action' scenario are not the purpose of this report, however, many stakeholders will be interested in the projected cost of achieving this decarbonisation pathway. Devising an appropriate reference scenario with which to compare the decarbonisation scenario is inevitably inherently difficult.

Australia taking no abatement action is inconsistent with both government and opposition policy, and would appear risky from a geopolitical perspective, given that most major countries are already undertaking measures to cut emissions. A realistic scenario of 'no action' by Australia in the context of global deep decarbonisation therefore needs to consider the potential responses by our trading partners, including possible trade sanctions and other adverse ramifications in Australia's external political and commercial relationships.

3 The economic results presented in this section correspond to the illustrative pathway, based on the *100% renewable grid* scenario. It is not expected that economic results would differ significantly if other electricity scenarios were used. See the power sector results for more detail around electricity scenarios.

In addition, there are well-known fundamental shortcomings in estimating the economic cost of emissions reductions estimates using the type of economic models employed in the present analysis and similar exercises.

Standard computable general equilibrium models of an economy, in this case the MMRF model, do not include the physical and economic impacts of climate change, and therefore ignore the economic benefits arising from a reduction in climate change impacts over time. These omitted benefits include direct economic effects, benefits from reduced risk of extreme climate impacts or crossing global tipping points and non-market values, such as the existence of iconic ecosystems such as coral reefs (Garnaut 2008; Kolstad et al. 2014; Pindyck 2013).

> The models ignore immediate co-benefits from climate change mitigation. For example, there are health and labour productivity benefits from reduced urban air pollution from combustion of fossil fuels (including transport) and benefits for energy security from more stable energy system costs and reduced demand for oil imports (Fleurbaey et al. 2014).

> Standard economic models are not well suited to represent the potential for growth-enhancing effects of mitigation policies. For example, increased energy efficiency could lead to productivity gains throughout the economy and increased global innovation could lift global growth rates. Research by the ClimateWorks Foundation for the World Bank (Akbar et al. 2014) suggests that improving energy efficiency performance could boost global GDP by US$1.6-2.6 trillion per annum above business as usual by 2030 (see for example Ward et al. 2012).

Comparisons between estimated economic activity in the policy and reference case are therefore not a useful guide to whether deep decarbonisation is beneficial. Recent research demonstrates that the world pursuing strong mitigation action, compatible with a 2°C target, is desirable and could yield economic benefits (see for instance The Global Commission on the Economy and Climate 2014). A significantly warmer world poses impacts and risks generally seen as economically, socially and environmentally unacceptable (Field et al. 2014; The World Bank 2012a).

Nevertheless, the box on the following page describes some comparisons to a technical reference case, in order to provide comparisons to previous studies. Estimates of economic costs are in the same range as previous modelling exercises. This is despite emissions levels in the present study's analysis coming down to much lower levels than in previous exercises and the technical reference case overstating the amount of action required. Like all previous studies, this study finds that Australia can achieve substantial reductions in emissions while maintaining robust economic growth (see Treasury 2011, Box 5.3)

The primary reasons why this study finds that greater emissions reductions may be achieved at similar macroeconomic effects are that:

> the observed and projected costs for many zero and low-emissions technologies have fallen significantly over recent years

> this analysis includes a much more thorough investigation of mitigation potential from industrial production, buildings and transport, and

> the analysis conducted for this study suggests a larger supply of profitable carbon sequestration from land-use change and forestry (see technical report).

Comparison with cost estimates in previous studies

The technical reference case in this analysis assumes no mitigation action in Australia, while other countries are decarbonising, so differences to the policy scenario will be overstated. The decarbonisation scenario in this study has much deeper cuts in domestic emissions levels than strong mitigation scenarios in previous Australian studies.

Nevertheless, the aggregate cost estimates are similar to those from previous modelling studies produced by the Australian government, where the most ambitious scenarios showed a lesser extent of reductions in emissions.

The overall pattern is that the estimated impacts on GDP (domestic economic activity) are somewhat larger in this scenario than in previous modelling, while the impacts on GNI (which also measures international financial flows) are less than in the most ambitious emissions reductions scenarios in relevant previous reports. This is because in this study, all required emissions reductions are cost-effectively achieved domestically, while previous studies assumed large purchases of overseas emissions reductions units.

For example the "high price" scenario in Treasury's (2011) modelling showed an annual difference in GNI (GDP) of 0.19% (0.12%) with a cumulative effect of 7.1% (4.7%) at 2050. Domestic emissions were 66% lower than in the reference case and 42% lower than in 2000. An 80% reduction target at 2050 was modelled through the purchase of overseas emissions units.

This compares to an annual difference in GNI (GDP) of 0.12% (0.19%) with a cumulative effect of 4.6% (6.6%) at 2050 – that is, it takes the economy two years longer to achieve an approximately 150% increase in gross national income. Meanwhile net domestic emissions in the DDPP scenario decline to zero by 2050, a 100% reduction relative to the reference case and relative to today.

	Annual average growth		Annual average growth relative to reference case		Economic parameters at 2050, compared to reference case			Emissions level relative to reference, 2050		Emissions reductions from 2000 to 2050	
	GDP	GNI per person	GDP	GNI per person	GDP	GNI per person	PFC	Domestic emissions	Net emissions	Domestic emissions	Net emissions*
DDPP scenario	2.4%	1.1%	-0.19%	-0.12%	-6.6%	-4.6%	-4.9%	-100%	-100%	-100%	-100%
2011 Treasury "high price" scenario	2.5%	1.0%	-0.21%	-0.19%	-4.7%	-7.1%	-8.3%	-66%		-42%	-80%
2008 Treasury "Garnaut 25" scenario	2.2%	1.1%	-0.14%	-0.17%	-5.8%	-6.7%	-6.5%	-83%		-69%	-90%

Notes: All economic values are real (adjusted for inflation). GDP measures the value of economic activity or gross domestic production. GNI per person measures gross national income per person and is equivalent to GDP adjusted for capital inflows and outflows. PFC refers to real private consumption. Domestic emissions refers to all greenhouse gas emissions occurring within Australia as defined in the international negotiations (including emissions attributable to exports). Net emissions adjust domestic emissions for trade in international permits. Most previous studies require the use of international permits to meet the national emissions targets assumed in those studies. This project does not rely on international units due to a combination of deeper cuts in emissions and greater land sector sequestration. Economic comparisons to 2011 and 2008 studies report MMRF results.

The DDPP shows that deep decarbonisation with continued economic growth can be achieved in all 15 countries involved.

Results for the 15 countries involved in the DDPP show that in aggregate, CO_2 energy emissions fall to 12.3 $GtCO_2$ by 2050, which is a 45% reduction from the 22.3 $GtCO_2$ that these 15 countries emitted in 2010 (SDSN & IDDRI 2014). This is led by strong reductions in energy emissions from developed economies and a reversal of growth trajectories in emissions from developing economies (Figure 7, left graph). All of Australia's peers achieve energy emissions reductions of more than 80% between 2010 and 2050 (Figure 7, right graph[4]).

This is while population across the 15 countries is expected to increase by 33% between 2010 and 2050 and GDP is expected to almost quadruple over the same period. This means the 15 DDPs collectively cut their per capita CO_2 energy emissions in half (from 5.4 tCO_2 energy to 2.4 tCO_2 energy per capita) and cut their CO_2 energy intensity of GDP by 88% (from 464 to 55 tCO_2 per $ GDP, USD 2005) by mid-century.

The emissions reductions achieved in 2050 in the modelling results are slightly higher than the IEA 2DS scenario, which modelled the required emissions reductions to stay within the 2°C target (IEA 2014a; SDSN & IDDRI 2014). In 2015 the DDPP research teams will investigate further options for deeper decarbonisation.

4 Note that most other countries in the DDPP have only reported CO_2 emissions from energy

Figure 7: Energy-related CO_2 emissions reduction trajectories, $GtCO_2$

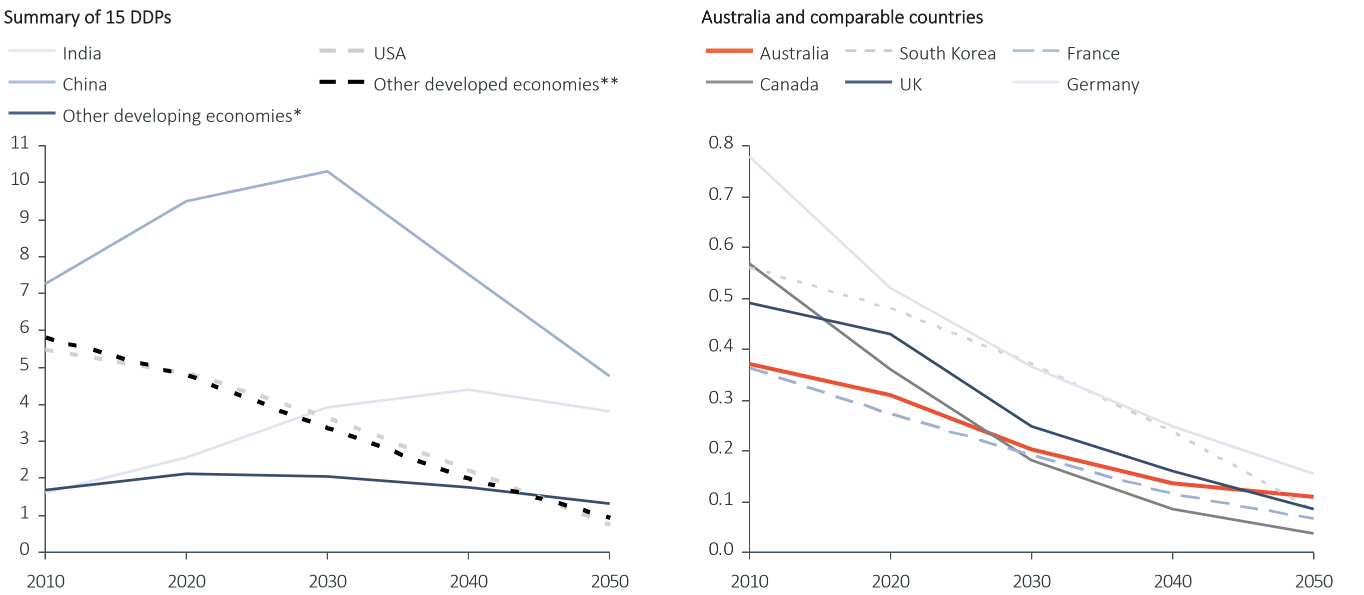
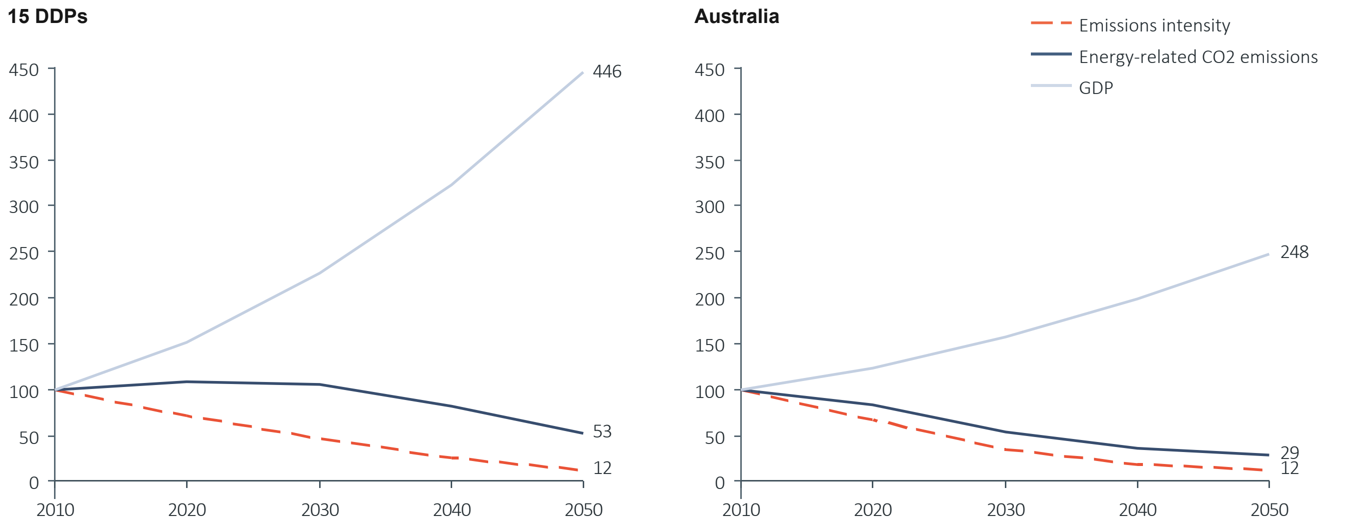


Figure 8: Total energy-related CO_2 emissions, GDP growth and emissions intensity, indices (SDSN & IDDRI 2014)



Some decarbonisation is already underway

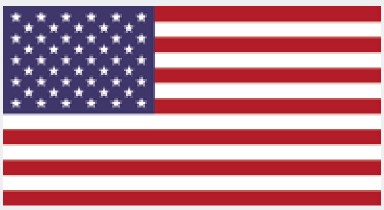
Major economies, including China and the United States, have policies in place to limit and reduce greenhouse gas emissions and, in some cases, ambitious long-term targets. In many respects decarbonisation is also aligned with their development goals, which include improved air quality, energy security, access to fresh drinking water and improved standards of living.

Worldwide investments in renewable generation capacity have grown from USD$100 billion in 2001 to nearly USD$300 billion in 2011 (IEA 2014b). Since 2007, clean energy investment originating from outside the Organisation for Economic Cooperation and Development (OECD) grew at 27% per year while investments from OECD countries grew at 10% per year (WEF 2013).

Emissions reduction policies in China and the United States

China has an immediate focus on reducing air pollution and also aims to enhance energy security while becoming a leader in new energy technologies (Jotzo & Teng 2014). These objectives are in line with lower carbon dioxide emissions. China has regulatory policies in place to cut coal use, increase the supply of renewable and nuclear power and increase energy efficiency. Seven regional pilot emissions trading schemes covering a population of more than 200 million people are in place (Jotzo & Teng 2014; Zhang et al. 2014), with a national emissions trading scheme foreshadowed. China has been reducing the emissions intensity of its economy by around 4% per year, on track to reach its 2020 target, reducing CO_2 emissions per unit of GDP by 40-45% below 2005 levels (China View 2009). A peak in coal consumption is anticipated this decade. China's DDP shows a peak in national emissions by 2030 and many observers consider a peak in China's carbon emissions at an earlier time possible.

The United States is working to increase its energy security and to drive innovation in energy technology and productivity. A target is in place for a 17% reduction in emissions by 2020 and 83% by 2050 (compared to 2005 levels) (UNFCCC 2010b). The US EPA has published proposed rules that will further reduce emissions from the power sector (US EPA 2014). A number of the US states have also adopted targets that support renewable energy supply and energy efficiency (more than 60% and 40%, respectively) (The White House 2013). Regional emissions trading schemes are in place in California (since 2013) and in nine east coast states (Regional Greenhouse Gas Initiative (RGGI), since 2009; Talberg & Swoboda 2013).



3 Deep decarbonisation pathways

For all countries, deep decarbonisation of energy systems relies on three pillars and, for Australia, there is a fourth pillar of non-energy emissions reduction.

Three 'pillars' of decarbonisation of national energy systems are common to all country pathways and a fourth applies to countries where non-energy-related emissions are substantial. In Australia, non-energy emissions account for more than one third of total emissions.

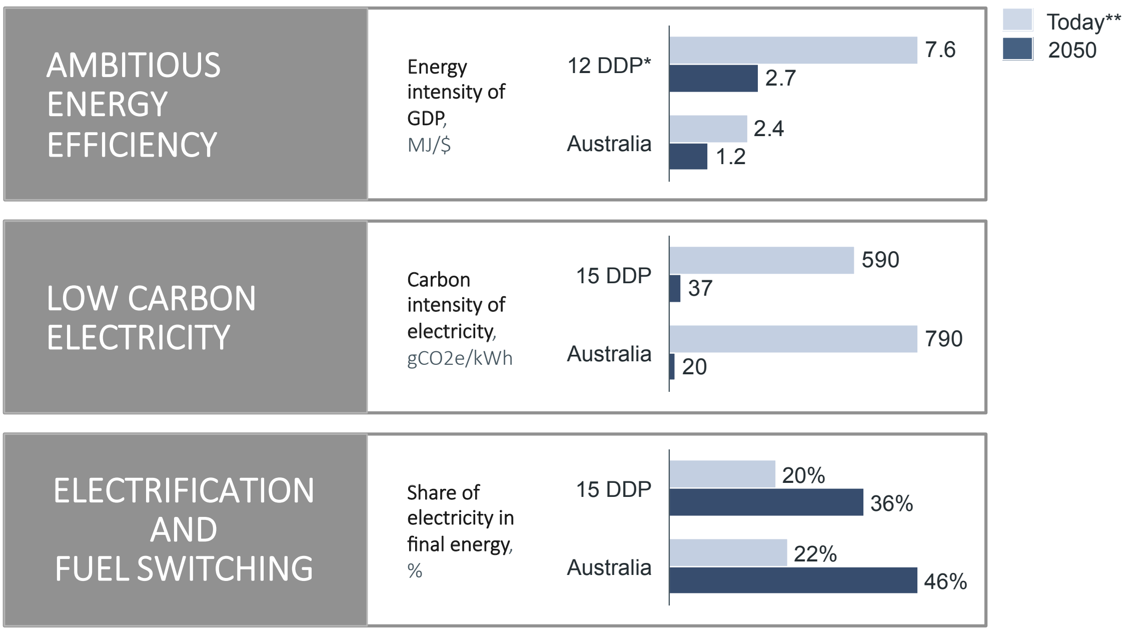
The pillars of deep decarbonisation are

1. **Energy efficiency:** Greatly improved energy efficiency in all energy end-use sectors, including passenger and goods transportation, through improved vehicle technologies, smart urban design and optimised value chains; residential and commercial buildings, through improved end-use equipment, architectural design, building practices and construction materials; and industry, through improved equipment, material efficiency and production processes, re-use of waste heat.
2. **Low carbon electricity:** Decarbonisation of electricity generation through the replacement of existing fossil fuel-based generation with renewable energy (e.g. hydro, wind, solar and geothermal), nuclear power and/or fossil fuels (coal, gas) with carbon capture and storage (CCS).
3. **Electrification and fuel switching:** Switching end-use energy supplies from highly carbon-intensive fossil fuels in transportation, buildings and industry to lower carbon fuels, including low carbon electricity, other low carbon energy carriers synthesised from electricity generation (such as hydrogen), sustainable biomass or lower carbon fossil fuels.
4. **Non-energy emissions:** These emissions can be reduced through process improvements, material substitution, best practice farming and implementation of carbon capture and storage. In addition, carbon can be stored in the soil and vegetation, in particular through reforestation, offsetting some of the emissions created by other sectors.

What other country pathways achieve

The results from the global report highlight some commonalities between decarbonisation options for the 15 countries participating in this project, driven through the three energy system pillars (Figure 9).

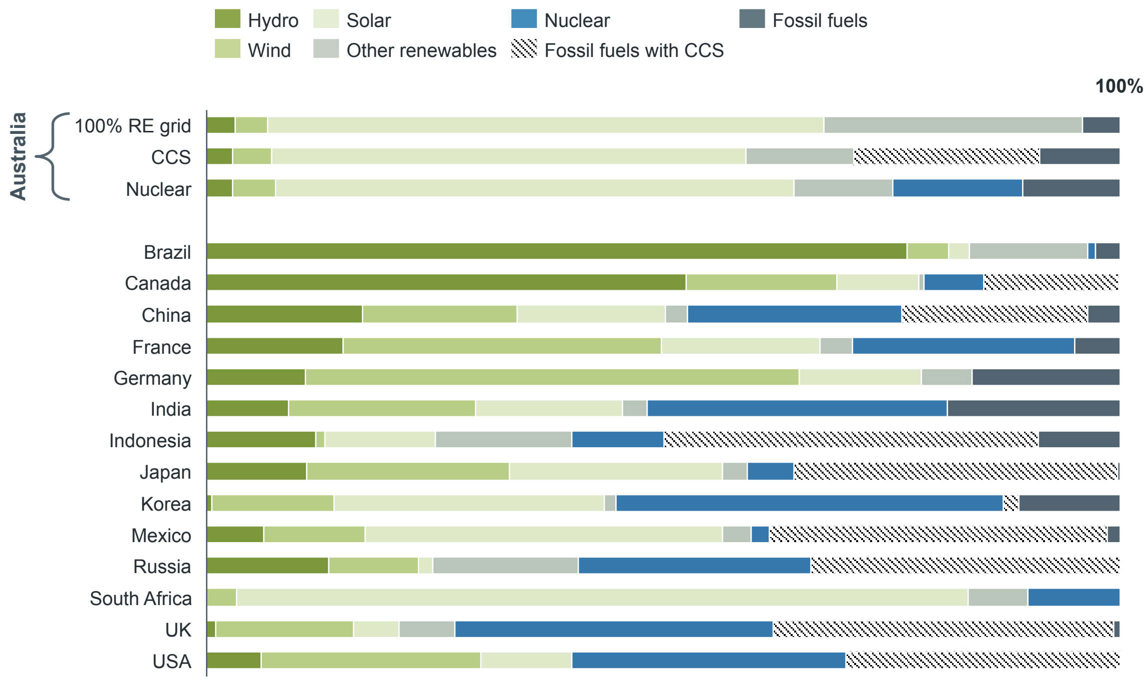
Figure 9: Energy system decarbonisation pillars for the 15 DDPs (SDSN & IDDRI 2014)



* Based on complete country chapters, excluding India, Brazil and Germany; ** 2012 for Australia, 2010 for DDP countries

All DDPs achieve a near-zero emissions intensity of electricity by 2050. Countries use a variety of strategies and technologies to reach this result (Figure 10).

Figure 10: Electricity generation mix in 2050 for the 15 DDPs (SDSN & IDDRI 2014)



Country research teams-and some of Australia's key trading partners-have identified potential decarbonisation pathways through this project. Some highlights from Canada, China, Japan and the US are noted below.

US

> Energy emissions reduce by 86% while GDP nearly doubles, resulting in a 74% reduction in the economy's energy intensity (MJ/$).

> A move to electricity and gas is modelled in all sectors, with significant CCS use in industry.

> Fossil fuels (oil, coal and natural gas, with and without CCS) decrease from 92% of primary energy supply in 2010 to 47% of primary energy in 2050.

China

> Emissions reduce by 34% while the economy grows more than six-fold.

> The share of coal in primary energy consumption falls to 20% in 2050, while the use of natural gas and non-fossil fuels increase, contributing 17% and 43% respectively.

> Industry emissions are strongly curbed through energy efficiency, structural change and CCS.

Canada

> Reduces its overall GHG emissions by nearly 90% while its economy triples.

> The economy diversifies away from the industrial sector to some extent, with output from the refining, cement and lime sectors falling compared to the reference case scenario, while output from the electricity, biodiesel and ethanol sectors rises. Output from the oil and gas sector still doubles.

Japan

> Achieves an 84% reduction in energy emissions while GDP grows by 56%.

> CCS is used with coal in industry and electrification is mostly used in buildings and transport.

> Reliance on fossil fuels is reduced by 60% compared to the 2010 level due to reduction in energy demand and deployment of renewable energy, which accounts for 40% of electricity generation.

There are a range of options for decarbonising the Australian economy.

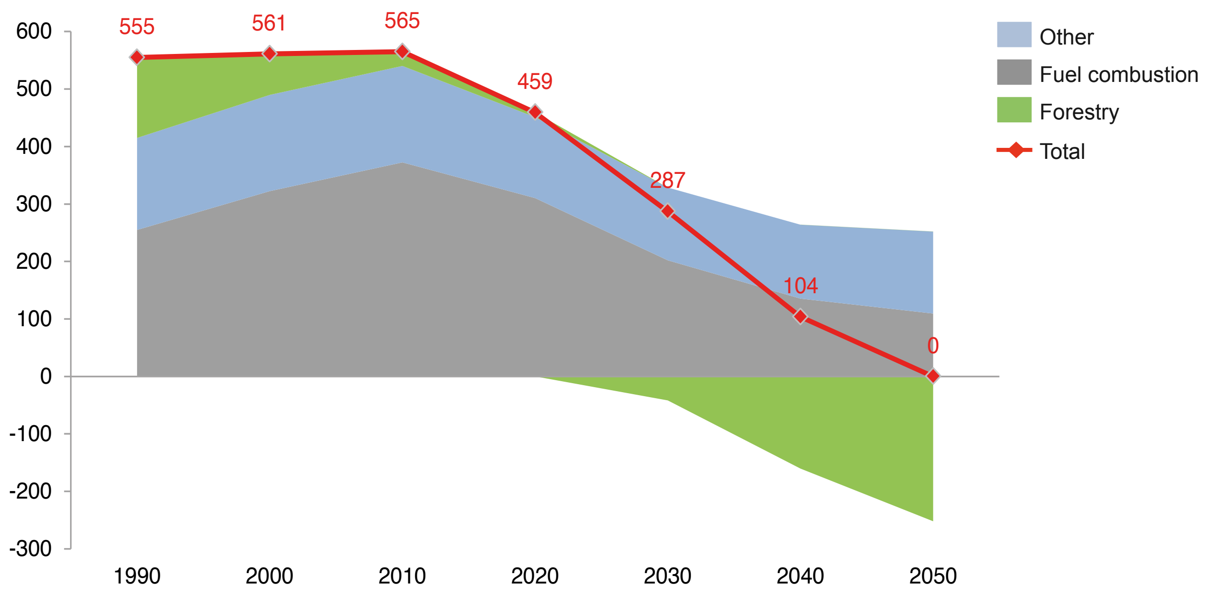
This study shows that the Australian economy can achieve net zero emissions by 2050 via a range of options. The illustrative pathway applies the three pillars of energy system decarbonisation, as well as addressing non-energy emissions, across the various sectors of Australia's economy, as detailed in Figure 11. This section details how each pillar contributes to the illustrative deep decarbonisation pathway for Australia (further detail can be found in the technical report)[5].

5 The data presented for 2012 is directly extracted from the model and may in some instances differ slightly from official energy and emissions statistics.

Figure 11: Decarbonising the Australian economy – the illustrative pathway in summary

Sector	Ambitious energy efficiency	Low carbon electricity	Electrification and fuel switching	Non-energy emissions
Electricity	▪ Improved efficiency of on-site and remote gas generation through use of solar panels and cogeneration	▪ Renewables or a mix of renewables and either CCS or nuclear provide near-zero emissions electricity ▪ Variable supply is supported by battery and thermal storage		
Industry	▪ Continuation of current trends deliver 30 to 40% improvement in energy efficiency ▪ Offset in mining by structural energy intensity increases		▪ Electrification of heating and mining processes leads to tripling of electricity use ▪ Decrease in coal use ▪ Bioenergy increase nine-fold in particular through 50% shift oil to biofuels in mining	▪ Process improvements, materials substitution, increased combustion/catalysation of gases with high global warming potential ▪ Implementation of CCS (up to 50%) for CO_2
Transport	▪ Strong energy efficiency in all modes ▪ Trend to smaller cars ▪ Small shift from air to rail & teleconferencing	▪ Uptake of batteries supports management of variable electricity supply	▪ Cars and LCVs shift to electric vehicles, hybrids and fuel cells by 2050 ▪ Road freight shifts to gas ▪ 50% biofuels in aviation	
Buildings	▪ Halving of energy use per households and energy use per m² in commercial buildings	▪ Rooftop PV generation multiplies 10 to 15-fold across three scenarios	▪ Near full electrification of buildings energy use	
Agriculture & Forestry				▪ Best practice farming reduces emissions ▪ Shift to profitable carbon forestry offsets all residual emissions

Figure 12: Greenhouse gas emissions trajectory, $MtCO_2e$, 1990–2050 (DOE 2014)



AMBITIOUS ENERGY EFFICIENCY

Ambitious energy efficiency in all sectors leads to a halving of the energy intensity of the economy.

In the illustrative pathway, the final energy use associated with each dollar of GDP halves by 2050. This is driven by strong improvements in energy efficiency in all sectors of the economy.

Buildings

In the buildings sector, there is a reduction in energy use per household of over 50%, while commercial sector energy use per square metre reduces by just under 50%. This substantial improvement in comparison to recent trends does not require a substantial technological leap as it can be achieved through ensuring that new buildings are as efficient as possible and by replacing equipment by best practice models at the end of its useful life. For example, LEDs can reduce energy use by almost 80% compared to halogen globes, and can even provide 25% savings compared to efficient compact fluorescent lamps (CFLs) (CWA 2013b). Similarly, eight star new builds have demonstrated that 80% less energy use for heating and cooling compared with current homes is possible across much of Australia's climate zones[6]. In most cases, the cost of energy saved over time more than offsets the additional upfront costs at standard rates of return.

Industry

In manufacturing, the energy intensity of production decreases by approximately 40% by 2050 (before electrification), through implementation of process improvements and equipment upgrades for existing plants and implementing best practice technologies at the time of construction. For existing plants, this includes, for example, reducing thermal losses from heating processes such as furnaces, kilns and boiler systems; or capturing waste heat to pre-heat materials, reducing the fuel inputs required to perform other industrial processes (CWA & DRET 2013). These improvements usually generate financial savings and reduce production costs for companies. The improvement modelled corresponds to maintaining the recent level of energy efficiency implementation for the next two decades and accelerating it slightly to 2050 (CWA 2013c).

In mining, similar levels of energy efficiency are achieved. In the short term, energy savings are achieved through operational improvements, such as changing the gradient of the slope upon which vehicles travel, reducing the amount of time vehicles stop and start and improving load management (CWA & DRET 2013). In the longer term, improvements in technology such as geological analysis and early ore and waste separation or effective crushing and high-pressure grinding rolls, can deliver significant additional savings (CWA 2010). Mining energy efficiency improvements are counterbalanced by a structural increase in energy intensity. Past energy intensity trends show that every year, around 3% more energy is needed to extract a similar volume of minerals as the year before, due in particular to a degradation in ore quality and increasingly difficult access to good resources. As a result, mining energy intensity doubles between today and 2050.

Transport

In the transport sector, a 70% improvement in the energy efficiency (i.e. litres per 100km) of cars and light commercial vehicles is achieved, mostly through electrification of vehicles, combined with fuel efficiency improvements and a continuation of the trend towards smaller vehicles. Hybrid vehicles commercially available today achieve up to 65% improvement in fuel efficiency compared to an average car[7]. Aviation achieves a 30% improvement in energy efficiency by 2050. Today, the A380 is already 18% more efficient per passenger seat than the previous generation of large aircraft (The World Bank 2012b). In freight, trucks experience a 15% improvement by 2030, while rail and marine achieve 17% and 22% improvement respectively by 2050 (Cosgrove et al. 2012).

Alternative pathways

Further improvements in energy efficiency in addition to those modelled include new technology developments, for example in material efficiency (such as 3D printing), which would reduce the amount of resource extraction and primary metals production, or in mining energy efficiency (such as through a move to landfill mining or other innovative practices). Alternative pathways for transport include reducing travel activity, for example through more widespread use of public transport, increase in local sourcing of products, or greater substitution of business travel with teleconferencing.

6 See the accompanying Technical Report for a detail of the analysis and references.

7 Average vehicle uses approximately 10.9L/100km (ABS 2013b), many efficient vehicles use less than 4L/100km (Allianz Australia 2014)

Barangaroo precinct

Barangaroo South, NSW, is planned to become Australia's first large-scale carbon-neutral precinct. This precinct is converting a former container wharf in Sydney's CBD to a financial services hub with commercial, residential, retail and hotel/integrated resort uses.

The project integrates sustainability into its design, including the adoption of a neighbourhood scale, shared infrastructure approach to services for the new precinct. The plan includes innovative features to save energy, such as harbour water heat rejection and a district chilled water network to replace cooling towers. The precinct's on-site solar generation is designed to power all public spaces and the on-site wastewater treatment plant. This blackwater treatment plant enables recycled water to be exported for re-use in the surrounding areas of the Sydney CBD.

The project is establishing a community carbon fund, which will purchase renewable energy certificates and carbon offsets to ensure that the precinct is carbon neutral in operation.

LOW CARBON ELECTRICITY

Low carbon electricity is supplied by renewable energy or a mix of renewable energy and either CCS or nuclear power at similar costs.

Decarbonisation of the electricity sector relies primarily on the use of three main technology types: renewables, CCS and nuclear. Three scenarios[8], representing the upper range of penetration of each technology type, have been modelled (Figure 13): *100% renewable grid*, CCS included (*CCS*), and Nuclear included (*Nuclear*).

All three scenarios lead to similar emissions intensities by 2050, with the *100% renewable grid* resulting in the lowest emissions by 2050 (Figure 13). The *Nuclear* scenario could achieve similar emissions levels if constraints were applied to the share of gas generation allowed in the generation mix, which was not done in this modelling exercise. Electrification across all sectors drives a 2.5-fold increase in electricity demand by 2050 (Figure 13).

The modelled scenarios highlight a number of key findings:

> All scenarios include a dominant share of renewables, driven by the decrease in cost of renewable technologies, such as solar and wind, over recent years (see for example, IEA 2014b; IEA-PVPS 2013; Trancik 2014), with a minimum penetration of 48% by 2030 and 71% by 2050. They are expected to be the lowest-cost technologies to achieve decarbonisation until their penetration requires significant additional costs for the management of variability.

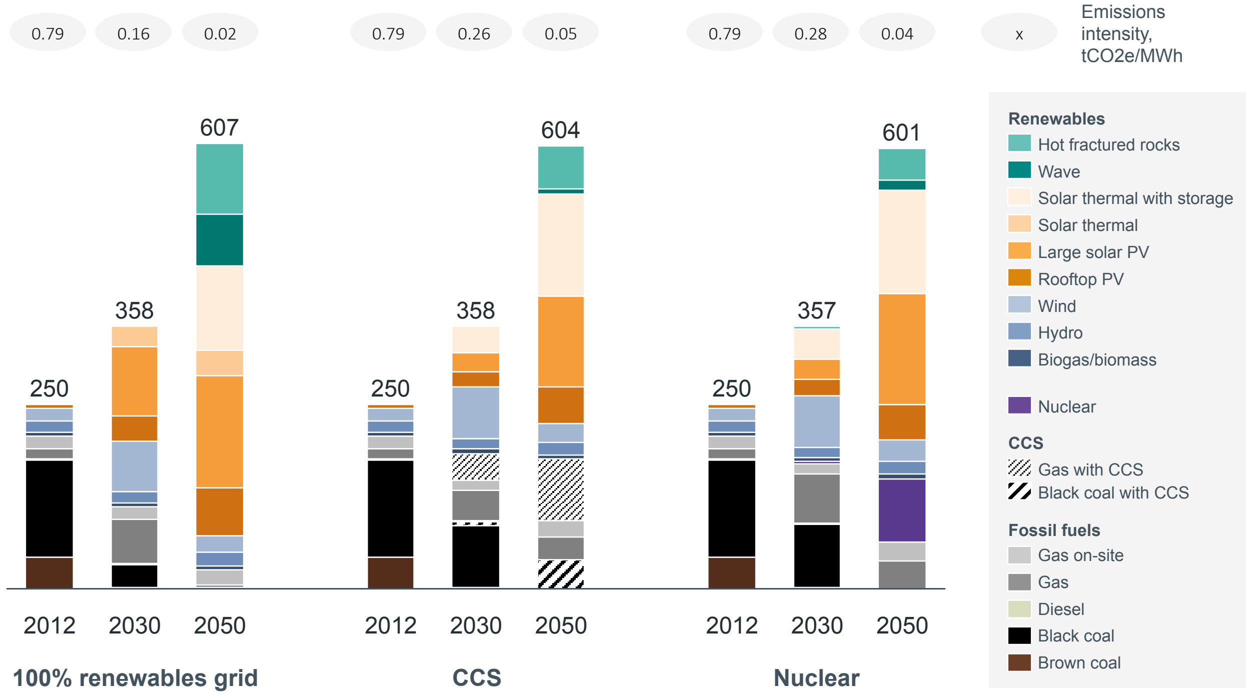
> The major difference between scenarios is how the variability of wind and solar is managed. In the *CCS* and *Nuclear* scenarios, back-up for variability is met by these technologies[9], combined with peaking gas, while in the *100% renewable grid* scenario it is met by combining *storage* with renewables and use of non-variable renewable technologies, such as geothermal (ARENA International Geothermal Expert Group 2014).

> Solar becomes the dominant technology by 2050. The high share of solar power (either photovoltaic or solar thermal) in the electricity generation mix is a reflection of both their cost advantages and also that a third of electricity consumption occurs in Western Australia, due to increases in mining activity and electrification of mining processes, where conditions for solar power are particularly favourable. Taking into account the need to invest in back-up capacity to cover variable supply, solar becomes more profitable than wind power towards 2050.

8 To achieve deep decarbonisation, a variety of scenarios beyond these three are possible. A wider mix of technologies may be less likely given that any of those technologies requires significant investment to deploy and support them (e.g. storage facilities for *CCS*, intermittency management for renewables and radioactive waste management infrastructure for nuclear), so that a focused strategy is likely to result in lower system costs.

9 For the *Nuclear* scenario, this is the case for the east coast. In the main scenario, nuclear generation has been excluded for WA, given the high level of uncertainty on the future structure of the grid and the potential transmission and distribution costs associated in creating a large enough grid in the state to accommodate large-scale nuclear plants. If nuclear generation was included in WA, then nuclear generation would amount to 27% of total generation by 2050.

Figure 13: Generation for three electricity scenarios, TWh



Projected wholesale electricity prices for the three scenarios differ very little over the projection period, reflecting that the technology costs of the higher-cost renewable technologies, *Nuclear* and *CCS* are in a similar range. An analysis of retail prices was conducted for the *100% renewable grid* scenario. Including an increase in transmission and distribution costs, it is expected that retail prices increase at an average rate of 0.9% per year or around 40% to 2050, but average household electricity use (excluding for electric vehicles) falls by half, so that average household power bills are reduced by 30%. Taking into account a projected 56% increase in average per capita incomes to 2050, the share of electricity expenditure in household income is halved, on average for households that are using only electricity today[10].

The *100% renewable grid* scenario was selected for the whole of economy modelling because it achieved the lowest emissions. An alternative land use scenario was developed to illustrate how the carbon budget could be met under one of the other scenarios and the economic results are not expected to vary significantly under alternative electricity scenarios. Independent of the electricity sector scenario, some CCS is applied in industry.

10 If there were any costs involved in reducing electricity use per capita via energy-efficiency measures, the cost of these measures would need to be included in a full analysis of electricity supply and end-use costs.

Alternative pathways

Alternative approaches to these three scenarios could include further measures to reduce demand. In particular, electricity demand improvements in mining have a significant impact on the total electricity generation in 2050. On the supply side, additional technologies could be considered such as biomass with CCS, generating electricity with net negative emissions, or the use of biogas to power remaining gas turbines without CCS. Both of these options require the sourcing of additional biomass feedstocks. Accelerated reduction in the cost of low carbon energy technologies and storage could also speed up decarbonisation of the electricity sector.

Nuclear

While estimates do vary and may or may not include items such as decommissioning and waste disposal, studies generally find that nuclear power is an economically competitive technology relative to other low greenhouse gas emission-intensive electricity generation options, such as renewables or carbon capture and storage (BREE 2012, 2013b; DPMC 2006). Nuclear power can be deployed at scales greater than a gigawatt down to small modular reactors less than 200 megawatts.

Adoption of nuclear is technically feasible in Australia, which has abundant uranium reserves, a stable system of government and a considerable capacity to store nuclear waste on a geologically stable continent. At present, nuclear faces challenges in terms of creating a social licence to operate within Australia, which has a research reactor but no operating power plant, and long-standing government legislation preventing nuclear power generation. Significant public engagement and education is required in order to begin to address concerns related to safety and waste disposal. Some experts have suggested that one entry point might be to trial installation of a small modular reactor at a remote, energy-intensive mining project (with scalability by adding other modules as required) that could provide a test bed for public acceptance.

CCS

Carbon capture and storage (CCS) captures CO_2 produced by large industrial and electricity generation plants, transports the CO_2 via pipelines, trucks or ships to a suitable site, where it is injected into a rock formation suitable for geological storage. Technology to capture, transport and inject CO_2 has been used for decades in certain applications. The key challenge for widespread deployment of CCS is the integration of these component technologies into successful and cost-competitive, large-scale demonstration projects in new applications, such as electricity generation.

There are currently 22 large-scale CCS projects in operation or under construction globally, double the number since 2011. The total CO_2 capture capacity of these 22 projects is around 40 million tonnes per annum. There are another 34 large-scale integrated projects in earlier stages of development. The world's first large-scale CCS project in the electricty sector, Boundary Dam in Canada, is scheduled to become operational in 2014 (GCCSI 2014a). Outside the electricity sector, the world's first iron and steel project to apply CCS at large-scale moved into construction during 2014 in the United Arab Emirates.

Australia has three large-scale CCS projects under development. The Gorgon Project is a natural gas facility in Western Australia that is forecast to capture and inject over 100 million tonnes of CO_2 over the lifetime of the project. The project has commenced construction and is expected to commence injection in 2016 (GCCSI 2014b). The CarbonNet Project in Victoria and South West CO_2 Geosequestration Hub in Western Australia are in earlier stages of development. Both projects propose to capture CO_2 from multiple industrial facilities for storage.

Solar thermal

Concentrated Solar Thermal (CST) technologies have the potential to provide near-zero emissions electricity by transforming solar radiation into thermal energy, which is then converted into mechanical energy and ultimately into electricity. CST technologies have advantages over many other renewable energy technologies, namely that this energy can be stored and converted to electricity when needed, allowing dispatchable power generation.

While CST technologies are promising, CST power plants currently have high upfront costs, which is a significant barrier to their market deployment. Researchers at the Australian Solar Thermal Research Initiative (ASTRI) anticipate the cost of generating CST power could be reduced from 26.5c per kWh to around 12c per kWh by 2020. This reduction in cost means that CST power plants can be cost-competitive with traditional power plants.

CST power plants are already deployed a relatively large-scale overseas, particularly in the United States, Spain, South Africa and Morocco. Australia does not currently have any commercial large-scale CST plants in operation; however it is leading research into this technology on a number of fronts. Researchers at CSIRO have recently used CST technologies to produce "supercritical" steam, similar to what modern fossil fuel power plants can produce. ASTRI's research is focusing on reducing capital costs, increasing capacity factor, improving efficiency and increasing the value proposition of CST and solar chemistry technologies. These technological advances substantially increase the cost-competitiveness of CST technologies worldwide.

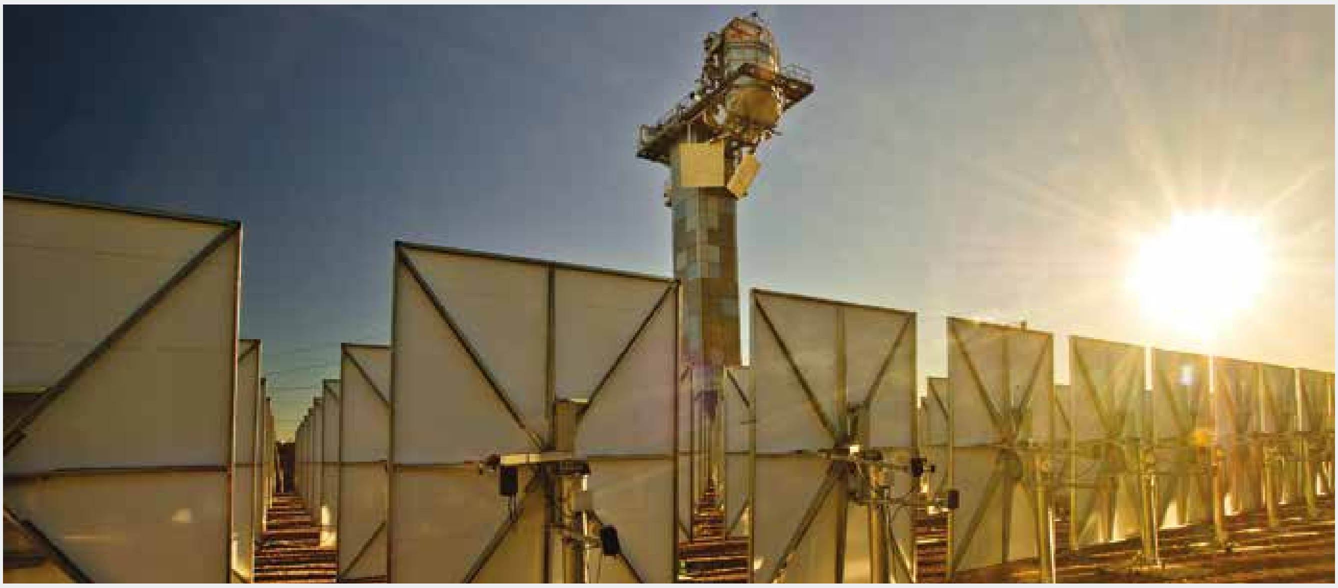


Photo courtesy of CSIRO

Managing variability of electricity supply

Many of the lowest cost, widely available renewable energy options generate variable electricity; they produce energy in the right conditions, rather than in line with energy demand. Successful management of this variability is a key success factor of low-cost decarbonisation of electricity. Many people have studied this problem of managing variability under high renewable power supply. Australian studies include AEMO (2013), Graham et al. (2013), Elliston et al. (2012), Wright and Hearps (2010) and Trainer (2012), while Reedman (2012) provides a full international literature review.

In the modelling for this report, several strategies are employed to ensure that this variability can be managed and demand can still be met under unfavourable weather conditions, including trading between regions, use of flexible fossil fuel or renewable technologies (such as hydro, enhanced geothermal and solar thermal with thermal storage) and battery storage. The model projects a halving in battery costs by 2030, which is conservative relative to other recent projections (Muenzel et al. 2014) and in the context of a decarbonised world. Demand-side participation is an alternative way of balancing demand and supply should these strategies not be sufficient.

The King Island Renewable Energy Integration Project is a good example of how variability can be managed. The project aims for renewable energy from wind, solar and bioenergy to provide over 65% of the annual energy demand for the island. This is facilitated by battery and flywheel energy storage, smart grid infrastructure with fast acting demand-side management, biodiesel generation and integrated diesel-flywheel systems known as an 'uninterruptible power supply', allowing for instantaneous backup when generation falls below demand. These systems allow for a reliable energy supply and up to 100% renewable energy use at times of high renewable energy production.

ELECTRIFICATION AND FUEL SWITCHING

Electrification and fuel switching from fossil fuels to bioenergy, and from coal and oil to gas, reduces emissions from transport, industry and buildings.

As electricity generation switches to low carbon energy sources such as renewable energy technologies, nuclear power or CCS, electricity becomes the least emissions-intensive energy source. This drives widespread electrification across transport, buildings and industry and results in substantial decreases in emissions from these sectors. As a result, electricity's share in final energy use increases from 22% today to 46% in 2050. Fuel switching from fossil fuel to bioenergy and from coal to gas drives further emissions reductions.

Buildings

A switch from natural gas to a decarbonised electricity supply results in near elimination of emissions from buildings by 2050 (Figure 14). This involves a move from gas to electricity for all heating, hot water and cooking equipment.

Industry

In industry, there is a significant shift from coal and oil use towards electricity, bioenergy and gas, driving an approximate 60% reduction in energy emissions. Electricity use triples, driven by an increase in iron and steel production from Electric Arc Furnace (EAF) technology, a shift to electricity for heating processes and, most significantly, a shift in mining from trucks to electricity-based technologies, such as conveyors for materials handling. Bioenergy is utilised for half of the remaining mining oil use, increasing bioenergy consumption nine-fold compared to 2012 levels, with 15% of remaining direct fuel shifted to biomass/biogas in manufacturing.

Figure 14: Building energy demand, PJ (left) and building emissions, $MtCO_2e$ (right)

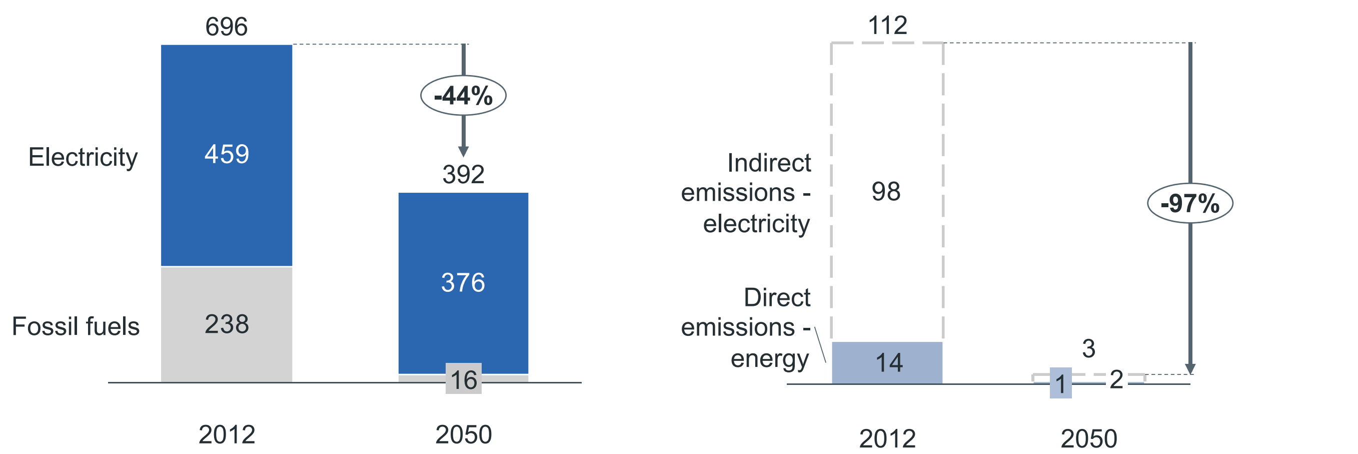
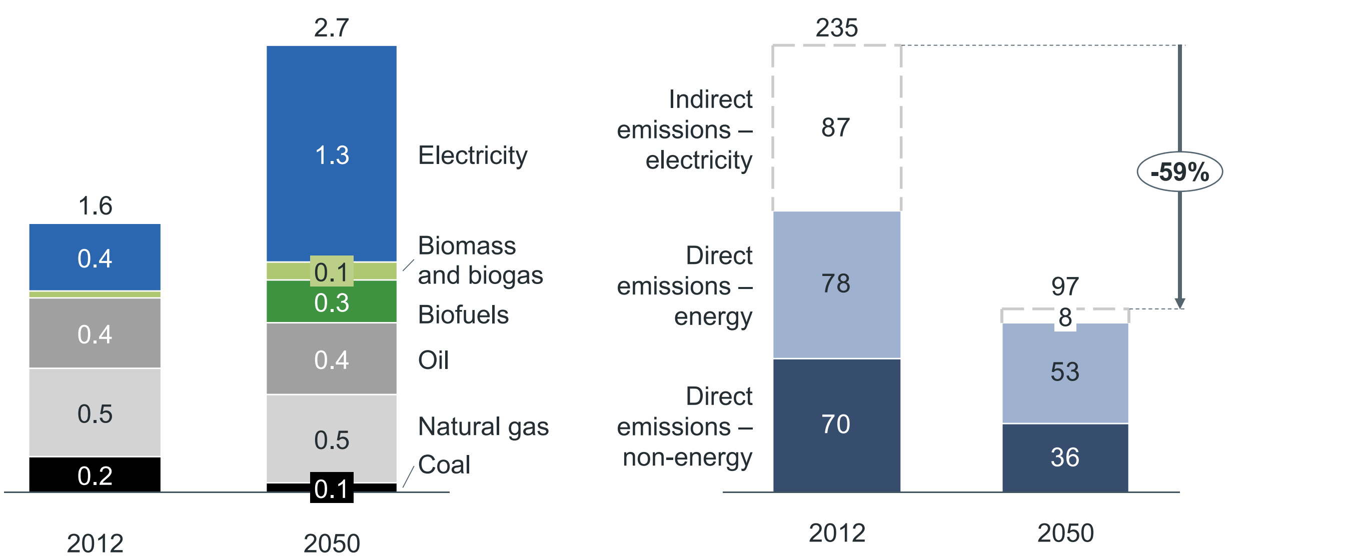


Figure 15: Industrial energy use by fuel type, EJ (left) and industrial emissions by source, $MtCO_2e$ (right)



Transport

Cars and light commercial vehicles shift from internal combustion engines to electric and hybrid drivetrains and, to a lesser extent, hydrogen fuel cells (Figure 16). Hydrogen is created through electrolysis and can be considered another form of electrification, providing an attractive opportunity for the use and storage of any surplus renewable electricity generation.

Natural gas is used in place of oil for road freight (Figure 16), lowering oil use in the sector by 85% between 2012 and 2050. As a result, CO_2 emissions are reduced by two thirds, while vehicle kilometres travelled nearly double. Approximately 15% of air travel gets replaced by electric fast rail between the large east coast cities. In addition, biofuels replace 50% of oil use in aviation, the only fuel switch option currently available for this sector. The marine and rail sectors are assumed to experience a relatively modest switch to gas and biofuels. In the future, alternative pathways could be investigated that include the use of hydrogen to power large trucks or increased use of biofuels if additional feedstocks are available.

Electric vehicles

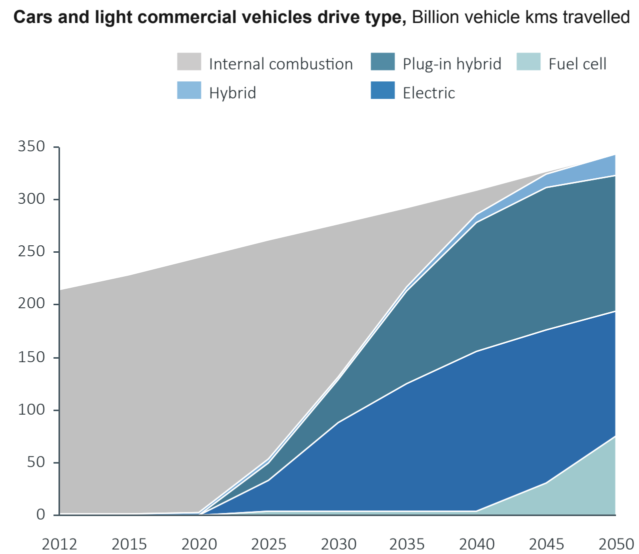
Electric vehicles have been around for almost as long as their combustion engine-powered counterparts. Improvements in battery technology and lightweight vehicle design, growing environmental awareness and cost reductions afforded by growing the manufacturing scale of core electric vehicle systems and components, have put electric vehicles within striking distance of the affordability and performance offered by conventional internal combustion vehicles.

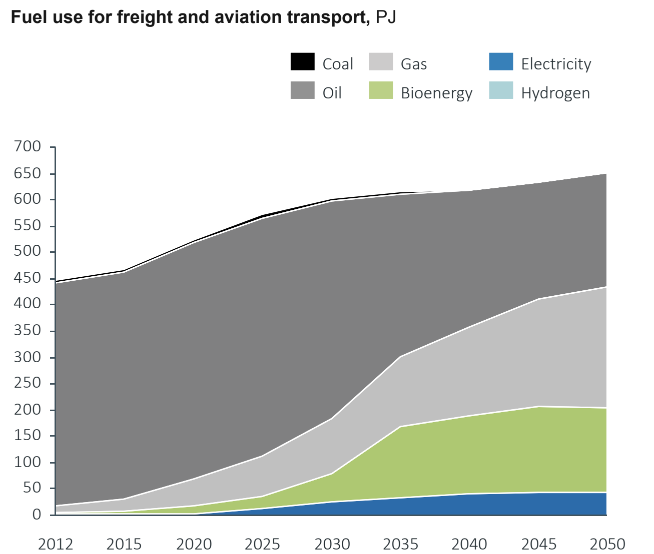
Tesla Motors, Inc. is quickly winning fans across the world for their electric vehicles and are soon to launch the Model S in Australia.Globally Tesla expects to deliver over 35,000 Model S vehicles in 2014 (Tesla Motors 2014a), which may be small in the context of global car sales but is already greater than the combined sales of the Holden Commodore and Ford Falcon in Australia in 2013 (Hagon 2014).

Tesla have targeted the upper end of the market, with the Model S luxury sedan following the Tesla Roadster sports car, while building a vertically integrated supply chain of key electric vehicle subsystems. This strategy has allowed them to initially target buyers willing to pay a premium for luxury, performance and sustainability, while building experience and scale to allow for lower-cost models in the future, with the potential for far greater sales volumes (Musk 2006). The company is also developing supercharger and battery swap stations along major traffic corridors in the US and other key markets (including Australia) to improve the practicality of the car to a wider market (Simpson 2014).

The momentum gained has not been missed by well-known traditional vehicle manufacturers such as Renault-Nissan Alliance, Ford, General Motors and BMW, who have developed all-electric vehicles of their own to get a foothold into this emerging market. Nissan is already offering their Leaf, a four-door all-electric vehicle for less than $40,000 (Nissan 2014).

Figure 16: Transformation of the transport sector





Bioenergy feedstocks

Bioenergy utilised in the modelled pathway is exclusively sourced from second and third-generation feedstocks, meaning there is no significant impact on agricultural production. These feedstocks include agriculture and forest residues (e.g. bagasse, stubble and sawmill residues), wastes and energy crops such as pongamia (a type of oil seed tree), grasses, algae and coppice eucalyptus (mallee), accounting for approximately 1000 PJ of potential. Some of these feedstocks could be replaced and/or complemented by woodwaste from the newly planted carbon forests or other feedstock depending on the relative costs of production.

Innovations in the use of biomass

Biomass is a versatile renewable resource that is often a waste product from agriculture or grown as dedicated energy crops. In many cases, the products from biomass can be used as direct replacements in vehicle engines or industrial processes, making the process of decarbonisation fairly simple. Currently biomass is cost-competitive, where a feedstock is cheap, readily available in large quantities and able to be converted cost-effectively into fuels and energy.

Innovations in biorefining could open the door to greater production of liquid fuels and other bio-based products from feedstocks that do not compete with food production. Biorefineries can sustainably process biomass into a host of marketable commodities (food, feed, materials and chemicals) and energy (fuels, power and heat), replacing the same products from fossil fuels such as coal and crude oil. Companies such as Borregaard in Sarpsborg, Norway have been operating biorefineries for more than 40 years and today there is significant momentum towards commercialisation, with many new plants in construction or operation around the world.

The Mackay Renewable Biocommodities Pilot Plant in Queensland commenced operations in 2010 on the site of the Mackay Sugar Racecourse Mill. It is a unique research facility, run by the Queensland University of Technology (QUT), demonstrating the processes for converting plant material into bio-based products. The facility investigates the use of various fibre plant feedstocks, which can be converted, for instance, to ethanol, aviation fuels, building materials, bioplastics, paper and car components. This fuel source could also lead to economic and agronomic benefits for farmers who provide the feedstocks.

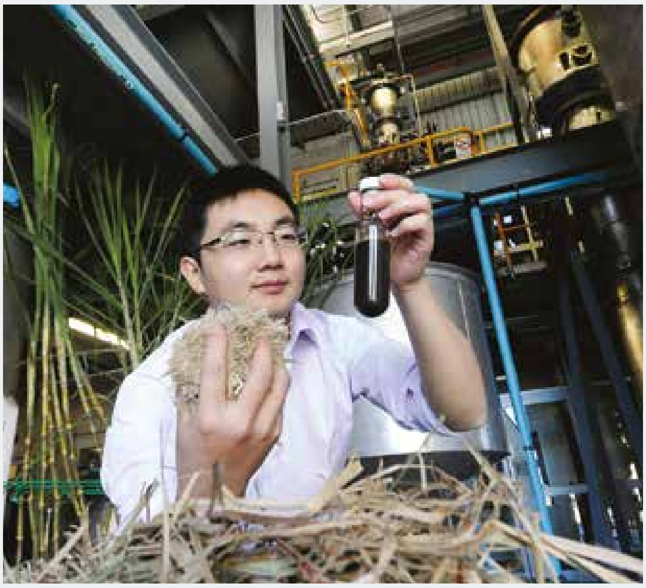


Photo courtesy of QUT Marketing and Communication

NON-ENERGY EMISSIONS

Non-energy emissions from industry are reduced through CCS and process improvements, while a profitable shift from livestock grazing to carbon forestry offsets any remaining emissions.

Industry

Process emissions and fugitive emissions from the industry sector are reduced via various means, including the partial use of bio-coke in iron and steel production, increased combustion/catalysation of gases with high global warming potential and CCS. Non-energy emissions are well-suited for the use of CCS, given the relatively high purity of CO_2 outflows.

Natural refrigerant gases

Technologies used for heating, ventilation, air-conditioning and refrigeration (HVACR) are among the most energy-intensive processes in Australia, responsible for over 22% of all electricity consumption in 2012 (Brodribb & McCann 2013). Additionally, many of the gases used for refrigeration, such as hydrofluorocarbons (HFCs), have a very high global warming potential, thousands of times more potent than carbon dioxide. When these gases leak into the atmosphere during operation or decommissioning, they can have a substantial impact on Australia's emissions.

The use of natural refrigerants such as ammonia, carbon dioxide and some hydrocarbons instead of HFCs has the potential to significantly reduce the energy consumption of these processes and also eliminate the emissions of these highly potent synthetic greenhouse gases. Ammonia for example has zero global warming potential and has already been demonstrated in large industrial applications, with cost reductions from reduced energy bills.

The Australian Refrigeration Association (ARA) estimates that Australia has the potential to reduce the energy bill and operating costs from HVACR by over $8 billion per annum through the use of best practice natural refrigerants. This would have the potential to reduce emissions from HVACR by over 50%, by 2030 which equates to a 7% reduction in national emissions. Short-term action to support the eradication of high global warming potential refrigerants could include the requirement that all new HVACR systems be based on natural refrigerants or low greenhouse potential synthetic gases by 2030.

Agriculture

Soil and livestock emissions are reduced through the implementation of best practice farming techniques. For beef production, a major source of methane emissions, this includes intensification of breeding, improvement in feeding and pasture practices, as well as enhanced breeding and herd selection for lower livestock methane emissions (see Herrero et al. 2013). Growth in beef demand slows as a result of increases in beef prices in a decarbonised world. Overall growth in demand sees agricultural emissions grow by 20% from 2012 to 2050. Some of this production, and the associated emissions, is attributable to exports.

Carbon forestry

Australia has great potential to offset emissions via forestry biosequestration. Under price incentives for afforestation, large shifts in land use from agricultural land (in particular livestock grazing) to carbon forestry are identified as profitable (Bryan et al. 2014) in the analysis produced for our scenarios. For the illustrative pathway, the total uptake of carbon forestry was capped by the volume required to meet the budget recommended by Australia's Climate Change Authority (2014). The amount is approximately a quarter of the total economic potential identified and around a third of plantings offering returns at least five times higher than their original use. A range of environmental factors, including land use, water availability and biodiversity priorities have been considered in this analysis (see technical report for further detail).

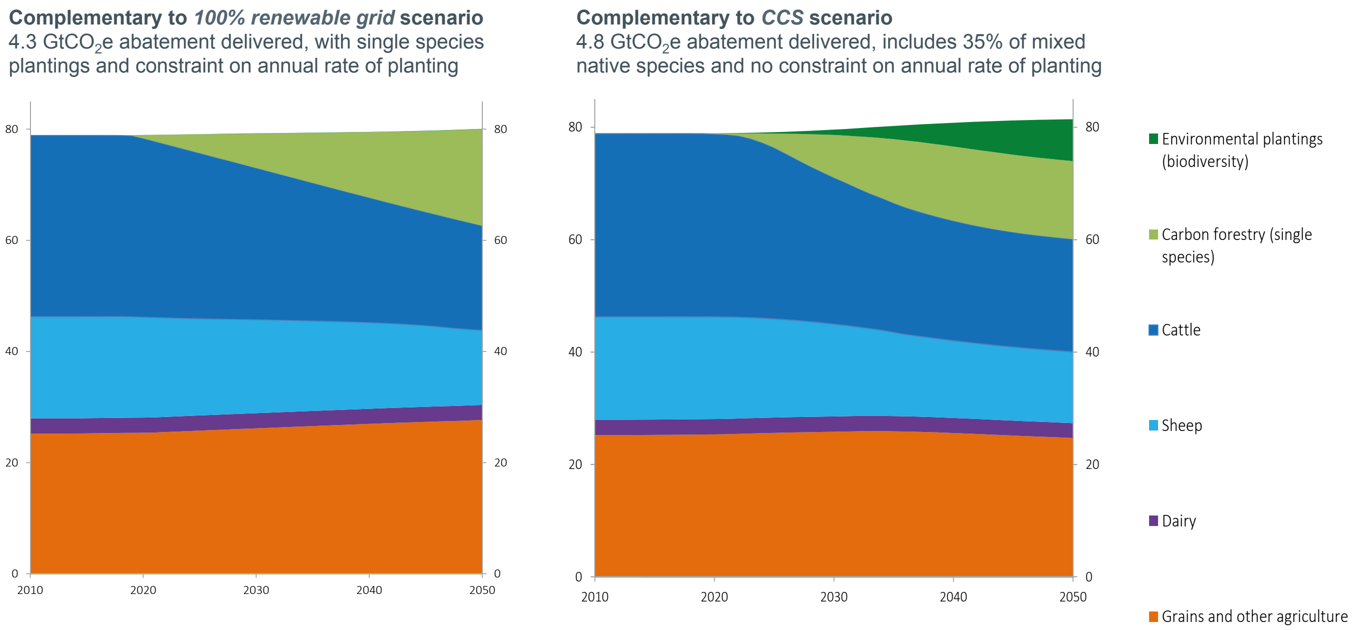
Several scenarios were developed to investigate the total land area and the annual planting rate required to compensate for all remaining positive emissions by 2050. The scenarios explored included options to offset the residual emissions from the *100% renewable grid* scenario (requiring 4.3 $GtCO_2e$ of sequestration to 2050) and the additional emissions associated with the *CCS* scenario (requiring an additional 0.5 $GtCO_2e$ to 2050) (Figure 17). Both of these scenarios are conservative in that the total volume of required abatement is delivered even with constraints such as annual planting rates (capped to 0.6 Mha per annum) or allowances for achieving biodiversity outcomes. These variations result in 20-30% more land being required to offset residual national emissions than required in an unconstrained approach, giving no attention to biodiversity.

Two illustrative scenarios are presented in Figure 17, corresponding to combinations of abatement delivered and constraints applied. On the left graph, abatement is delivered to offset residual emissions from the *100% renewable grid* scenario. On the right graph, abatement is delivered to offset residual emissions from the *CCS* scenario.

In the *100% renewable grid* scenario, single species plantings with higher rates of carbon sequestration per hectare are assumed and a constraint applied on the annual rate of planting. In the *CCS* scenario, 35% of mixed native species is assumed, with no constraint on annual planting rate assumed. Under both scenarios the majority of land use change occurs from livestock grazing to carbon forestry, with relatively modest impacts on the area of cropland.

Under modest productivity assumptions this implies wool and sheep meat volumes peak and then decline to around current levels in 2050, while national beef output volumes increase by around 10% (as around half of national beef production occurs outside the intensive-use zone) and grains output volumes increase by around 20. The gross value of output grows strongly across all commodities, due to projected price increases of around 50 for grains and more than 75% for livestock.

Figure 17: Land use change occurring under illustrative land use scenarios



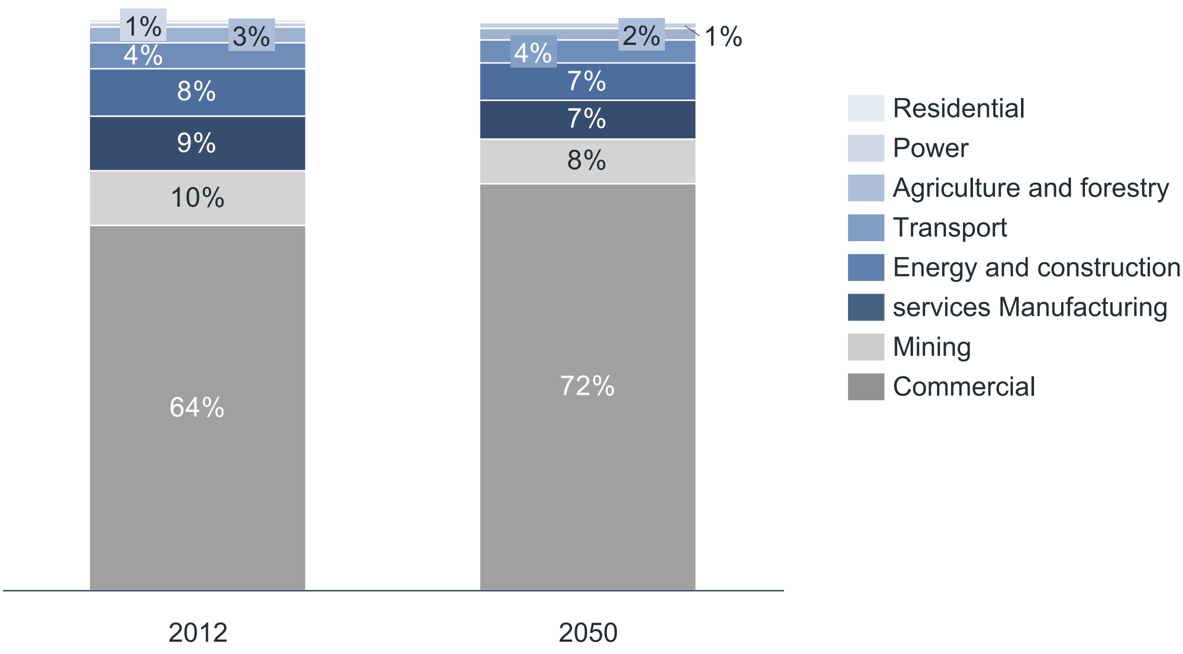
4 Implications and opportunities

Australia's economic structure does not change significantly, with primary industries remaining a significant share of the economy.

Under the deep decarbonisation pathway, the overall structure of Australia's economy does not change significantly. The commercial sector's contribution to the economy continues to grow at a similar rate as over the past four decades (ABS 2014), while the share of manufacturing continues on a gradual decrease, although more slowly than to date (ABS 2014). The agricultural and forestry sector maintains a similar share of GDP. The contribution of each sector to the economy in 2012 and 2050 is shown in Figure 18.

Traditional mining and manufacturing industries continue to grow in terms of real value added, including iron ore (138%), metal ore (150%), other mining (329%), other chemical production (113%) and aluminium, iron and steel production (37%), with a decrease in coal, oil and petroleum. More detail on industry value added by sub-sector is presented in the accompanying technical report.

Figure 18: Sectoral contribution to GDP, %



Some technologies and activities decline, but others rise and contribute to continued economic growth. The largest changes occur in electricity generation, resources extraction and land management.

Although the overall structure of the economy remains largely the same, significant changes occur within some sectors.

Modelling by the International Energy Agency (IEA 2013) estimates that under a deep decarbonisation scenario, global demand for coal decreases by 40% between today and 2050, resulting in a decrease in the unit price for coal, while global demand for oil decreases by 30% over the same period. At the same time, coal demand from Australia's key export markets (namely Japan, South Korea and China) decreases by more than 50%, strongly impacting fossil fuel extraction in Australia and lowering coal prices (IEA 2013a). In all three of the electricity generation scenarios in this analysis, electricity generated from coal decreases. For the *100% renewable grid* scenario and *Nuclear* scenarios the decrease is 100%, whereas under the *CCS* scenario it is 70%.

The decline in the contribution of these sectors to the Australian economy is offset by the increase in renewable electricity generation (excluding hydro) and gas extraction. Furthermore, the analysis shows job creation in the renewable electricity generation sector is double the job losses from the coal-fired electricity generation sector[11].

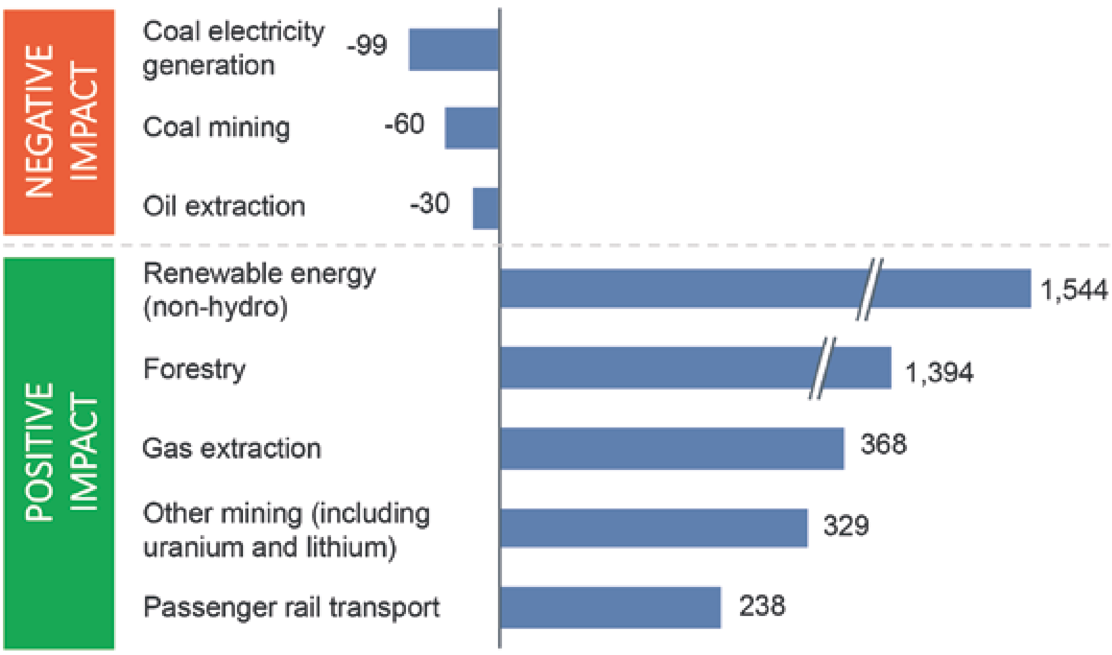
DDPP results show that global demand for gas increases under a deep decarbonisation scenario, largely due to its use in industry and road freight. This is supported by the IEA (2013a) results, which suggests that global demand for gas increases by around 15% between today and 2050. This increase in global demand contributes to an increase in gas extraction in Australia.

Carbon forestry expands strongly due to its role in offsetting non-energy GHG. Also, global demand for minerals such as uranium and lithium increases (IEA 2013a), leading to increased mining production in Australia. Results from the DDPP show that nuclear power quadruples across the 12 DDPP countries, due to its role in decarbonising the electricity systems of many countries (in particular China and the US), while global demand for lithium is driven by the widespread uptake of batteries in the electricity and transport sectors.

Figure 19 shows an extract of the economic results for the illustrative pathway. It shows the sectors most impacted, either positively or negatively, by deep decarbonisation.

11 Any changes in job numbers in a particular industry will be compensated by changes in employment in other parts of the economy over the long-term periods considered in this report.

Figure 19: Key sectors impacted by decarbonisation, growth in value added between 2012 and 2050 in %



Decarbonisation of Australia's economy can be achieved without significant lifestyle changes.

Deep decarbonisation in the illustrative pathways is mostly characterised by technological transitions, our everyday needs continue to be met in a manner similar to what we experience today. Similarly, since deep decarbonisation does not drive significant structural shifts in the economy, employment is predominantly in the services sector, as it is today, as well as in the industrial sector.

Due to widespread electrification, the most noticeable change is that the majority of household and commercial building energy comes from electricity, supplied via a centralised grid, as it is today, or via localised distributed generation, augmented by battery storage.

Buildings are heated and cooled more efficiently, they contain more efficient, smarter appliances and the services they offer are mostly electrified. For example, highly efficient (possibly induction) electric cooktops replace gas stoves and electric heaters replace gas heaters.

A wide variety of vehicles are available, mostly fuelled by low carbon fuels, including electricity and hydrogen, while plug-in hybrid vehicles are available for longer trips, or where vehicle range is a constraint. Air travel is available, with biofuels gradually taken up in the aviation sector, and rail provides a viable alternative to air travel on some routes.

There are a number of lifestyle changes that could further reduce emissions, which have not been included in the analysis. These changes may be driven by other social, economic and environmental factors and could include:

> smaller houses, greater range of tolerance in heating/cooling requirements (where feasible), less travel, more widely available public transport, less emissions-intensive consumer products and decreased beef consumption, and

> substitution of business travel with teleconferencing and preferential sourcing of less emissions-intensive products and services.

CSIRO's Australian Zero Emission House project in Victoria, photo courtesy of CSIRO

Australia is rich in renewable energy opportunities and has substantial potential for geological sequestration.

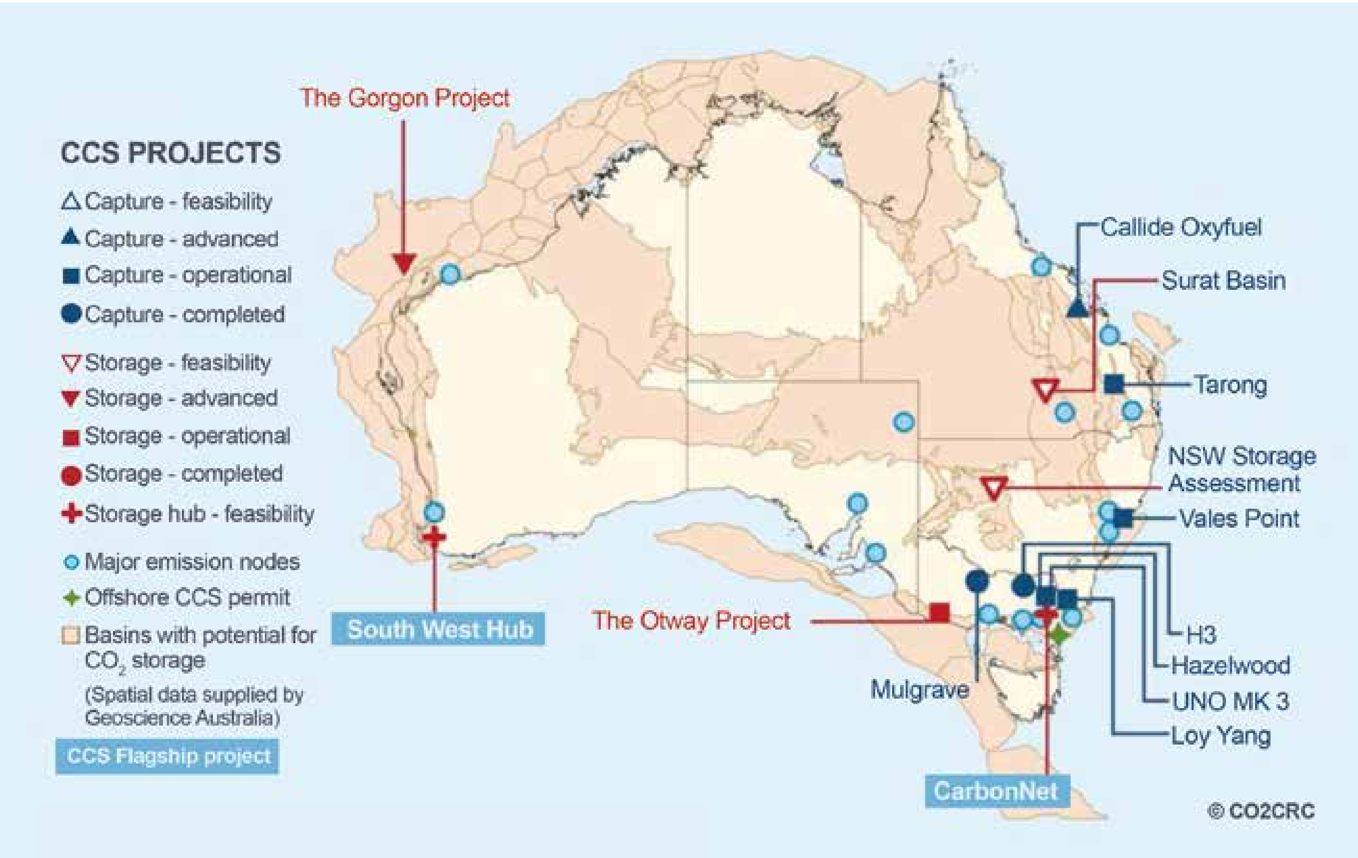
The potential for generating energy from renewable resources in Australia is far greater than Australia's total energy use today (Table 2). The challenge for Australia is not the availability of renewable resources, but harnessing the potential. Australia also has substantial potential for geological carbon storage with large storage basins across the country, including a number in close proximity to fossil fuel reserves and major industrial areas (Figure 20).

Table 2: Renewable energy potential and status in Australia[12]

Renewable energy source	Potential in Australia*
Solar	▪ 58 million PJ solar radiation per year ▪ 10,000 x today's energy use
Wind	▪ > 10,000 PJ per year ▪ > 1.7 x today's energy use
Biomass	▪ ~1000 PJ per year by 2050 ▪ 1/6 of today's energy use
Hydro	▪ 216 PJ per year ▪ limited additional potential
Geothermal	▪ 441,000 PJ of recoverable heat per year ▪ > 70 x today's energy use
Ocean	▪ Supplying <10% of electricity demand by 2050 may require as little as 150km of coastline

12 Sources: BREE 2014a; CSIRO 2012; Geoscience Australia & BREE 2014; D Honnery 2014, pers. comm 16 May; Honnery & Moriarty 2009; Technical Report. *Potential refers to technical potential except for solar (theoretical) and biomass (technical-environmental). Today's energy use refers to total net energy consumption in 2012-13 (5884 PJ).

Figure 20: Australian CCS projects (CO_2CRC 2014)



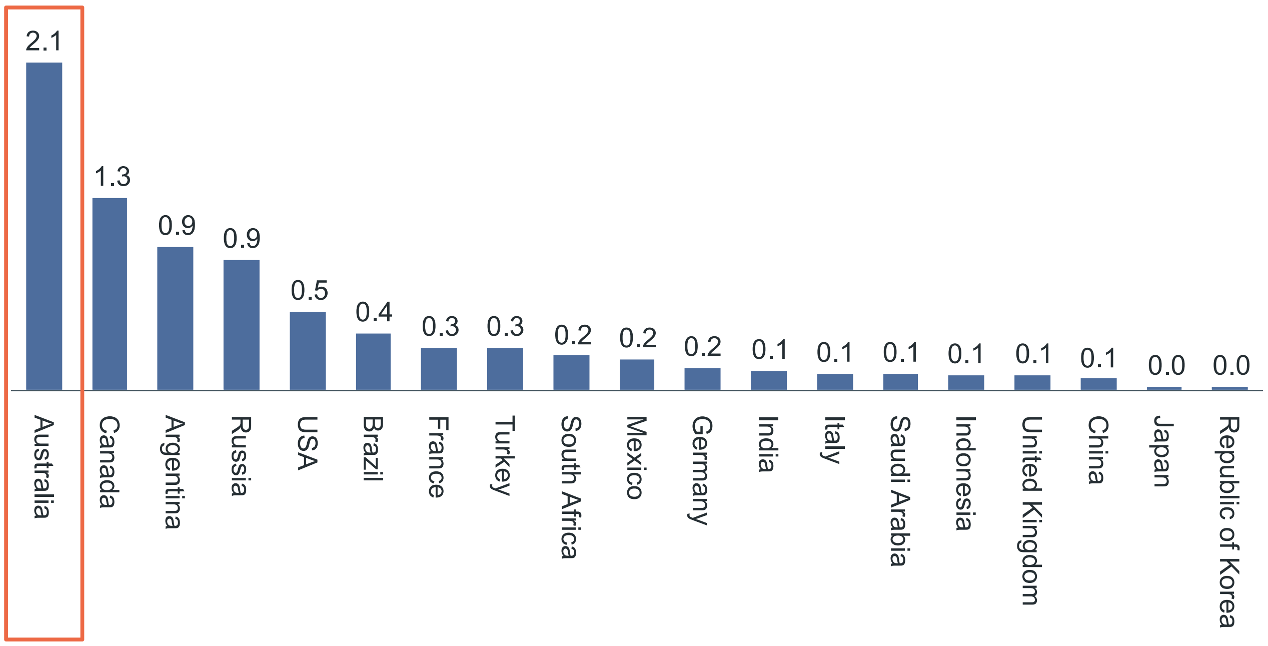
Australia has vast land available for carbon forestry to mitigate residual emissions.

Australia has more arable land per capita than any other G-20 country (Figure 21). This represents a significant opportunity for a range of carbon forestry plantings that could offset residual emissions from electricity generation, industrial processes and agriculture.

Recent modelling by CSIRO has found that carbon plantings could profitably deliver significant carbon abatement between today and 2050, given the value of carbon emissions reductions implicit in our scenarios. Realising this potential significantly increases land sector incomes, but it also requires a number of challenges to be overcome, such as establishing supply chains, as well as supporting services and managing impacts on water availability and food production (Bryan et al. 2014).

If the challenges are overcome and there is strong demand for emissions offset credits from other countries, this has the potential to enable Australia to become a net exporter of carbon offsets by 2050, given the cost of reducing residual emissions in other countries is higher than the cost of planting carbon forests in Australia.

Figure 21: Arable land in G-20 countries*, 2011, hectares per person (The World Bank & FAO 2014)



*European Union excluded, Arable land (hectares per person) includes land defined by the FAO as land under temporary crops (double-cropped areas are counted once), temporary meadows for mowing or for pasture, land under market or kitchen gardens and land temporarily fallow. Land

Addressing challenges in the land sector

The transition in the land sector is significant and faces a number of challenges that require addressing. In particular, it is necessary to:

- provide an environment conducive to investors-long-term certainty is required, as well as developments in accounting to recognise this new asset class
- support rapid development of the required supply chains and labour force
- improve existing knowledge on the best species for each type of landscape and especially those which provide good performance and stability over the long-term
- understand the actual risks related to water and bushfire management, so that appropriate mitigation plans can be developed
- assess social impacts and proactively manage potential challenges, and
- understand the strategies that are required to optimise the volume of abatement delivered (e.g. active management of forests), as well as the associated challenges and opportunities, for example workforce requirements or bioenergy feedstock supply.

Deep decarbonisation creates opportunities for Australia.

In a decarbonised world, Australia's abundant renewable energy resources, as well as its geological storage potential could form the basis of a new comparative advantage in low carbon electricity generation, replacing the existing comparative advantage derived from fossil fuels. The realisation of this comparative advantage could eventually result in a revival of energy-intensive manufacturing industries, such as aluminium smelting, and the potential to develop renewable energy carriers for export markets, such as biogas or hydrogen.

The prerequisite for these opportunities is that all major producing economies face strong carbon constraints, either through their domestic frameworks or through import demand favouring products from zero or low carbon sources.

Australia also has the opportunity to be a global leader in CCS expertise and technology development, due to its great potential for CCS. The DDPs of a number of countries show very large volumes of CCS, implying a large demand for research and engineering services.

Prospects for the extraction, refining and export of minerals, such as non-ferrous metals and ores, uranium, lithium and other precious metals, are also good.

Australia's substantial potential for carbon forestry, bioenergy generation and biosequestration could also contribute to the economic revitalisation of regional and rural communities, biodiversity protection and improved water quality[13].

If the world's major economies decarbonise, Australia could be disadvantaged if it does not act.

Amongst the key success factors for global decarbonisation is global alignment on the conditions for trading of emissions-intensive commodities. Arrangements might include preferential treatment of goods with lower embodied emissions, barriers to the trade of goods with higher embodied emissions or global carbon accounting requirements.

An example of these types of arrangements was explored for the aviation sector in the European Union, where legislation including emissions from flights to, from and within the European Economic Area (EEA) under the EU Emissions Trading Scheme (ETS) was adopted in 2008. While the EU ETS currently applies to emissions from flights within the EEA (2013–2016), the EU ETS requirements for flights to and from non-European countries have been suspended until an international mechanism for the aviation sector is established (EC 2014).

Australia's electricity emissions intensity is nearly double the OECD average and the third highest in the G-20 behind South Africa and India (IEA 2013b). Furthermore, Australia's top exports are highly emissions-intensive, including commodities such as metal ores, liquefied natural gas and primary metals (DFAT 2012). A Climate Institute (2013) report scored Australia 17th out of the nineteen G-20 countries on a low carbon competitiveness index. As such, if global arrangements intended to favour the trade of lower emissions-intensive commodities were introduced, Australian exports could become less competitive in global markets.

In addition, other studies have shown that the costs of achieving a given emissions target are greater if action is delayed (see for example CWA 2011 and Treasury 2011 on the costs of achieving Australia's 2020 targets). Most of the increased cost was shown to come from lost opportunities, for example those pertaining to not buying more efficient (new)vehicles or not building more efficient (new) buildings between 2010 and 2015. Similarly, the Potsdam Institute for Climate Impact Research (Luderer et al. 2013) found that delaying action to reduce emissions until 2030 triples mitigation costs to 2050 compared to starting action in 2015. Changing paths later is also likely to mean increased disruption to the economy, for example through the need for early retirement of industrial or electricity generation assets that are emissions-intensive.

13 See for instance Eady et al. 2009; Stucley et al. 2012.

5 Achieving deep decarbonisation

While decarbonisation is a significant transition for Australia, it is achievable. Australia's economy has proven time and again that it is flexible, adaptable and resilient.

This report shows that deep decarbonisation is possible for Australia, requiring transitions in how we both use and produce energy, and also how we manage our land to sequester remaining emissions.

Shifts of this nature have been made in the past, Australia's economy has demonstrated that it is flexible, adaptable and resilient, with a long history of benefiting from new trends in the global economy. In the past, Australia's prosperity has been built on gold mining and wool production, today the main export drivers include tourism, education, coal production and minerals extraction. The transitions were made without damage to Australia's overall economic fortune. In fact, adapting to new circumstances historically has benefited Australia.

Many factors will drive change in Australia's economy over the next decades. Global growth areas that Australia can most likely benefit from include agribusiness, gas, tourism, international education and wealth management. Decarbonisation is just one of many influences.

The technologies required for decarbonisation are available or under development; further efforts in commercialisation, enhancement and integration will improve cost-competitiveness and performance.

The rate of development of low emissions technologies has progressed rapidly in recent years, with many technologies now mature in Australia or other similar economies, and some, such as energy efficiency, offering cost savings without any policy measures. The current status of the various elements of the illustrative pathway, with examples of their current progress and further improvement required, is summarised in Figure 22.

Some of the technologies in the illustrative pathway require further development to improve performance or reduce costs. Where technologies are not yet mature, pilot projects demonstrate the potential of the technology to be deployed at a large scale. Deployment allows continuous improvement through the manufacturing, supply and operation of the technology.

For example, the development of solar PV has seen prices reduce by approximately 10% per year, with production increasing by 30% per year over the last 30 years (Trancik 2014).

There are early signs of rapid improvement of battery storage for renewables integration and electric vehicles. These improvements mean that electric vehicles can already offer superior performance to conventional internal combustion engines. For example, the Tesla Model S electric vehicle has been recognised as the best performing new car by a number of reviewers (e.g. McKenzie 2013; Zenlea 2012).

Figure 22: Deep decarbonisation pathways summary

✔	Yes
✓	Yes, in some cases
Empty	Not currently

Sector	Element of pathway (implementation / improvement modelled)		Mature technology	Cost effective	Equal performance	Widespread implementation	Examples of current progress	Improvement required
ELECTRICITY SCENARIOS	**Renewables** (70% to 96% of generation by 2050)	Variable (wind, solar PV, wave)	✔	✓	✓	✔	▪ Renewables provided 14.8% of Australia's electricity[1], wind provided 33% of Danish electricity in 2013[2] ▪ 2 geothermal & wave energy plants operating in Australia[3] ▪ On King Island, batteries allow a renewable penetration of over 65%[4].	▪ Intermittent energy to be managed through storage, demand response and deployable energy generation ▪ Development and commercialisation of baseload renewable technologies ▪ Reduction in costs through large scale implementation
		Baseload (geothermal, solar thermal w storage)	✓		✓	✓		
		Integration (storage)	✔	✓	✔	✓		
	Nuclear (up to 27% generation from nuclear, 11% from gas, remaining renewables)		✔	✓	✔		▪ 393 GW installed worldwide[5], 75% generation in France is from nuclear[6]	▪ Development of supporting infrastructure and skills ▪ Enhancement of smaller grid networks to accommodate scale
	Coal or gas with CCS (up to 21% with CCS, 9% gas, remaining renewables)		✓		✔		▪ First CCS coal power plant expected to start operating in 2014 in Canada[7]	▪ Integration of plant elements proven in other applications
TRANSPORT	**Energy efficiency** (~75% for cars, 20-33% for other modes)		✔	✓	✔	✓	▪ Australian new light vehicle efficiency improved by 20% from 2002-2012[8]. ▪ A380 is 18% more efficient than avg[9]	▪ Uptake of best available technology and processes
	Electric vehicles & plug-in hybrids (~35% cars/LCVs by 2050 each)		✔	✓	✓		▪ 5% of 2013 Dutch sales are electric or plug in hybrid[10] ▪ Range for EVs now up to 425km[11]	▪ Reduction in costs through scale and continuous development ▪ Development of infrastructure
	Fuel cell cars (~20% cars/LCVs by 2050)		✔		✔		▪ Demonstration cars exist[12] ▪ Commercialisation expected 2015[12]	▪ Commercialisation of vehicles ▪ Development of hydrogen infrastructure and supply chain
	Shift to gas and biofuels (~70% gas for road freight and 50% biofuels for air transport by 2050)		✓	✓	✔	✓	▪ Gas used for 3.9% of road transport in 2012[13] ▪ First 100% biofuel-powered international commercial flight 2014[14]	▪ Development of gas infrastructure ▪ Adaptation for Australian applications ▪ Large scale supply chain for biofuels
	Bioenergy production Additional 1050 PJ primary energy (85% for mining and transport' 12% for bio-coke)		✓	✓	✓	✓	▪ Bioenergy 4% of energy use today[13] ▪ Mackay pilot plant (QLD) producing ethanol from diverse feedstocks[23]	▪ Development of technology & supply chain for large scale commercialisation
INDUSTRY	**Energy efficiency** (1.0% to 1.2% improvement p.a.)		✔	✔	✔	✓	▪ Tripling of energy efficiency since 2007-08 from 0.4% p.a. to 1.2% p.a[15]	▪ Commercial focus on energy management and continuous improvement
	Fuel shift (Electricity share ~doubles, bioenergy replaces 50% oil in mining and 15% gas in manufacturing, coal/oil to gas)		✓	✓	✔	✓	▪ 10% bioenergy in manufacturing[13] ▪ Gas use 3x larger than coal[13] ▪ Conveyor use in brown coal mines	▪ Demonstration of electric technologies ▪ Strong uptake & continuous improvement
	CCS (25-50% capture of non-energy emissions in several sectors)		✓	✓	✔		▪ One of the world's largest carbon CCS projects is under development at Gorgon Gas Development in WA[16]	▪ Integration of plant elements proven in other applications ▪ Cost reduction and commercialisation
	Mitigation of highly potent GHG (90% reduction in N-2O, very strong reduction in methane)		✓	✓	✔	✓	▪ N_2O reduced by 65-85% in pilots[15] ▪ VAM oxidation plant at BHP's West-cliff Coal Mine operating since 2007[17]	▪ Widespread implementation of best practice technologies
	Product/input substitution (shift to natural refrigerants, increased clinker substitution, 50% bio-coke in Iron & Steel)		✓	✓	✓	✓	▪ 31% of supplementary materials used in cement[15] ▪ Bio-coke tested in Australia[18]	▪ Development of installation and service industry for natural refrigerants ▪ Further demonstration of bio-coke
BUILDINGS	**Efficiency of central buildings services** (55% to 80% improvement in most technologies)		✓	✓	✓		▪ Demonstration 8 star homes use 80% less energy than average[19] ▪ New offices 33% more efficient than average existing offices[20]	▪ Commercialisation of best performing building technologies and systems. ▪ Improved efficiency of heat pump and solar in colder climates
	Efficiency of appliances and equipment (~50% improvement in energy intensity)		✔	✔	✔	✓	▪ Most efficient TVs 75% more efficient than least efficient[21] ▪ Refrigerator efficiency improved by 42% between 1996 and 2007[22]	▪ Uptake of best available technology and processes ▪ Improvements in energy efficiency must keep pace with new uses
	Electrification of energy use (~full electrification of buildings)		✔	✓	✔	✓	▪ Many homes & businesses already use 100% electricity for energy	▪ Improved efficiency of electric heat pump and solar in colder climates ▪ Consumer uptake of induction cooking

1.CEC 2014, 2. DWIA 2014, 3. Refers to 2013-early 2014; Baghaei 2014; CEC 2014, 4. Marchment Hill Consulting 2012, 5. IEA, 2014b, 6. World Nuclear Association 2014, 7. GCCSI 2014a, 8. NTC 2013, 9. The World Bank 2012b, 10. RVON 2013, 11. Tesla Motors 2014b, 12. See for example Toyota Motor Sales (2014), 13. BREE 2014b, 14. Amyris 2014, 15. CWA 2013c, 16. GCCSI 2014b, 17. WCA 2008, 18. Mathieson et al. 2011, 19. ClimateWorks analysis based on NatHERS 2013, 20. GBCA 2013 21. Differences between lowest and highest energy intensity appliances for similar size and function from energyrating.gov.au (2014), 22. DCCEE 2013, 23. RIRDC 2013.

A global effort is required to enable some of the transitions for decarbonisation.

International collaboration, along with domestic and global leadership, is required to address a number of key challenges. This can be achieved through focused efforts.

> **A global effort to push technology development and cost reduction.** Large investments in research and development are needed to improve the performance of existing low carbon technologies to required levels or explore potential game changers, which could accelerate decarbonisation or provide further options. In addition, large-scale implementation of emerging technologies is required to bring the costs of those technologies down, as has been experienced with solar PV.

> **Alignment regarding trading of emissions-intensive commodities and goods.** A key enabler for the decarbonisation of the Australian economy is to have commensurate policy action in all the major industrialised countries. If competitors in other countries are subject to similar decarbonisation pressures and policy drivers, many Australian industries could remain competitive or gain an advantage in global markets.

> **Agreement on how to finance the transition.** Significant investment is needed in all countries, in particular in the energy and transport networks and infrastructure, which requires policy support. In addition, some support may be required for the transition of current high-emissions industries and regions, for example for retraining of workers, phase-out provisions and transitional support for newly established industries.

> **Proactive management of trade-offs.** There are many trade-offs that need to be managed. For example, in the allocation of land between bioenergy feedstocks, agriculture (livestock and crops), carbon forestry and ecosystem services, it is important to ensure that global food needs and biodiversity requirements are met while at the same time enhancing carbon reduction opportunities.

The development of deep decarbonisation pathways can support the global effort by helping countries develop a common long-term vision and by highlighting key areas where collaboration is required. This process should be one of continuous improvement, with countries updating their pathways regularly to reflect advancements in knowledge, technologies and local context.

Past developments demonstrate that technology can help make great change possible

There is no question that decarbonising the global economy will be challenging and today it might be hard to imagine how the transition to a low carbon future might unfold, but technology can help make great change possible.

Who would have imagined in 1933, when the world was struggling to emerge from the Great Depression, that 36 years later there would be a man standing on the moon? And who would have imagined in the 1980s, when telephones had rotary dials and were only found in houses and offices, just how much the smartphones of today would be capable of? That time period, 36 years, is the same time period that we have for reducing carbon emissions to almost zero.

Technology development and adoption is speeding up as the cost of technologies comes down. For example, today solar panels cost 90% less than in 1980 and 50% less than in 1998 and they are becoming even cheaper. Who knows what technological breakthroughs might speed up the transition to a low carbon future–it could come from the Victorian Organic Solar Cell Consortium, who are researching flexible, printable solar panels, which could revolutionise how and where energy could be produced.

Investment decisions in Australia need to be made in a long-term context but action needs to accelerate now.

As the Deep Decarbonization Pathways Report (SDSN & IDDRI 2014, p.xiv) argues, "the current focus of the international negotiations on mitigation is on emission reduction targets to 2025 or 2030. Yet if countries do not work with a longer time horizon and backcast from this long-term target, they are likely to adopt strategies that fall far short of what is needed to stay below the 2°C limit."

The DDPP process highlights the need to start making decisions today based on the required long-term emissions reductions. An incremental approach does not enable the deep emissions reductions needed, but instead increases the costs involved in the transition. In particular, if Australia wants to achieve the emissions reductions required, then it is necessary to:

> **Accelerate action to reduce emissions now.** Many emissions reductions opportunities are already profitable today, such as energy-efficiency improvements. Implementing those opportunities now means that less emissions reductions are required in the future to meet the carbon budget, providing greater flexibility and also reducing the cost of action.

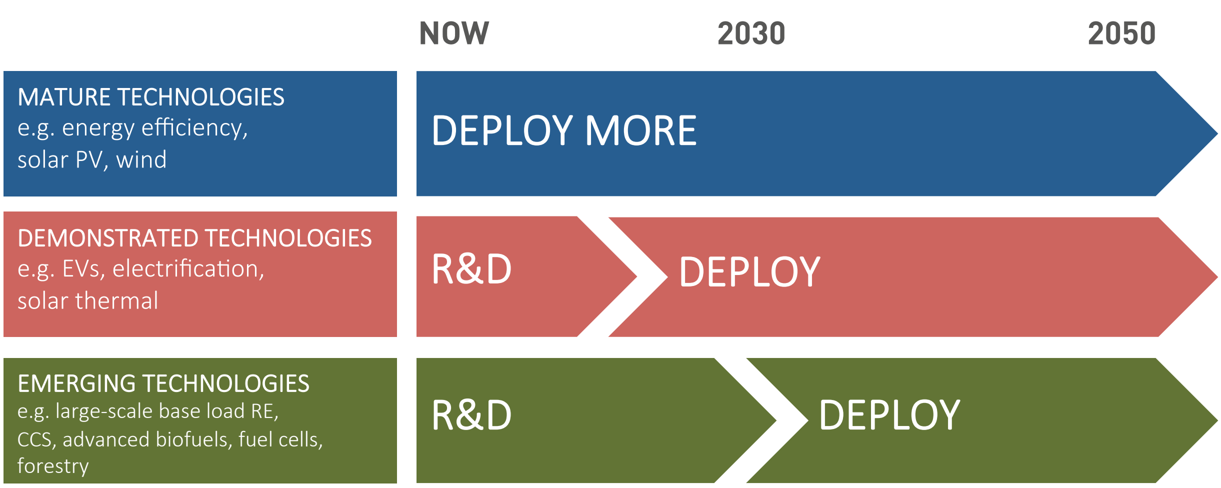
> **Avoid lock-in of emissions-intensive technologies.** It will be crucial to provide clear signals about Australia's likely long-term emissions pathways to inform investment decisions. The majority of assets built today that affect emissions (for example buildings, manufacturing facilities or power plants) will still be in operation by the middle of the century. Long-term signals ensure that new assets are compatible with the long-term emissions reduction pathway, either by implementing low carbon technologies upfront or by ensuring that they can be retrofitted at a later date.

> **Invest in R&D.** Large investments in research and development are needed to fill the technology and knowledge gap, as well as bring down the cost of low carbon technologies.

> **Create skills and supply chains.** Australia will need to build the supply chains that support low carbon technologies (for example, biomass collection and seedlings for carbon forestry), as well as develop local skills and capabilities in these new technologies and processes (for example to manage natural refrigerant gases or implement deep energy efficiency).

> **Explore pathways.** Finally, it is important to develop and continually refine country, sector and region pathways, helping to inform investment decisions and to help make the transition run smoothly.

Figure 23: Technology deployment timeframe



6 Next steps

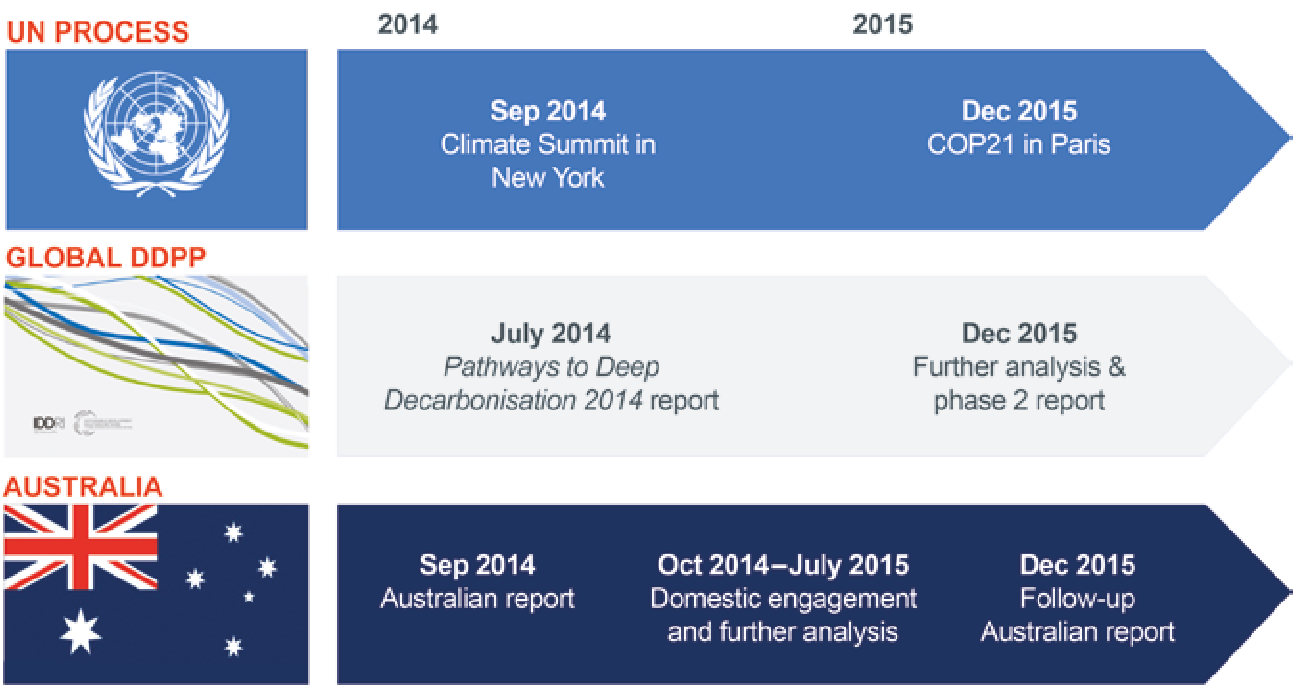
This report has outlined a range of possible scenarios to achieve deep decarbonisation within Australia, as well as the economic implications of one illustrative pathway for achieving Australia's carbon budget.

Over the next year, ClimateWorks and ANU will engage with business, government and other experts to further identify the key opportunities and challenges to achieving deep decarbonisation and to help Australia plan for this transition. A number of forums will be conducted, aiming to identify alternative pathways and technologies, the key challenges and further research.

A publicly available online calculator tool, called 'My 2050', is under development and is designed to allow users to explore the implications of different decarbonisation pathways and the trade-offs and interdependencies amongst them.

In addition to this domestic engagement, ClimateWorks and ANU will continue to lead Australia's participation in the second phase of the global DDPP. The next DDPP report, to be published in 2015, will include a greater array of technology options, scenario analysis, further detail on the issue of infrastructure stocks and estimates of cumulative CO_2 emissions from 2010–2050. It will be aimed to support the international climate negotiations towards the 2015 United National Climate Change Conference (COP21) in Paris.

Figure 24: Key project milestones



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Notes

CONTACT US

For further information about this project, contact ClimateWorks Australia.

Amandine Denis
HEAD OF RESEARCH
EMAIL: amandine.denis@climateworksaustralia.org

Anna Skarbek
EXECUTIVE DIRECTOR
EMAIL: anna.skarbek@climateworksaustralia.org

ClimateWorks Australia
Level 1, 31 Flinders Lane
Melbourne Victoria 3000
PHONE: +61 3 9902 0741
EMAIL: info@climateworksaustralia.org

Frank Jotzo
DIRECTOR
EMAIL: frank.jotzo@anu.edu.au
Centre for Climate Economics and Policy
Crawford School of Public Policy
Australian National University
Canberra ACT 0200
PHONE: +61 2 6125 4705

This report was authored by
Amandine Denis
Frank Jotzo
Scott Ferraro
Andy Jones
Niina Kautto
Rob Kelly
Anna Skarbek
John Thwaites

With technical input from
Philip Adams
Paul Graham
Steve Hatfield-Dodds

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