Energy Efficiency Scenario Modelling

Client: Energy Efficiency Council, ANZ

Final Report

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Executive Summary

Australia has a significant challenge to meet its 2030 carbon reduction target of 43% below 2005 levels and to achieve net zero by 2050. To reach these targets Australia will need to quickly deploy all available abatement opportunities. The urgency of the challenge has been amplified in the recent Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) Synthesis Report,[1] which urges real commitment and action on all fronts. The modelling included in this report has been conducted to determine the potential for energy efficiency and electrification to play an increased role in delivering on Australia's targets. The contribution that energy efficiency can make is often overlooked and has not been effectively supported in the past. Energy management solutions, including energy efficiency and electrification, are largely technically and commercially available. With increased focus and policy support they can be quickly deployed at scale and could deliver rapid emissions reduction at relatively low cost.

This modelling was commissioned by the EEC and ANZ to raise awareness about the potential for energy efficiency & more broadly electrification to contribute to emissions reduction in Australia. The modelling was conducted in February - March 2023 using a bottom-up assessment of emissions reductions achievable with current technology and costs. As described in the limitations section, more detailed and broader scope assessments certainly are possible. This modelling is presented to encourage more discussion and further investigation into energy efficiency and electrification's potential.

Our analysis undertook a bottom-up assessment of the magnitude of opportunity available within the key energy using sectors and identified potential impacts of four scenarios as follows:

a) **Business as Usual (BAU):** based on what Australia is currently doing, i.e., current policy and programs.
b) **Enhanced Energy Efficiency (EEE):** ambitious, but demonstrated and available energy efficiency improvements; demonstrates an improvement from BAU.
c) **High Electrification (HE):** based on Enhanced Energy Efficiency scenario but promoting greater electrification.
d) **High Renewable Fuels (HRF):** based on Enhanced Energy Efficiency scenario but promoting greater use of renewable fuels such as green hydrogen and biofuels.

The analysis showed that energy efficiency could provide up to 18.5% (or ~29 Mt CO_2-e) and 13.5% (or ~68 Mt CO_2-e) of the necessary emissions reduction by 2030 and 2050, respectively, from solutions that are practical, relatively easy to implement and cost effective and have the added benefit of helping Australia reduce energy expenditure. These energy efficiency solutions go "hand-in-hand" with many electrification solutions which could deliver an additional ~20 Mt CO_2-e and ~170 Mt CO_2-e of abatement, or 12.8% and 33.9% of Australia's 2030 and 2050 targets, respectively. The scenarios modelled provide potential pathways to enable Australia to make achieve its 2030 and 2050 targets.

In all scenarios, Australia is not expected to meet the 2050 emissions reduction target from a combination of energy efficiency, electrification, renewable electricity, and renewable fuels, and will require CO_2 removal to account for the balance. In the BAU scenario, removals account for 31.8% of the abatement, which is considered extremely challenging.

The use of enhanced energy efficiency and electrification techniques reduces the amount of carbon removals that would otherwise be required to achieve net zero in 2050 and can reduce reliance on renewable fuels that currently face challenges to scaling up. Enhanced energy efficiency also reduces the magnitude of requirements for renewable electricity, reducing costs in transitioning the electricity grid.

[1] Source: https://www.ipcc.ch/report/sixth-assessment-report-cycle/

Additional energy efficiency and electrification savings are available but will be more challenging to implement and may be in competition with other more costly solutions, like the use of biofuels and hydrogen, as well as many CO_2 removal technologies.

The results from the analysis conducted on the four scenarios are provided in Figure 1.

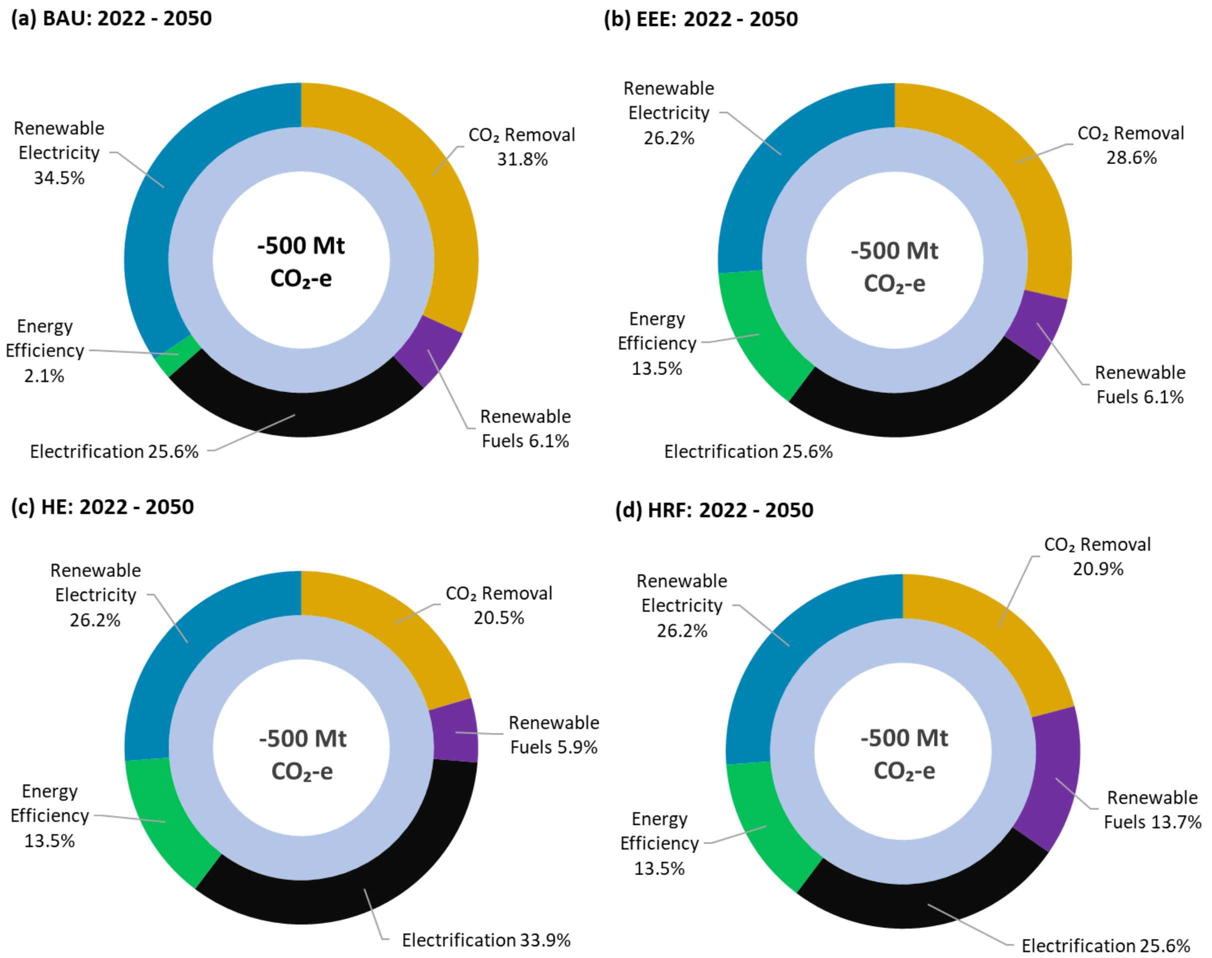


Figure 1. Predicted carbon emissions reduction at 2050: (a) Business as Usual (BAU), (b) Enhanced Energy Efficiency (EEE), (c) High Electrification (HE), and (d) High Renewable Fuels (HRF)

The results indicate that:

- Under the BAU scenario there is a heavy reliance on CO_2 removals to meet the 2050 target.
- Energy efficiency can help reduce the reliance on renewable energy and CO_2 removal to meet the emissions reduction target by ~41 Mt CO_2-e (or 24%) and ~16 Mt CO_2-e (or 10%), respectively.
- Increased focus on electrification can bolster the gains made by energy efficiency by up to ~42 Mt CO_2-e (or 62%).
- Renewable fuels have a place as a solution but are likely to compete with other solutions, like electrification and CO_2 removal, for ‘hard-to-abate’ emissions.

The analysis sought to identify which solutions should be considered first and shows that energy efficiency should be the first emissions reduction activity undertaken. This is illustrated by the marginal abatement cost curve and viability versus marginal cost plot provided in Figure 2 and Figure 3, respectively.

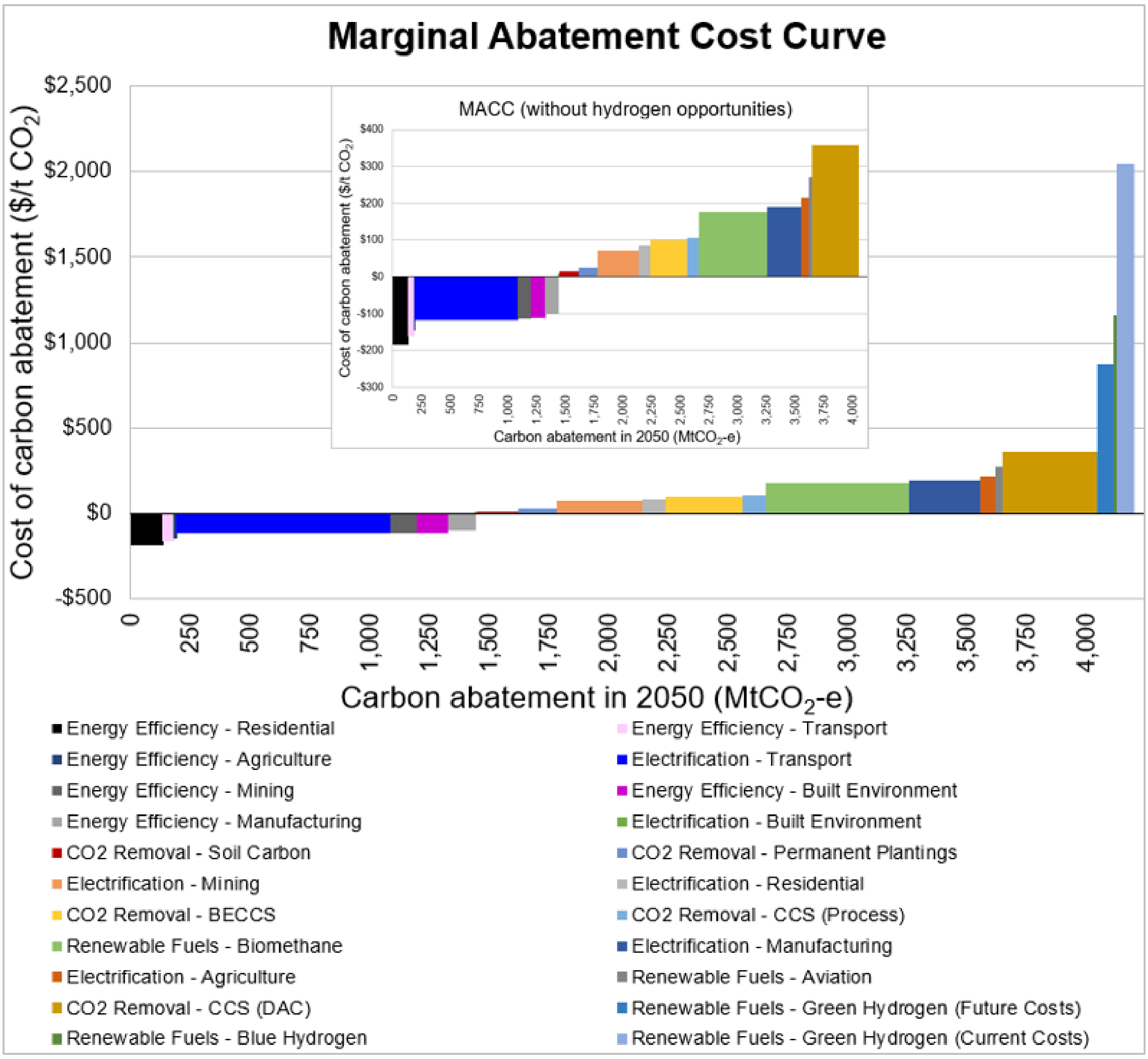
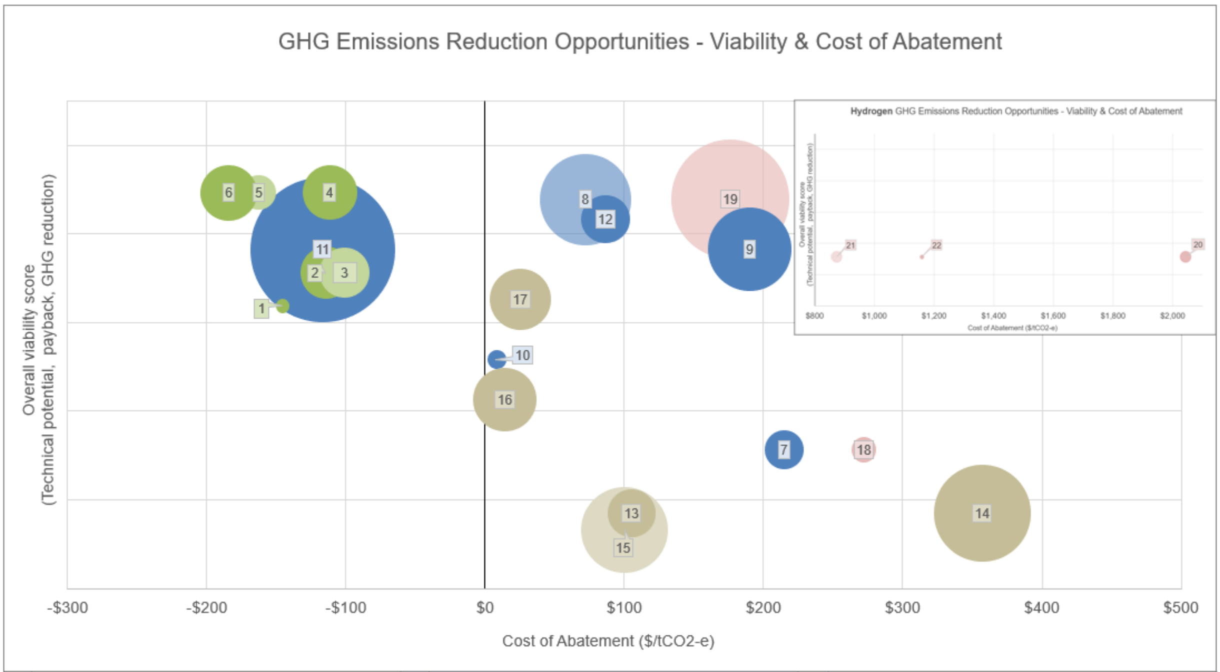


Figure 2. Marginal Abatement Cost Curve

The Marginal Abatement Cost Curve (MACC) shows that the energy efficiency opportunities all result in negative costs of abatement (cost savings), as does electrification of transportation (refer to Section 2.5 for an explanation of the MACC). The remaining opportunities (electrification, renewable fuels and CO_2 removal) result in positive costs of abatement (cost increases). Electrification opportunities result in large emissions reductions, due to the efficiency gained by a change in technology in combination with the transition to emissions-free electricity (by 2050). Note that green hydrogen opportunities are represented twice - with current and future pricing to illustrate the expected reduction in costs that will come with a high degree of research, development and deployment. It should be noted that the MACC provides a static comparison of costs in present values, and as such should be treated as indicative rather than definitive. Its purpose is to guide prioritisation of opportunities. Costs will shift over time as deployment rates increase and/or policy takes effect. This assessment could be updated in 2-3 years to reflect changes in market conditions.



1	Energy Efficiency - Agriculture	9	Electrification - Manufacturing	16	CO2 Removal - Soil Carbon
2	Energy Efficiency - Mining	10	Electrification - Built Environment	17	CO2 Removal - Permanent Plantings
3	Energy Efficiency - Manufacturing	11	Electrification - Transport	18	Renewable Fuels - Aviation
4	Energy Efficiency - Built Environment	12	Electrification - Residential	19	Renewable Fuels - Biomethane
5	Energy Efficiency - Transport	13	CO2 Removal - CCS (Process)	20	Renewable Fuels - Green Hydrogen Current Costs
6	Energy Efficiency - Residential	14	CO2 Removal - CCS (DAC)	21	Renewable Fuels - Green Hydrogen Future Costs
7	Electrification - Agriculture	15	CO2 Removal - BECCS	22	Renewable Fuels - Blue Hydrogen
8	Electrification - Mining				

Figure 3. Viability score and cost of abatement for energy efficiency, electrification, renewable fuels and CO_2 removal initiatives

The viability score is developed using a combination of criteria including technical and commercial readiness, availability and complexity of technology and cost impact. Refer to Section 2.6 for the full explanation. The viability versus marginal cost plot shown in Figure 3 presents the rated viability of energy efficiency, electrification, renewable fuels and CO_2 removal initiatives against the marginal cost of abatement. The potential volume of emissions abatement is represented as the size of the circle.

The energy efficiency initiatives plus transportation electrification represent the lowest cost of abatement and highest viability. Using the cost of abatement as a guide to prioritisation, it has been demonstrated that the energy efficiency driven reductions represent the least cost option, and their high viability will enable them to be executed sooner to make rapid progress towards Australia's 2030 and 2050 targets. Not executing the most viable/least cost reduction opportunities leaves Australia relying upon more expensive and less viable (therefore greater risk) measures to achieve its net zero targets.

Further investigation was carried out on individual sectors to identify where companies and government should focus their investment to have the most significant impact on their decarbonization journey. The results of this assessment are shown in Figure 4.

This analysis shows that the early stages of improvement programs in key energy using sectors should target first:

- **Agriculture:** electrification and renewable fuels.
- **Mining:** energy efficiency and electrification.
- **Manufacturing:** energy efficiency and electrification.
- **Commercial buildings:** energy efficiency followed by electrification.
- **Transport:** electrification.
- **Residential buildings:** energy efficiency and electrification.

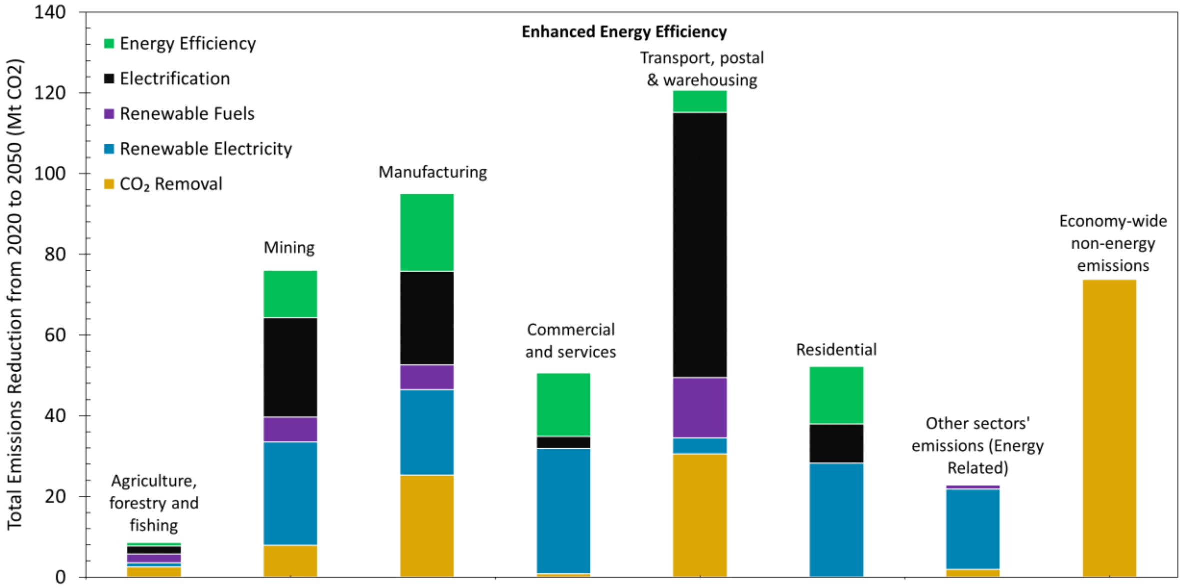


Figure 4. ANZSIC sector level emissions reduction in 2050 for Enhanced Energy Efficiency Scenario

Renewable electricity is not listed as a priority for improvement programs in any sector as the Australian Energy Market Operator's 2022 Integrated System Plan expects renewables to account for 82% of electricity generation in the National Electricity Market by 2030[2], and effective policies are in place to continue the transition to renewable electricity. However, to complete the task of decarbonising energy use, a focus on demand-side, or behind-the-meter activities like energy efficiency and electrification is required.

While it is recognised that Australia needs to consider all solutions on its journey to net zero, without a focused and sustained drive for improved energy efficiency and electrification the journey will be so much more arduous.

Energy efficiency represents both the least cost means of abatement, and in many cases the most immediate suite of opportunities for emissions reduction. However, there are currently limited policy signals to encourage activity in energy efficiency in Australian companies, and potential abatement associated with energy efficiency remains not fully realised.

[2] Source: https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

Contents

1 Introduction

1.1 Background

Australia currently has legislated emissions reduction targets, committing to reducing emissions by 43% below 2005 levels by 2030, and to net zero emissions by 2050.[3] To date, plans for emissions reduction have focussed on decarbonising the electricity system through a transition to renewable energy sources. However, electricity generation represents around a third of Australia's emissions, and no clear pathway exists to achieve the remaining required emissions reductions. This study aims to identify low cost pathways to achieve emissions reductions amongst the numerous technological options available.

Energy efficiency technologies, supported by energy management systems, are an affordable method of reducing carbon emissions, but their potential contribution to Australia's emissions reduction targets remains poorly understood. Informed consideration of the potential of energy efficiency to reduce emissions in key sectors, as well as the associated economic costs and benefits, is necessary to drive discussion and policy support for energy efficiency and determine the role it will play in the energy transition in the coming years.

The work presented here aims to provide a quantitative evaluation of possible future energy scenarios to inform the discourse around energy efficiency and energy management's role in meeting Australia's 2030 and 2050 carbon reduction targets. The scenarios analysed have been informed by approaches proposed by several international bodies[4] supported by data from Australian industries and government commitments, to determine possible pathways for Australia's energy transition. Combining the scenarios with practical insights and data on the energy efficiency potential in key industries, the contribution that can be made by prioritised energy efficiency technologies to the energy transition has been projected.

A description of each scenario is provided in Section 1.4, followed by the details of the model produced in Section 2, and the key outputs and interpretations of the model in Section 3.

1.2 Modelling Purpose

This modelling was commissioned by the EEC and ANZ to raise awareness about the potential for energy efficiency & more broadly electrification to contribute to emissions reduction in Australia. The modelling was conducted in February – March 2023 using a bottom-up assessment of emissions reductions achievable with current technology and costs.

As described in the limitations section, more detailed and broader scope assessments certainly are possible. This modelling is presented to encourage more discussion and investigation into energy efficiency's potential.

1.3 IRENA Emission Reduction Predictions

International bodies, such as IRENA, propose that energy efficiency technologies and methodologies could contribute 25% of the reduction in emissions necessary to meet the world's 2050 emissions targets and limit global warming to less than 1.5°C (Figure 5). Achieving this, however, would require an increase of 2.5 × the current rate of deployment of energy efficiency measures worldwide.

[3] Source: Climate Change Act 2022.
[4] Including IRENA, Intergovernmental Panel on Climate Change (IPCC), and International Energy Agency (IEA).

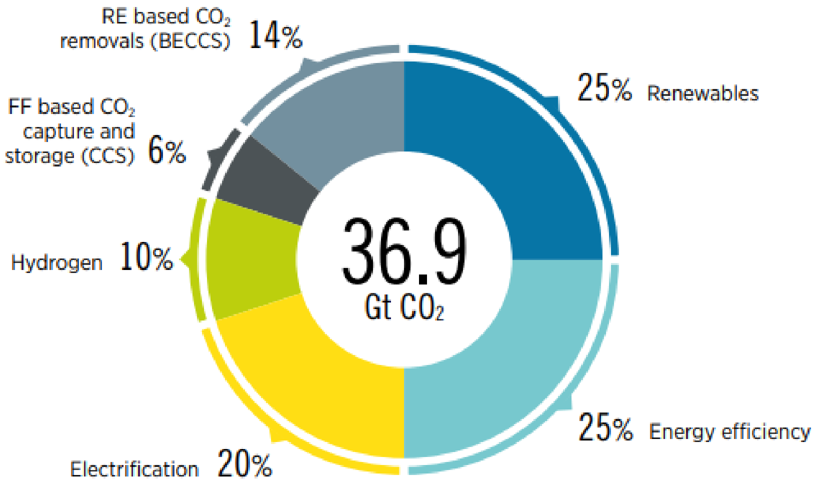


Figure 5. IRENA Emission Reduction Predictions[5]

The level of energy efficiency required under the IRENA prediction (25%) is heavily dependent on the introduction of policies and the introduction and achievement of mandates for improvement in energy efficiency along with the provision of sufficient funding to facilitate the transition. Examples of requirements needed across the globe include:

- Minimum fuel efficiency standards for transportation, energy efficiency standards and carbon intensity limits on processes and products and improved building codes and renovation targets.
- Substantial improvement in circular economy practices and the integration of alternative industrial processes to reduce associated emissions.
- 9 times the current investment in energy efficiency.
- An improvement in global primary energy intensity (global total energy supply per unit of gross domestic product) of 2.5 times the historical average.

It is unclear whether the standards would be able to be adopted universally, how they will be rolled out and who will pay for it.

By contrast this study seeks to provide increased clarity regarding the emissions reductions practically achievable within Australia using a ‘bottom-up’ approach. The study considers the unique issues facing Australia including its current energy sources, geographic location and magnitude of land mass and population along with the potential emissions reduction contribution of key industries through different fuel types, efficiency technologies and market trends. This was achieved through the development of a Business as Usual (BAU) baseline and three scenarios modelling different levels of contribution of emissions reduction options. These scenarios are described in Section 1.4 below.

1.4 Scenario Description

The scenarios below were arrived at by reviewing the IRENA World Energy Transitions Outlook initially, considering the pathways most suitable for Australia, and completing a workshop with the Energy Efficiency Council.

BAU scenario (BAU): based on what Australia is currently doing, i.e., current policy and programs, which includes those that have already been legislated and not yet enacted.

Core scenario - Enhanced Energy Efficiency (EEE): ambitious, but demonstrated and available EE improvements, in line with IRENA modelling and therefore demonstrates an improvement from BAU.

[5] International Renewable Energy Agency (IRENA). 2022. World Energy Transitions Outlook 2022.

High Electrification scenario (HE): based on the core Enhanced Energy Efficiency scenario with enhanced electrification above BAU.

High Renewable Fuels (HRF): based on core Enhanced Energy Efficiency scenario and includes a focus on potential for renewable fuels (including biofuels and green hydrogen).

1.5 Electrification as energy efficiency

In this modelling exercise, we have presented results for both 'electrification' and 'energy efficiency' techniques for emissions reduction. Energy efficiency is categorised as reducing the amount of energy used to do a particular task, and electrification is fuel-switching to electricity. It should be noted that electrification itself has a significant component of energy efficiency, as electric devices are typically more energy-efficient than their fossil-fuelled counterparts. For example, replacing a gas boiler with a heat pump is accompanied by a large reduction in emissions, which is a combination of the substantially higher level of energy efficiency of a heat pump, combined with the savings in changing from gas to electricity.

1.6 Carbon dioxide removals

The use of carbon dioxide removals in emissions reduction projections can sometimes be contentious. Carbon dioxide removals can either be technology-based through carbon capture and storage techniques, or biologically based through sequestration in forests, soils and biochar. At present, technological solutions have not been demonstrated that would permit abatement of 100% of Australia's current emissions, and even the most ambitious emissions reduction scenarios typically rely on a certain amount of carbon dioxide removals. In 2023, there are emissions that are both energy and non-energy emissions that are expected to be 'hard-to-abate' and will require offsetting by removals to reach net zero. In this modelling exercise, carbon dioxide removals are used to reach 'net zero' once the other modelled emissions reduction techniques have been exhausted. This approach is consistent with other exercises, such as those by IRENA[6], the IEA[7] and Climateworks Centre[8].

However, it should also be noted that the emissions projections, and associated removals, reflect technologies available in 2023. As technological progress advances, we would expect that the need to rely on carbon dioxide removals will decrease. For example, if this modelling exercise were repeated in 2030, it is likely that there would be a better understanding of the likelihood of low- or zero-emissions long haul road and sea transport, or improvements to agricultural practices to reduce enteric fermentation emissions. This report does not endorse any particular method of carbon dioxide removal, and we note that methods remain in various stages of development.

[6] International Renewable Energy Agency (IRENA). 2022. World Energy Transitions Outlook 2022.
[7] Global Energy and Climate Model (IEA). 2022. Source: https://www.iea.org/reports/global-energy-and-climate-model
[8] Decarbonisation Futures: Solutions, actions and benchmarks for a net zero emissions Australia (Climateworks Centre). 2020. Source: https://www.climateworkscentre.org/resource/decarbonisation-futures:-solutions,-actions-and-benchmarks-for-a-net-zero-emissions-australia/

2 Methodology Summary

2.1 Introduction

This section of the report outlines the methodology adopted for the scenario modelling. Initially, the sources utilised and assumptions made to develop the BAU scenario are discussed. This is followed by an explanation on the key differences between the BAU scenario and the enhanced scenarios (i.e., Enhanced Energy Efficiency, High Electrification and High Renewable Fuels). Furthermore, the existing policies and programs influencing uptake of energy efficiency, and the methodology adopted to conduct an economy wide cost benefit analysis of various opportunities and to create a multi-criteria decision matrix have also been discussed. The section concludes by highlighting the key assumptions associated with sensitivity analysis and the limitations associated with this study.

2.2 BAU Scenario Assumptions and Carbon Mitigation Targets

2.2.1 National BAU Scenario: Energy Consumption

The national BAU scenario was analysed to determine the energy consumption of key ANZSIC[9] sectors and their sub-sectors. The sub-sector level analysis was critical to defining the magnitude of opportunities for electrification and energy efficiency for each sub-sector. The primary data sources used in the analysis were:

- **Australian Bureau of Statistics (ABS):** Table F from Australian Energy Statistics 2022, which includes energy data by industry[10] and fuel type up to FY2021, was used to identify the energy consumption in the BAU scenario up to the year 2020. The values for 2021 and 2022 were forecast based on recorded data from previous years.
- **Australian Energy Market Operator (AEMO) forecasting tool**: AEMO's national energy and gas forecasting tool was used to project the electricity (central scenario) and natural gas (progressive change scenario) demand from 2022 to 2050.[11,12]
- **AEMO 2022 Integrated System Plan Report[13]:** According to AEMO's report, the step change scenario for coal retirement (i.e., 60% and 100% of the coal use for electricity generation will be retired by 2030 and 2042, respectively) is most likely. Hence, the step change scenario was adopted to predict the fossil fuel requirement for electricity generation up to the year 2050.

Electrification is expected to play a major role in determining the overall balance of future energy consumption as it provides solutions that are more energy efficient than traditional fossil fuel-based systems (such as heat pumps being significantly more energy efficient than gas boilers). The estimated rate of electrification for the BAU scenario has been informed by the recent government support programs[14,15], market activity and the associated interest expressed by the end users.

To predict the national energy consumption from the year 2022 to 2050 several key assumptions were made, including:

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[9] Australian and New Zealand Standard Industrial Classification (ANZSIC)
[10] Including sub-categories within each industry e.g., Manufacturing is further divided into wood, paper and printing, petroleum refining, etc.
[11] Note: There was no data available for Western Australia and the Northern Territory. It was assumed that these regions will experience a similar growth rate to other states and territories.
[12] A step change scenario was not considered for electricity and gas, as the step change 2022 scenario already includes a significant amount of electrification beyond what is widely considered business as usual.
[13] Source: https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en
[14] Victorian Heat Pump Subsidy Program: https://www.energy.gov.au/rebates/solar-and-heat-pump-hot-water-system-rebate
[15] NSW hot water system upgrade program: https://www.energy.nsw.gov.au/households/rebates-grants-and-schemes/household-energy-saving-upgrades/upgrade-your-hot-water

- The AEMO forecasting tool accounts for the rise in electricity demand due to electrification, resulting in reductions in fossil fuel energy consumption.[16]
- For simplification, 100% of the electricity demand is assumed to be supplied via renewable electricity by the year 2050, which will reduce the total energy demand as the inefficiencies of generating electricity from fossil fuels will be avoided (e.g., per 1 GJ of natural gas burned, less than 0.35 GJ of electricity is generated). In reality, a very small percentage of the electricity sector emissions will still be present for example system backup, however, is difficult to quantify and is excluded from the study.

2.2.2 National BAU Scenario: Carbon Emissions

Australia's overall carbon emissions data was extracted from RepuTex Energy's "The Economic Impact of the ALP's Powering Australia Plan" report[17] and the carbon emissions associated with ANZSIC sectors were calculated using the ABS data. The bottom-up assessment of carbon emissions using the ABS data was conducted to identify energy-related carbon emissions associated with each ANZSIC sector and to identify non-energy related carbon emissions.

The data from RepuTex Energy's report, which was used as a baseline for the BAU scenario, accounts for Australia's plan to achieve a 43% reduction on 2005 emission levels by the year 2030. Australia's emissions target for 2050 is to achieve net zero carbon emissions[18] which is assumed achievable for the BAU scenario, but may require high CO_2 removal (e.g., via carbon sequestration, biochar, and afforestation/reforestation).

The carbon emissions for each ANZSIC sector were estimated using the ABS Energy data, by considering the fuel types used in each sector and the associated emissions factors. The emissions factor for each fuel type and the projected (up to 2035) national electricity grid emission factors were obtained from the "Australian National Greenhouse Accounts Factors" report[19] and "Australia's Emissions Projection 2022" report[20], respectively.

A comparison of total carbon emissions[21] in the year 2022 (~500 Mt CO_2-e) and a bottom-up assessment of energy-related emissions[22] in the year 2022 (~426 Mt CO_2-e) highlighted that approximately ~74 Mtonnes of CO_2 emissions are not accounted for by energy consumption. This aligns with the National Accounts[23] for emissions associated with domestic livestock, fluorinated gases, fugitive emissions, etc., and is the value used for non-energy-related emissions in this study.

Other key assumptions made in the BAU carbon emissions analysis include:

- The national emissions factor for Australia's grid electricity will be 0 by 2050 as 100% of the electricity will be generated from renewable energy sources.
- Emission factors associated with different fuel types (e.g., natural gas, coal, diesel, etc.) will remain the same until 2050.

It should be noted that emissions reduction modelled to 2030 and 2050 are not based on any particular carbon budget or aligned with any sector specific pathway for achieving net zero emissions. While important considerations, these are beyond the scope of this modelling exercise. Should Australia adopt a higher level of emissions reduction ambition, relativities of the actions modelled would be indicative of what would be required to achieve a more rapid transition.

[16] Source: https://forecasting.aemo.com.au/
[17] Source: https://www.reputex.com/wp-content/uploads/2021/12/REPUTEX_The-economic-impact-of-the-ALPs-Powering-Australia-Plan_Summary-Report-1221-2.pdf
[18] Source: https://www.pm.gov.au/media/australia-legislates-emissions-reduction-targets
[19] Source: https://www.dcceew.gov.au/sites/default/files/documents/national-greenhouse-accounts-factors-2022.pdf
[20] Source: https://www.dcceew.gov.au/sites/default/files/documents/australias-emissions-projections-2022.pdf
[21] Extracted from the Reputex Energy report
[22] Calculated based on the ABS energy data
[23] Source: https://www.dcceew.gov.au/sites/default/files/documents/national-inventory-report-2020-volume-3.pdf

Similarly, this modelling exercise considers only Australian domestic emissions. While the role of exports in Australia's emission profile is a significant question for global achievement of net zero, these emissions are also beyond the scope of this report.

2.2.3 Measures for BAU Scenario Emissions Reduction

The following measures have been considered critical in achieving Australia's 2030 and 2050 emissions targets:

- **Renewable Electricity:** Emissions associated with electricity generation will be eliminated by 2050 according to the step scenario presented in AEMO 2022 Integrated System Plan Report.[24]
- **Energy Efficiency:** Emissions savings from energy management in the BAU scenario from 2022 to 2030 were estimated by projecting the tonnes of carbon saved each year in the past decade due to energy efficiency projects (based on VEECs, ESCs and ACCUs creation[25] data)[26]. It is assumed that limited additional emissions savings from energy efficiency projects will be achieved between 2030 to 2050, due to the following reasons:
    - The majority of the projects to date are electricity-based efficiency projects and with a decreasing grid emissions factor, the interest in such projects is likely to diminish unless the existing policies are revised.
    - The future of impact of existing energy efficiency schemes beyond 2030 is difficult to model effectively, as policy settings or the extent of contribution for these schemes beyond 2030 are unclear in most jurisdictions [27].
- **Electrification:** Major ANZSIC sectors (such as transportation, manufacturing, agriculture, mining, residential and commercial) were considered for electrification in the BAU scenario based on the type and amount of fuel consumed, and the potential for processes to be electrified with existing technologies (both developed and developing). Assessment of the timing of implementation was backed up by documented evidence where possible. For example, there is a push to eliminate combustion engines by 2035[28], which was used as a reference to assume that by 2050 majority of the road transport will be electrified in the BAU scenario. The emissions savings from the electrification opportunities in each sector were calculated based on the type and quantity of energy saved.
- **Renewable fuels:** The carbon emission savings from the utilisation of renewable fuels (including biofuels and hydrogen) in place of conventional fuels was focused on process heat in various sectors and selected instances in the transportation sector e.g., replacing jet fuels with Sustainable Aviation Fuels (SAF) for air transport. According to a 2021 study commissioned by ARENA[29], bioenergy has the potential to reduce the national emissions (in 2019) by 9% and 12% by the 2030s and 2050s, respectively. This is considered an ambitious target under current circumstances i.e., current government policies, readiness of hydrogen-based technologies for various applications, current and near future costs of hydrogen and other biofuels, and current industry behaviour. Hence, for the BAU scenario, it is assumed that the 2030 and 2050 targets will only be partially achieved.
- **CO_2 Removal:** Any energy-related carbon emissions that the preceding four measures are unable to abate, as well as non-energy process emissions that are 'hard-to-abate' will require CO_2 removal via measures such as carbon sequestration, biochar, direct air capture, enhanced mineralisation and afforestation/reforestation. Overall, the need for CO_2 removal in the BAU scenario is expected to be dominated by non-energy related sources (~74 Mt CO_2-e).

[24] Source: https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en
[25] It is assumed that all major energy efficiency related projects are captured by the certificates
[26] Victorian Energy Efficiency Certificates (VEECs), Energy Saving Certificates (ESCs) and Australian Carbon Credit Units (ACCUs)
[27] For example, the NSW Energy Savings Scheme has set an ambitious energy savings target of 13% per annum between 2030 to 2050 including savings from electrification, fuel switching and renewable energy activities which have been accounted for elsewhere within the modelling. It is not clear as to how that target will be achieved and what portion will be associated with energy efficiency.
[28] Source: https://www.theguardian.com/environment/2022/jul/22/australia-ev-electric-vehicle-uptake-canberra-petrol-car-ban-act
[29] Source: https://arena.gov.au/assets/2021/11/australia-bioenergy-roadmap-report.pdf

2.3 Enhanced Scenarios Methodology

The Enhanced Energy Efficiency, High Electrification and High Renewable Fuels scenarios were modelled based on the improvement opportunities identified in the ANZSIC sectors. A brief methodology of how each of these models were developed is described below:

- **Enhanced Energy Efficiency:** Potential for further efficiency improvements in the agriculture, mining, manufacturing, commercial and services, transport and residential sectors were identified based on current processes within those sectors, availability of energy efficient technologies, market behaviour and previous experience. In particular, appropriate energy management of compressed air systems, refrigeration systems, pumps, fans, HVAC (heating, ventilation and cooling), lighting systems, steam generation, process heat, generators and internal combustion engines were identified as key equipment where energy efficiency opportunities lie. This scenario assumes that significant emphasis will be placed on energy efficiency in the next three decades, and future government policies and schemes will enable various sectors to implement energy efficiency projects. The key energy efficiency opportunities considered in the analysis are presented in Appendix A.
- **High Electrification:** The potential for further electrification in each of the ANZSIC sector was analysed based on the type and amount of fuel consumed, and the potential for processes to be electrified with existing technologies (both developed and developing). Most importantly, the scenario assumes that significant emphasis will be placed on both energy efficiency and electrification projects in the next three decades, and future government policies and schemes will enable various sectors to implement energy efficiency and electrification projects much earlier. Hence, much greater level of electrification can be achieved within the next three decades compared to the BAU scenario. The key electrification opportunities considered in the analysis are presented in Appendix A.
- **High Renewable Fuels:** The high renewable fuels scenario assumes that significant emphasis will be placed on both energy efficiency and renewable fuels projects in the next three decades, and future government policies and schemes will enable various sectors to implement energy efficiency and renewable fuels projects much earlier and in much greater quantity. Hence, for the High Renewable Fuels scenario, 100% of the 2030s and 2050s bioenergy potential claimed by ARENA[30] is assumed to be met. Any additional requirement for renewable fuels was considered to be supplied by hydrogen, though it is noted that hydrogen solutions may compete with some of the currently more expensive biofuel alternatives. The utilisation of renewable fuels was targeted substitution of fossil fuels in the agriculture, mining, manufacturing and transportation sectors. It is noted that renewable fuels may be part of the transition of grid electricity to renewable sources.

2.4 Existing Policies and Programs Influencing Uptake

The primary policy mechanisms and incentives promoting energy efficiency in Australia are delivered via certificate-based energy efficiency and carbon reduction schemes.

Certificate-based schemes promote reductions in energy consumption, or improvements in energy efficiency, through financial incentivisation proportional to the extent of energy reduction. A certificate is awarded per MWh of energy reduced or per tonne of carbon dioxide equivalent (CO_2-e) emissions that are avoided (due to the reduction in electricity or natural gas consumption). The certificates have a financial value on their own markets and can be sold to offset the cost of an energy efficiency upgrade, either upfront using ‘deemed’ methods, or after an ‘operational’ period (typically 12 – 18 months) using project-based methods.

The two main certificate-based energy efficiency schemes in Australia are state government initiatives: the Victorian Energy Upgrades program in Victoria, and the Energy Savings Scheme in New South Wales (NSW). The federal government has also implemented a certificate-based carbon reduction program, the Emissions Reduction Fund. The impact of each of these programs on the acceleration of energy efficiency initiatives in Australia has been considered within BAU and Enhanced Energy

[30] Source: https://arena.gov.au/assets/2021/11/australia-bioenergy-roadmap-report.pdf

Efficiency scenarios. There are other energy saving schemes available in South Australia (SA) and Australian Capital Territory (ACT), which have not been considered in the BAU scenario, due to having comparatively smaller energy savings than VEU and ESS and the lack of clarity around the future emissions reduction from these schemes.

State-Based Energy Efficiency Schemes

Victorian Energy Upgrades (VEU): The VEU program provides 'discounts' for energy efficiency upgrades and services via 'Victorian Energy Efficiency Certificates' (VEECs), electronic certificates each representing a reduction of one tonne of CO_2-e emissions. The program started in 2009 and has increased from a target of 2.7 Mt CO_2-e per annum to 6.9 Mt CO_2-e per annum for Victoria in 2023[31]. Targets are currently set through to 2025.

The VEU achieves emissions reductions through a combination of energy efficiency upgrades, decommissioning of inefficient products, or the installation of renewable energy generation systems to offset fossil fuel-based energy consumption within sites (i.e., 'behind the meter').

NSW Energy Savings Scheme (ESS): The ESS program operates in a similar manner to the VEU program, however, each 'Energy Savings Certificate' (ESC) represents a reduction of 1 MWh in energy consumed. The program also started in 2009 and as of December 2020 has reduced GHG emissions by 17 Mt CO_2-e[32]. Energy savings targets are set for the remainder of the program, with an increase of 0.5% p.a. to a 2030 target of 13%, which will be maintained until 2050.

SA Retailer Energy Productivity Scheme (REPS): The REPS is an energy productivity scheme introduced by the SA Government to encourage local businesses and households to reduce energy consumption by providing incentives such as discounts, free products, cash rebates and vouchers.[33]

ACT Energy Efficiency Improvement Scheme (EEIS): The EEIS obligates energy retailers in ACT to help small-to-medium businesses and households to reduce their energy consumption by delivering energy saving activities such as appliance upgrade, insulation and other activities that reduce energy consumption. The program started in 2013 and has since reduced GHG emissions by 0.7 Mt CO_2-e.[34]

Emission Reduction Fund (ERF)

The primary financial incentive for carbon reduction projects in Australia is through Australian Carbon Credit Unit (ACCU) generation as part of the Emissions Reduction Fund, managed by the Clean Energy Regulator (CER). Each ACCU issued represents one tonne of CO_2-e stored or avoided by a project and may be sold or surrendered. ACCU generation began in 2011 and has increased to 16.5 million tCO_2-e worth of certificates per annum in 2021-2022[35]. ACCUs can be created for energy efficiency projects which result in a reduction in Greenhouse Gas (GHG) emissions, either through the reduced use of fossil-fuel sourced electricity (e.g., from the grid) or reduced direct consumption of fossil fuels (e.g., natural gas boilers, or diesel fuel motors). To date, the ERF has principally incentivised CO_2 removals through carbon farming methods.

The ERF is considered a cornerstone of the Australian Government's plan to meet the emissions reduction targets for 2030 and 2050 and so is expected to continue operating throughout this period.

Other factors

Energy efficiency has played a major role in reducing Australia's carbon emissions to date. Regulations such as Greenhouse and Energy Minimum Standards (GEMS) resulted in meeting 9% to 15%[36] of Australia's 2020 emissions target[37]; the Commercial Building Disclosure (CBD) program resulted in a cumulative emissions savings of 0.6 Mt CO_2-e from 2012 to FY18[38] and National Australian Built

[31] Source: Victorian Energy Upgrade program, Essential Services Commission
[32] Source: Energy Savings Scheme, NSW Climate and Energy Action
[33] Source: https://www.escosa.sa.gov.au/industry/reps/overview
[34] Source: https://www.climatechoices.act.gov.au/policy-programs/energy-efficiency-improvement-scheme#About-the-scheme
[35] Source: Annual Report 2021-2022, Clean Energy Regulator
[36] Source: https://www.energyrating.gov.au/industry-information/publications/report-independent-review-gems-act-final-report
[37] 5% below 2000 levels i.e., a reduction of 27 Mt CO_2-e. Source: https://www.atse.org.au/wp-content/uploads/2020/05/ATSE-Emissions-Targets-Explainer-1.pdf
[38] Source: https://www.cbd.gov.au/sites/default/files/2020-09/cbd_review_cie_report_draft.pdf

Environment Ratings System (NABERS) reported a cumulative savings of 9.9[39] Mt CO_2-e from FY01 to FY21[40]. Increasing coverage and stringency of regulations such as GEMS and CBD programs will enhance energy efficiency's role in reducing carbon emissions in the future. Additional emissions reduction due to these programs have not been included in the BAU scenario, as further strengthening of minimum standards has not yet been made.

New regulations such as the safeguard mechanism will also play a role in emissions reduction in the future. The safeguard mechanism is targeted at Australia's largest emitters[41] and requires a 4.9% reduction per annum in their emissions intensity until 2030. This could be achieved by following measures such as reducing on-site emissions via energy efficiency, electrification, utilisation of renewable fuels, purchasing Safeguard Mechanism Credits (SMCs), buying and surrendering of ACCUs and 'banking and borrowing' of carbon offsets.[42]

International factors such as Task Force on Climate-related Financial Disclosures (TCFD) may also influence emissions reduction in Australia. TCFD requires organisations to be transparent about their emissions and commit to emissions reduction. Large organisations seeking international investments may sign up to such programs, and introduction of mandatory climate-related financial disclosure in Australia has been foreshadowed.[43] These requirements may encourage additional emissions reduction activity including through energy efficiency and electrification, but no specific abatement has been allocated to this initiative.

2.5 Costs-Benefit Analysis

To enable the comparison and prioritisation of the energy efficiency and electrification opportunities identified, a cost-benefit analysis was completed based on four key factors: energy use, emissions reduction, energy type, and industry sector, for each specific efficiency or electrification technology (e.g., air compressors, domestic heat pumps, etc.). Renewable fuels and CO_2 removal emissions reduction opportunity cost of abatement was sourced from reference sources[44,45,46,47] or industry knowledge.

To facilitate the assessment of the financial cost and abatement (reduction) of emissions of various measures, a Marginal Abatement Cost Curve (MACC) is utilised. This displays the following:

- X-axis: Extent of emissions reduction for a measure (width of each bar)
- Y-axis: Cost per tonne of CO2 abatement (emissions reduction)
  - Negative costs indicate a financial saving over 10 years.
  - Positive costs indicate an increase in financial expense over 10 years.

Importantly, it should be noted the whole-of-economy cost of each abatement has not been calculated (see section 2.8 – Study Limitations). The MACC illustrates the likely relative costs of different abatement initiatives.

A MACC was created[48] using 2050 values as inputs of aggregate emissions reductions per method and sector (e.g., energy efficiency – residential), aggregate cost of energy in present value terms[49], calculated using energy per method, sector and type. This represents the operational cost saving or increase. Capex was calculated by assuming a weighted average payback period for each opportunity and multiplying by the energy cost. This is aggregated as per the emissions and energy cost values. For

[39] Including CBD
[40] Source: https://nabers.info/annual-report/2021-2022/major-achievements/
[41] Emitting more than 1 Mt CO_2-e per year
[42] Source: https://www.cleanenergyregulator.gov.au/NGER/The-safeguard-mechanism
[43] Source: https://treasury.gov.au/sites/default/files/2022-12/c2022-314397_0.pdf
[44] Source: https://www.iea.org/data-and-statistics/charts/global-average-levelised-cost-of-hydrogen-production-by-energy-source-and-technology-2019-and-2050
[45] Source: https://www.sciencedirect.com/science/article/abs/pii/S0306261921014215?dgcid=author
[46] Source: https://www.csiro.au/-/media/Missions/TNZ/CCA-report/CCA-Report-Australias-Potential-Sequestration-Final-28-November-2022.pdf
[47] Source: https://www.iea.org/data-and-statistics/charts/levelised-cost-of-co2-capture-by-sector-and-initial-co2-concentration-2019
[48] Calculation completed using Northmore Gordon's internal MACC tool.
[49] Use average prices of energy from Northmore Gordon's clients in residential, commercial, and industrial/manufacturing sectors.

renewable fuels and CO2 removal, costs were calculated using the costs and energy type that would be replaced/offset.

Assumptions made in creating the MACC are costs/prices are in present value terms, and a discount rate of 7%. Outputs are shown in Section 3.4.

2.6 Multi-criteria Decision Matrix

A qualitative (and partly quantitative) multi-criteria assessment was completed to enable comparison of the viability of the emissions reduction opportunities identified. The criteria took into account:

- TRL - Technology Readiness Level[50]
- CRI - Commercial Readiness Index
- Availability of technology (in Australia)
- Complexity of the technology (with regards to installation/application/repeatability)
- Payback (years) with known incentives
- Operational cost improvement/degradation
- Scale of promotion program benefit (level of impact on Australia's emissions)

A weighting was assigned to each based on the ability of government assistance to influence each parameter. Each opportunity category for electrification, energy efficiency, renewable fuels and CO_2 removal were rated against the criteria. A viability rating score was calculated by multiplying each criterion score by the weighting and summing the result. Where possible the costs of emissions abatement defined including CO_2 removal costs (references listed in Section 2.5) were used in the MACC and this assessment. The potential $MtCO_2$-e of emissions abatement was then represented shown as the size of the data point on the chart. and displayed on a chart showing scale of abatement, cost of abatement and viability score.

It should be noted that the multi-criteria decision matrix assesses the opportunities based on current understanding of the costs, viability ratings and potential abatement and it is recognised that some of the variables may change in the future. An alternative methodology would be to utilise an equilibrium model, which would attempt to take into account future pricing and how technologies may improve and become more competitive over time, particularly with increased market drivers and potential support or funding. This alternative assessment would require additional investigation and is beyond the current scope of work, however it would be a useful extension to this work and would provide additional insight on likely impacts of evolving technologies.

2.7 Sensitivity Analysis

Sensitivity to the mitigation achieved were tested against some broad ranges of deviation in the performance of energy efficiency and other related policies. The following considerations were made in the analysis:

- Impact of delay in the switch from fossil fuel-based electricity to renewable electricity.
- Impact of delay in electrification of transportation.
- The role of enhanced energy efficiency in alleviating the situation.

There is potential for other factors to not go as planned in the BAU scenario (such as renewable fuels not developing to scale) that can result in increased need of CO_2 removal to meet Australia's 2030 and 2050 carbon emissions target, however, just the possibilities listed above have been considered in the sensitivity analysis as they are deemed sufficient to provide an insight to energy efficiency's role in alleviating the situation.

[50] TRL & CRI rated according to ARENA index – refer to Figure 14 in the Glossary of Terms

2.8 Study Limitations

This study is a high-level assessment of possible future energy and emissions scenarios to inform the discourse around energy efficiency and energy management's role in meeting Australia's 2030 and 2050 carbon reduction targets. Following are the key limitations associated with this study:

- This modelling exercise considers only Australian domestic emissions. While the role of exports in Australia's emission profile is a significant question for global achievement of net zero, these emissions are beyond the scope of this report.
- The results presented are based on a range of available information and provide a strategic assessment of achievable outcomes. However, the actual outcomes achieved in practice may differ due to current data limitations, context specific implementation constraints, behavioural change, market forces and the inherent uncertainty related to all forecasts.
- The scenarios were selected after reviewing existing policies, literature surveys, currently available technology and technology that will be available and commercially viable in the near future, market behaviour and Northmore Gordon's industry knowledge. If this exercise is conducted in the future (e.g., in 2030), the modelling results may look different depending on new policies, rate of maturation of technology and change in market behaviour.
- Emissions reduction modelled to 2030 and 2050 are not based on any particular carbon budget or aligned with any sector specific pathway for achieving net zero emissions. While important considerations, these are beyond the scope of this modelling exercise. Should Australia adopt a higher level of emissions reduction ambition, relativities of the actions modelled would be indicative of what would be required to achieve a more rapid transition.
- Future coal retirement is based on the step change scenario from AEMO's Integrated System Plan report[51], as this has been considered as the most likely national scenario. Announcements by various states (such as Queensland and Victoria) since then indicate that the coal retirement in those states may be faster than the federal government's plan. The impact of individual state coal retirement plans has not been considered.
- For simplification, 100% of the electricity demand is assumed to be supplied via renewable electricity by the year 2050. In reality, a very small percentage of the electricity sector emissions will still be present for example system backup, however, is difficult to quantify and is excluded from the study.
- The potential impact of future gas shortages has not been considered and it has been assumed that sufficient supply will be available to 2050. Similarly, the impact of potential closure of individual plants and refineries has not been considered.
- Energy efficiency and electrification opportunities in sectors such as electricity, gas and water supply and construction have not been considered. These sectors have been classified as "other sectors' emissions (energy related)" in this report[52]. It is expected that the majority of the emissions from these sectors will be negated once 100% of grid electricity is generated via renewable sources and as gas usage declines with the expansion of electrification activities.
- Current average energy prices have been used for assessment of emission reduction opportunities. Future pricing changes have not been modelled.
- Capital costs of opportunities are based on existing reference prices and high-level budget estimates from recent project work. No specific project quotes were obtained, nor any detailed design undertaken to develop more accurate price estimates. The exceptions to this are hydrogen and carbon removals which have been separately referenced.
- Limited optimisation of competing interactions between different emissions reduction methods has been modelled. For example, choosing a certain technology pathway for reducing emissions may have implications for the overall cost of achieving emissions reduction targets, which may be different to another pathway. This report does not determine the overall cost of each pathway to reduce emissions, but instead analyses availability, readiness and estimated costs of each technology.

[51] Source: https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

[52] Majority of emissions for "other sectors' emissions (energy related)" in this report are associated with grid electricity transmission and distribution losses.

3 Key Outputs

3.1 Predicted Carbon Emissions Reduction in 2030

Australia's emissions reduction target for 2030 is to reduce carbon emissions by 43% from 2005 levels, which is equivalent to a reduction of ~157 Mt CO_2-e from 2022 emissions levels. All scenarios are assumed to achieve this target, albeit the contribution from each carbon reduction measure varies depending on the scenario. The predicted emissions reduction breakdown in each of the four scenarios (described in Section 1.4) is shown in Figure 6.

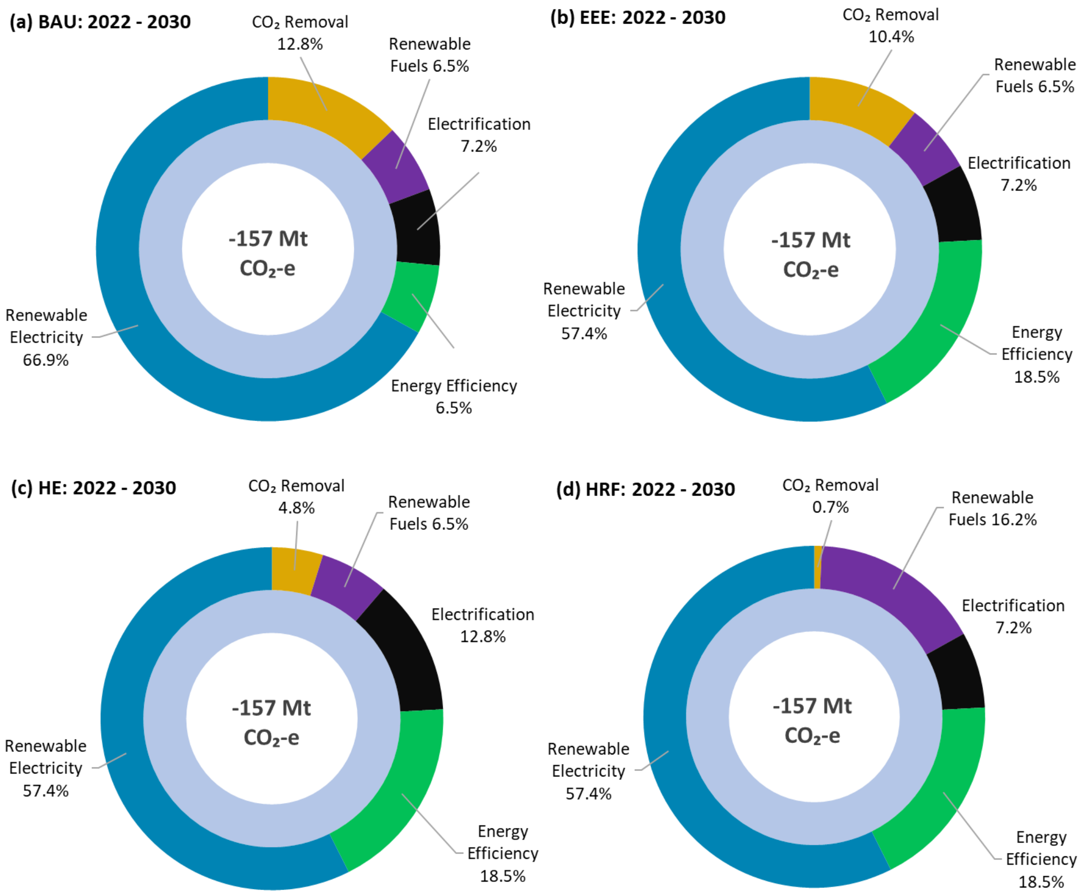


Figure 6. Predicted carbon emissions reduction at 2030: (a) Business as Usual (BAU), (b) Enhanced Energy Efficiency (EEE), (c) High Electrification (HE), and (d) High Renewable Fuels (HRF)

BAU Scenario

In the BAU scenario shown in Figure 6 (a), about 70% of the emissions target is expected to be met from the switch from fossil fuel-based electricity sources to renewable electricity sources. The majority of this emissions reduction is based on the assumption that 60% of coal-based electricity generation will be retired by 2030 [53]. Electrification, energy efficiency and renewable fuels are also expected to make small contributions to achieving Australia's 2030 emissions target, however, the sum of these contributions does not account for the remaining emissions reduction required. As such, in the BAU scenario meeting the 2030 target would require ~13% of the total reduction in emissions to be accounted for with CO_2 removal.

[53] Source: https://aemo.com.au/-/media/files/major-publications/isp/2022/2022-documents/2022-integrated-system-plan-isp.pdf?la=en

Enhanced Scenarios

In the Enhanced Energy Efficiency scenario shown in Figure 6 (b), the contribution from energy efficiency is much greater at 18.5% compared to 6.5% in the BAU scenario. The greater energy efficiency results in reduced electricity demand, which in turn reduces the contribution from renewable electricity to 57.4% and reduces CO_2 removal to 10.4%. The contributions from renewable fuels and electrification remain the same as level of renewable fuels utilisation and electrification is assumed to be the same as the BAU scenario.

In the High Electrification (Figure 6 (c)) and High Renewable Fuels (Figure 6 (d)) scenarios, the need for CO_2 removal in 2030 is further decreased to 4.8% and 0.7%, respectively. In the High Electrification scenario, both enhanced energy efficiency and a greater level of electrification are achieved, resulting in a much greater carbon reduction from these two measures compared to the BAU scenario. The High Renewable Fuels scenario maintains the same level of electrification as the BAU scenario, however, the contribution from renewable fuels and energy efficiency is much greater and all but negates the requirement for CO_2 removal in 2030.

3.2 Predicted Carbon Emissions Reduction in 2050

Australia's emissions reduction target for 2050 is to achieve carbon neutrality, which is equivalent to a reduction of 500 Mt CO_2-e from 2022 emissions levels. All scenarios are assumed to achieve this target, albeit the contribution from each carbon reduction measure varies depending on the scenario. The predicted emissions reduction breakdown in each of the four scenarios (described in Section 1.4) is shown in Figure 7.

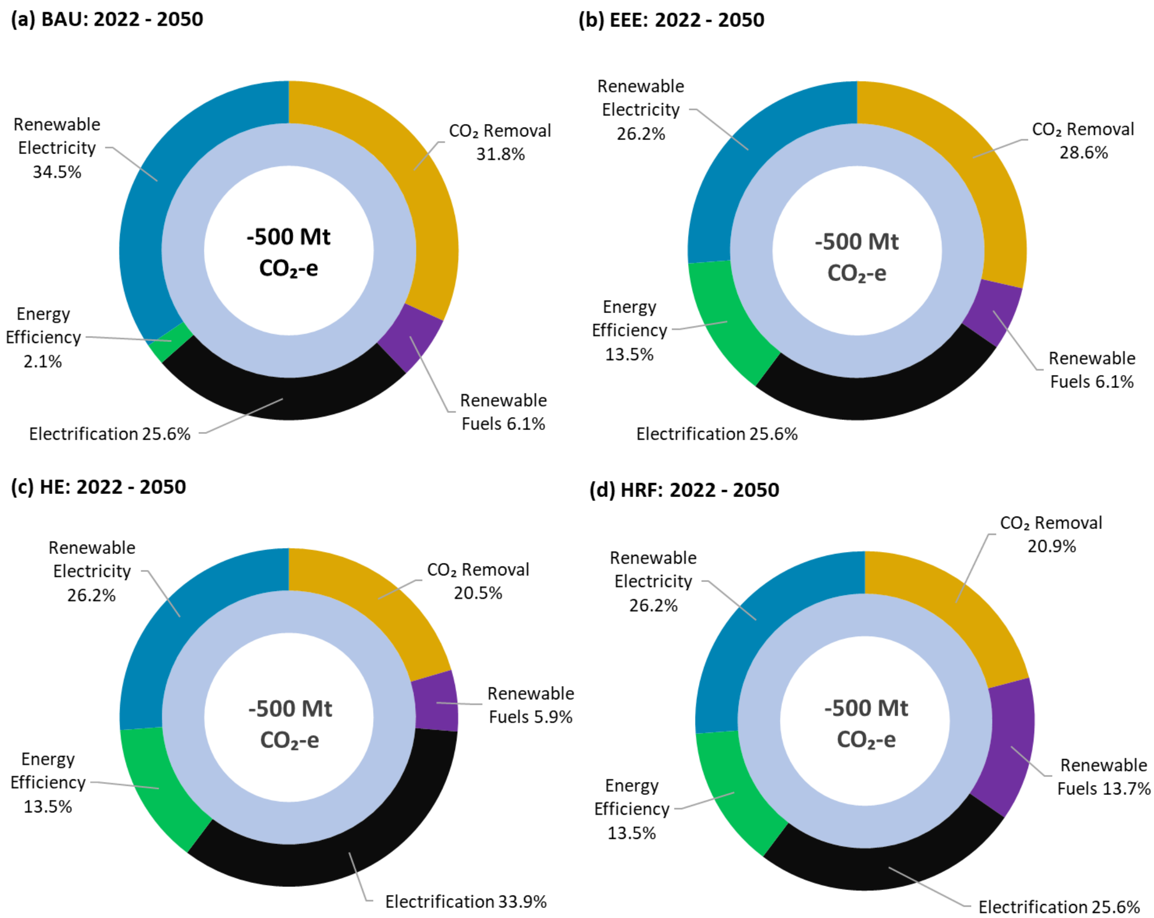


Figure 7. Predicted carbon emissions reduction at 2050: (a) Business as Usual (BAU), (b) Enhanced Energy Efficiency (EEE), (c) High Electrification (HE), and (d) High Renewable Fuels (HRF)

BAU Scenario

In the BAU scenario shown in Figure 7 (a), about 34.5% of the emissions target is expected to be met from the switch from fossil fuel-based electricity sources to renewable electricity sources. This emissions reduction assumes that 100% of fossil fuel-based electricity generation will be retired by 2050.

Electrification is expected to play a major role (25.6% of the total) in achieving the emissions reduction target. This is due to the increased interest in the electrification of fossil fuel-based energy systems in the residential, commercial, manufacturing and transport sectors, and the development of advanced electrification technologies that will enable the electrification of key energy intensive systems by 2050.

Considering current policies and industry interest in energy efficiency and renewable fuels, the carbon reduction from these two sources is expected to be minimal (2.1% and 6.1%, respectively).

In the BAU scenario, Australia is not expected to meet the emissions reduction target from the aforementioned methods and will require CO_2 removal to account for 31.8% of the 2022 emissions, which is considered extremely challenging.

Enhanced Scenarios

In the Enhanced Energy Efficiency scenario shown in Figure 7 (b), the contribution from energy efficiency is much greater, 13.5% compared to 2.1% in the BAU scenario, and the need for CO_2 removal in 2050 is reduced to 28.6% of the required emissions reduction. In the High Electrification (Figure 7 (c)) and High Renewable Fuels (Figure 7 (d)) scenarios, the need for CO_2 removal is further decreased to ~21%.

Note that the majority (~70%) of the CO_2 removal requirement in these scenarios is associated with non-energy related carbon emissions which cannot be avoided with energy related measures. Overall, the results indicate that Enhanced Energy Efficiency with either High Electrification or High Renewable Fuels will bring Australia much closer to achieving the 2050 target without being heavily dependent upon CO_2 removal.

To better understand the role of efficiency in achieving Australia's 2050 carbon emissions target, efficiency associated with renewable electricity generation and electrification is separated from the total and presented in Figure 8 for the High Electrification scenario. About ~62% of the total carbon emissions reduction in 2050 associated with renewable electricity is due to efficiencies gained from switching to renewable electricity generation from fossil fuel-based electricity generation. Similarly, about 58% of the emissions reduction from electrification in 2050 is associated with efficiency gains from switching from fossil fuel based systems to electricity based systems.

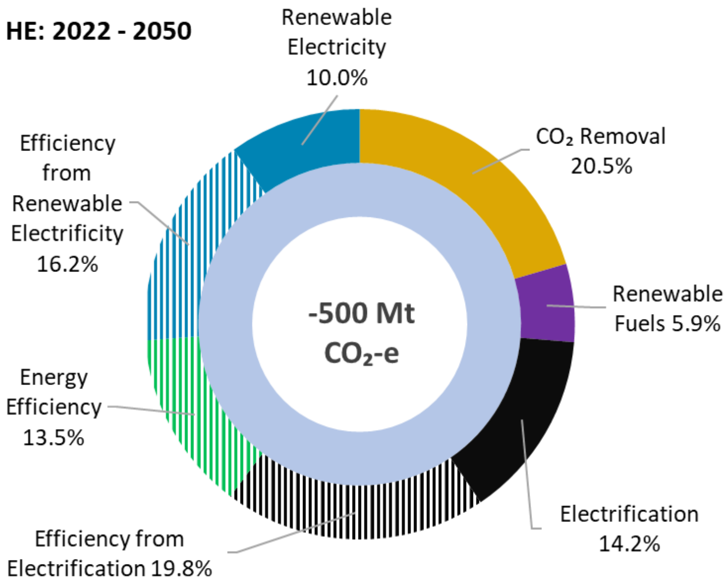


Figure 8. Role of efficiency in Australia's carbon emissions reduction in the high electrification scenario

Overall, 49.5%[54] of the carbon emissions reduction in 2050 in the High Electrification scenario is associated with efficiency gains, which highlights the critical role energy efficiency could play in the next three decades. This indicates the relative importance of promotion of efficiency in all its forms to encourage the uptake of energy efficiency, electrification and renewables projects.

Reducing Australia's Reliance on CO_2 Removal

CO_2 removal is necessary to enable Australia to achieve its net zero target by 2050 and covers a range of "hard-to-abate" emission sources including non-energy process, agricultural and waste emissions. In addition, changes to selected high emitting industry processes and improvements in the circular economy will also help reduce CO_2 removal.

Some examples of these emission reduction mechanisms include:

- Changes in industry processes – this covers a broad range of activities as indicated below:
  - The push towards "Green Steel" that promotes an increase in direct reduced iron and increased use of electric arc furnaces
  - Utilisation of cold pressing of oil seeds instead of thermal processes
  - Improved recycling of materials including steel, aluminium, plastics, etc.
- Reductions in "non-energy" process emissions including:
  - Reductions in clinker in cement processes
  - Use of inert anodes in the aluminium smelting process.
- Reduction in enteric emissions from ruminants, particularly cattle - could yield up to 40 Mt CO_2-e of abatement.
- Expansion of the use of ammonia as an energy source, or for energy storage.

Though some of the technologies have been technically proven, the cost of implementation is still prohibitive, while other technologies are still in the development or trial phases and will need significant support to enable deployment at scale.

These technologies are expected to compete with other high-cost energy management and electrification solutions, as well as existing or future CO_2 removal technology. Based on the Enhanced Energy Efficiency Scenario, it may be possible for the range of technology options to challenge for up to 50% of the residual CO_2 removals.

3.3 ANZSIC Sector Level Carbon Emissions Reduction in 2050

An ANZSIC sector level breakdrown for the carbon emissions reduction in 2050 is shown in Figure 9 and Figure 10. Emissions from small energy consuming sectors such as contruction have been included in the 'Others' category. The emissions reduction from non-energy related sources is also included.

BAU Scenario

In the BAU scenario presented in Figure 9, the majority of the emissions reductions in the mining, residential and manufacturing sectors are expected to be associated with the electrification of fossil fuel based energy systems and utilisation of renewable electricity, whereas the emissions reduction in the transport sector is expected to be dominated by electrification, due to the transition from internal combustion engine vehicles to electric vehicles. Currently, the majority of the energy efficiency projects are being conducted in the manufacturing and commercial and services sectors, hence, the carbon reduction from energy efficiency will mostly be from these two sectors. The adoption of energy efficiency projects is expected to remain limited unless energy management is promoted and schemes introduced to increase the uptake of energy efficient technologies and energy management systems or equivalent. A high level of CO_2 removal will be required in the mining, manufacturing and transport sectors, as well as for non-energy related emissions in order to meet Australia's emission reduction commitments.

[54] 16.2% efficiency gains associated with renewable electricity, 19.8% efficiency gains associated with electrification and 13.5% efficiency gains associated with energy efficiency projects.

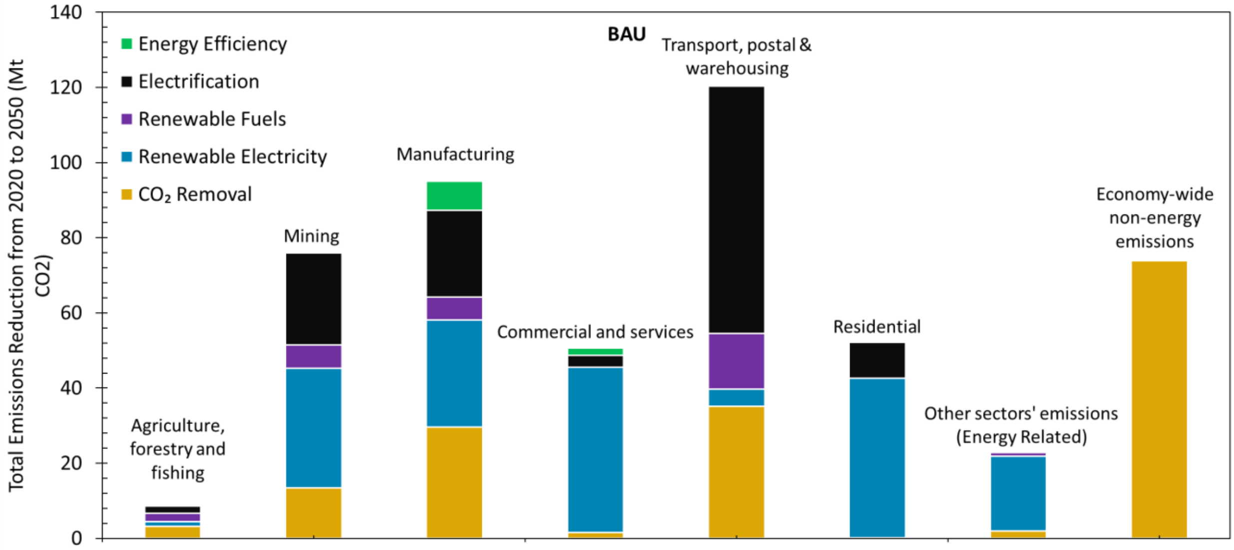


Figure 9. ANZSIC sector level emissions reduction in 2050 for BAU scenario

Enhanced Scenarios

The sector level breakdowns for the Enhanced Energy Efficiency, High Electrification and High Renewable Fuels scenarios are presented in Figure 10 (a), (b) and (c), respectively.

Major opportunities for energy efficiency were identified in the mining, manufacturing, commercial and services, transport, and residential sectors. Hence, in the Enhanced Energy Efficiency scenario shown in Figure 10 (a), significant carbon emissions reductions in those sectors are expected to be associated with energy efficiency improvements, which reduces the requirement for CO_2 removal.

Further electrification potential was identified in the agriculture, mining, manufacturing, residential and transport sectors, which is evident in the High Electrification scenario presented in Figure 10 (b). Electrification in conjunction with enhanced energy efficiency, BAU renewable fuels and renewable electricity will result in the elimination of 92% of the energy-related carbon emissions within the agriculture, mining, commercial and services, and residential sectors in this scenario.

The opportunity for increased utilisation of renewable fuels in the agriculture, mining, manufacturing, and transport sectors was identified in the High Renewable Fuels scenario, which is shown in Figure 10 (c). Renewable fuels in conjunction with enhanced energy efficiency, BAU electrification and renewable electricity will result in the elimination of 90% of the energy-related carbon emissions within the agriculture, mining, manufacturing, and transport sectors in this scenario.

In the High Electrification and High Renewable Fuels scenarios, the majority of the energy-related carbon emissions in the agriculture, mining, residential and ‘other’ sectors are expected to be eliminated via energy-related measures by 2050. However, in the transport and manufacturing sectors, some hard-to-abate carbon emissions will still require CO_2 removal (albeit in smaller quantities than the BAU scenario). These include water-based transport, remote area transport, and certain processes in the manufacturing industry that cannot be replaced due to a lack of available technology or financial viability.

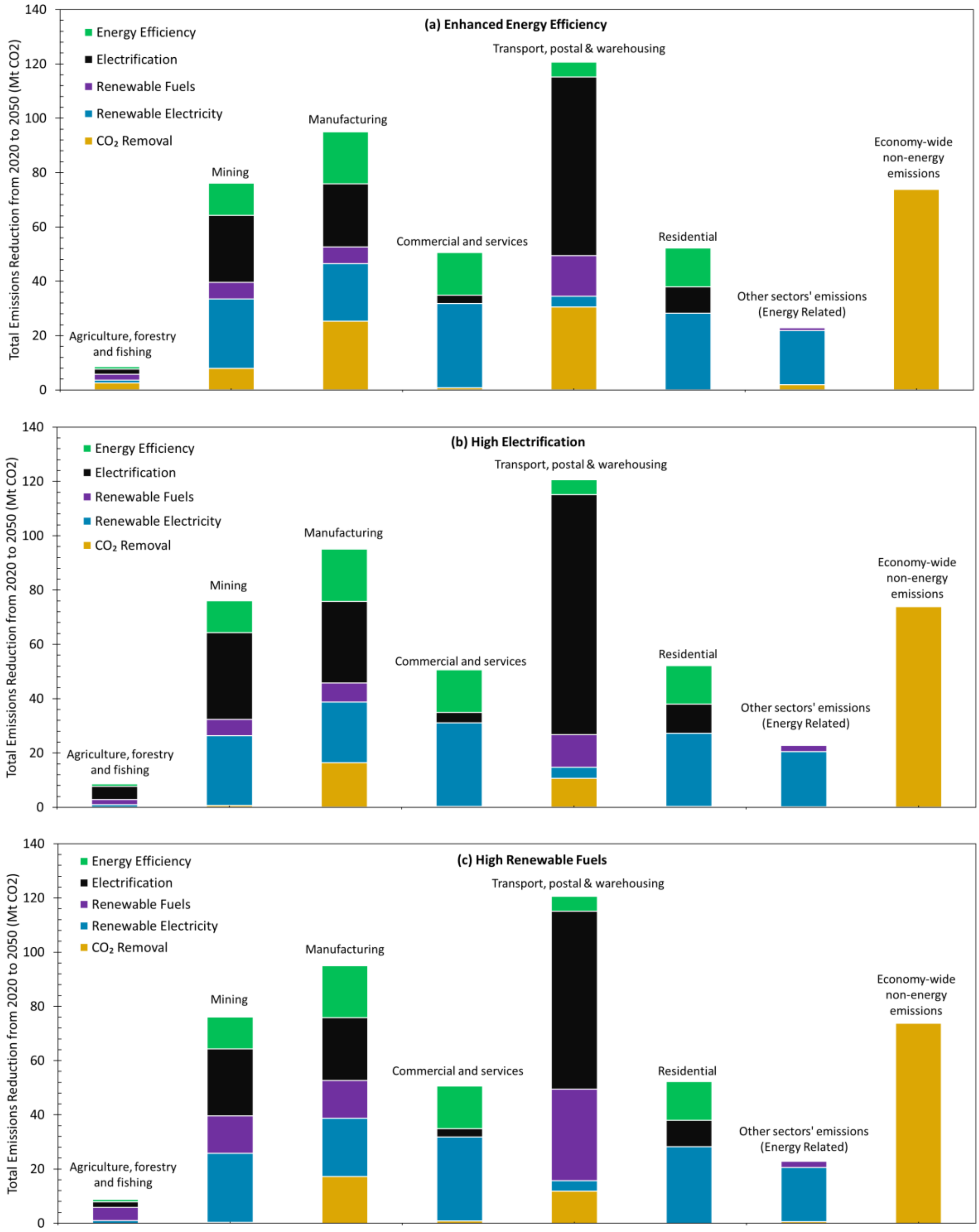


Figure 10. ANZSIC sector level emissions reduction in 2050 for enhanced scenarios (a) Enhanced Energy Efficiency, (b) High Electrification, and (c) High Renewable Fuels

3.4 Cost/Benefit & Prioritisation

Marginal Abatement Cost Curve (MACC)

Developed using the methodology described in Section 2.5, the MACC is shown in Figure 11. The horizontal axis shows the abatement achieved for a 10-year opportunity life and as such the total values should not be compared to the results shown in Section 3.3.

Opportunities are shown from the lowest to the highest cost of abatement from left to right, with the width of the bar equating to the extent of emissions reduction. Negative costs of abatement are those that would reduce costs, or have upfront investment paid back over the 10-year project period considered. Positive costs are additional expenses required by the party paying for the abatement.

Based on the current technology costs, the energy efficiency opportunities all result in negative costs of abatement, as does electrification of transportation. The remaining electrification opportunities result in positive costs of abatement. As new technology is introduced and becomes more mainstream, so the implementation costs is expected to decrease and some of these technologies may start to compete for a larger share of the market.

Electrification opportunities result in the largest emissions reductions, due to the efficiency gained by a change in technology in combination with the transition to emissions-free electricity (at 2050).

The outcomes described above and shown in Figure 11 are driven by:

- The extent of emissions abatement for a particular measure (for example energy efficiency improvements in a particular sector; and
- The differential between capital cost and operational cost for a particular measure

The measures with an appealing capital/operational cost result in more desirable $/tCO2-e values. Extent of emissions abatement is shown as the width of the bar in the chart below.

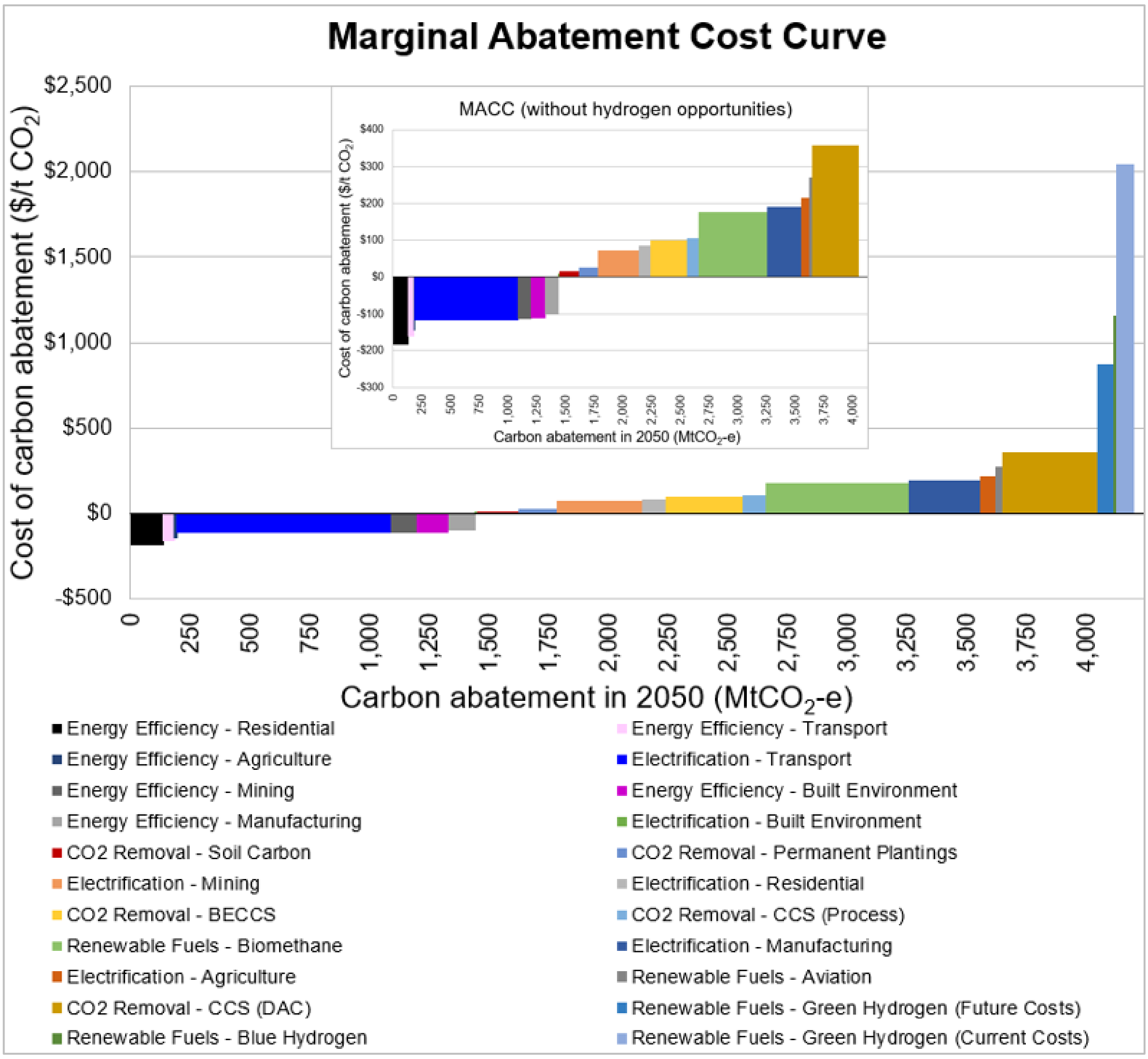


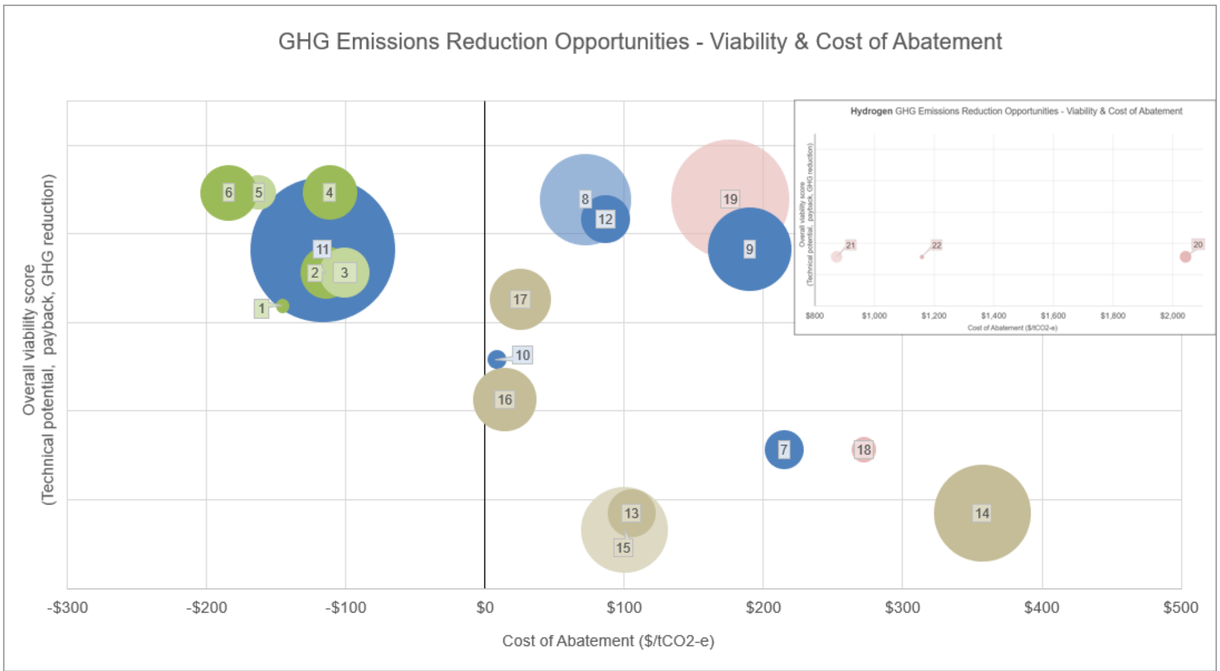
Figure 11. Marginal Abatement Cost Curve

Multi-criteria Assessment

The outcome of the multi-criteria assessment described in Section 2.6 is shown in Figure 12. A detailed version of this chart is included in Appendix A.

This chart includes:

- The viability score on the vertical axis (increasing from zero at the intersection with the horizontal axis).
- The cost of emissions abatement on the horizontal axis.
- The potential $MtCO_2$-e of emissions abatement is represented as the size of the data point.
- The green data points are the initiatives for energy efficiency emissions reduction in each major ANZSIC sector (residential, built environment, manufacturing, mining, transport & agriculture).
- The blue data points are the initiatives for electrification emissions reduction in each major ANZSIC sector (residential, built environment, manufacturing, mining, transport & agriculture).
- The pink data points are initiatives for renewable fuel emissions reduction (biomethane, Sustainable Aviation Fuel, hydrogen)
- The brown data points are initiatives for CO_2 removal (CCS, BECCS, soil carbon and permanent plantings).



1	Energy Efficiency - Agriculture	9	Electrification - Manufacturing	16	CO2 Removal - Soil Carbon
2	Energy Efficiency - Mining	10	Electrification - Built Environment	17	CO2 Removal - Permanent Plantings
3	Energy Efficiency - Manufacturing	11	Electrification - Transport	18	Renewable Fuels - Aviation
4	Energy Efficiency - Built Environment	12	Electrification - Residential	19	Renewable Fuels - Biomethane
5	Energy Efficiency - Transport	13	CO2 Removal - CCS (Process)	20	Renewable Fuels - Green Hydrogen Current Costs
6	Energy Efficiency - Residential	14	CO2 Removal - CCS (DAC)	21	Renewable Fuels - Green Hydrogen Future Costs
7	Electrification - Agriculture	15	CO2 Removal - BECCS	22	Renewable Fuels - Blue Hydrogen
8	Electrification - Mining				

Figure 12. Viability score and cost of abatement for GHG emissions reduction initiatives

The preferable position for opportunities in the above chart is the lowest cost of abatement and highest viability. The energy efficiency initiatives plus transportation electrification occupy this position. While transportation electrification represents a very large opportunity for emissions reduction, it will take significant cost and time to realise. The energy efficiency opportunities benefit from similar negative abatement costs and are able to be executed in a shorter timeframe.

The remaining opportunities (electrification, renewable fuels and CO_2 removal) result in positive costs of abatement (cost increases). Biomethane displacement of fossil fuels represents a sizable opportunity for emission reduction and is beginning to be cost competitive with natural gas. Furthermore, biomethane technology is mature and hence is considered to have high viability. The remaining renewable fuel opportunities have lower viability due to low commercial readiness. Note that green hydrogen opportunities are represented twice - with current and future pricing (this was done as hydrogen is touted as a "gamechanger" in some quarters and as increased focus is placed on it, significant cost reductions are expected/predicted. CO_2 removals are discussed in the subsection below.

Using the cost of abatement as a guide to prioritisation, it has been demonstrated that the energy efficiency driven reductions represent the least cost option, and their high viability will enable them to be executed sooner to make progress towards Australia's 2030 and 2050 targets.

CO_2 Removals – Low Viability

The CO_2 Removal opportunities shown in the MACC and viability graphics exhibit appealingly low costs of abatement and reduction potential. It should be noted however that the integrity of some Human Induced Regeneration CO_2 Removal methods have recently been called into question[55,56]. These and other questions around the longevity (permanent plantings are at risk of bushfire and other natural disasters) and extent of abatement achieved[57] have resulted in the low viability scores shown in Figure 12.

3.5 Sensitivity Analysis

Sensitivity analysis was conducted on the model and the results are presented in Figure 13. The analysis focused on understanding the impact of a 5-year delay in coal retirement for electricity generation and delays in electrification of the transportation sector on Australia's carbon emission reduction by 2030. Furthermore, the role of energy efficiency in reducing the dependency on CO_2 removal to meet the 2030 carbon reduction target was also reviewed.

Figure 13 (b) shows that a 5-year delay[58] in coal retirement and delays in electrification of the transportation sector will result in significant dependency on CO_2 removals in 2030 (an increase from 12.8% to 60.7%) to meet the 2030 emissions target, which is an extremely difficult and costly process at this point in time. The carbon emissions reduction in 2030 from renewable electricity and electrification reduced from 66.9% to 22.2% and from 7.2% to 4.1%, respectively.

If energy efficiency projects are promoted and fast tracked to be completed by the end of 2030, these could play a major role in alleviating the problem, as shown in Figure 13 (d). In such a scenario, 43% of the carbon emissions reduction is expected from energy efficiency and the need for CO_2 removal significantly reduces to only 24.2%. This analysis further emphasises the importance of maintaining the expected timeline for retirement of coal-based electricity generation and to maintain steady progress on all other carbon emission reduction initiatives.

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[55] Source: https://australiainstitute.org.au/wp-content/uploads/2021/09/ACF-Aust-Institute_integrity-avoided_deforestation_report_FINAL_WEB.pdf
[56] Source: https://www.washingtonpost.com/world/2023/02/10/australia-carbon-farming-climate-environment/
[57] Source: https://news.climate.columbia.edu/2019/09/27/carbon-capture-technology/
[58] From AEMO 2022 Integrated System Plan Report's step change scenario

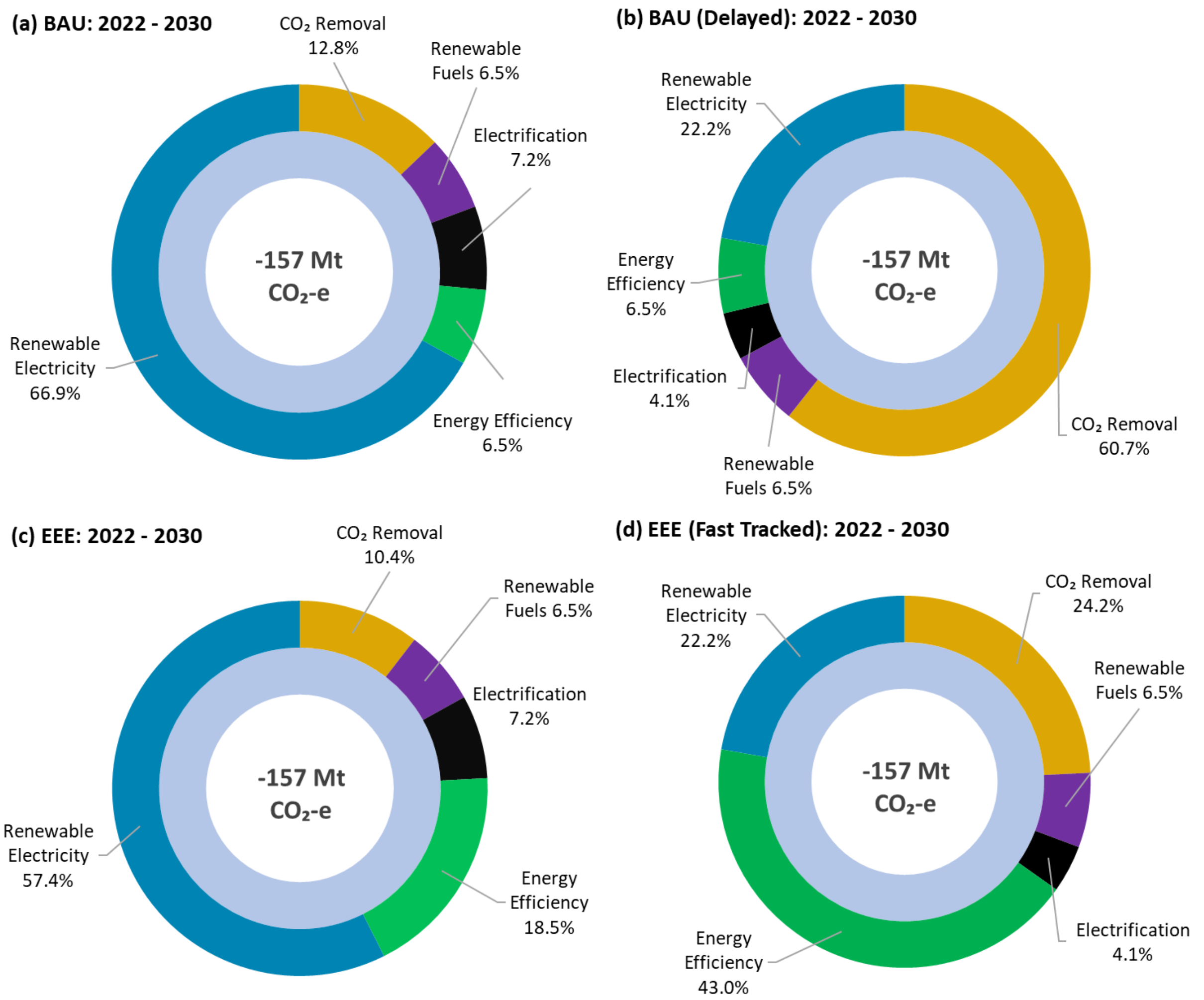

Figure 13. Sensitivity analysis: (a) BAU scenario, (b) BAU in a delayed coal retirement and electrification of transport scenario, (c) EEE scenario, and (d) EEE (Fast Tracked) Scenario

4 Conclusion

While it is recognised that Australia needs to consider all solutions on its journey to net zero, without a focused and sustained drive for improved energy efficiency and electrification the journey will be so much more arduous. Energy efficiency provides a much more certain abatement pathway than yet to be developed or proven technology change such as green hydrogen and CCS.

When taking action, energy efficiency should be considered first as most of the technologies are readily available at comparatively low cost. With sufficient investment and implementation support, these technologies could be implemented within relatively short timeframes. Electrification technologies require greater investment, and certain fields of application require further technology development.

This report has demonstrated that increasing the contribution of energy efficiency reduces reliance on other technology pathways, which have greater levels of uncertainty in the timeframe and scale of deployment. Energy efficiency and management can also provide a significant source of abatement that could help mitigate other risks in the transition, such as if the exit of emissions-intensive electricity generation infrastructure is delayed.

This analysis shows that the early stages of improvement programs in key energy using sectors should first target:

- **Agriculture:** electrification and renewable fuels.
- **Mining:** energy efficiency and electrification.
- **Manufacturing:** energy efficiency and electrification.
- **Commercial buildings:** energy efficiency followed by electrification.
- **Transport:** electrification.
- **Residential buildings:** energy efficiency and electrification.

There is a wide range of opportunities available to reduce emissions through energy efficiency and management. Government agencies can assist with the realignment of focus through guidance on minimum standards and potential regulation, coupled with targeted support programs, including the expansion of the state-based energy efficiency schemes. These actions will provide both the impetus and the support that will be needed for companies to act quickly.

5 Glossary of Terms

ACCUs	Australian carbon credit units (ACCUs) are issued by Clean Energy Regulator and one unit represents one tonne of greenhouse gas emissions avoided or stored by a project.
Baseline data	Baseline data is a set of data collected at the beginning of a study before intervention has occurred.
BECCS	Bioenergy with carbon capture and storage (BECCS) is a measure of capturing and storing CO_2 via a biogenic source.
CCS	Carbon Capture and Storage (CCS) refers to capturing and storing CO_2 emissions released into the atmosphere due to human activities.
CO_2 removal	Removing CO_2 from the atmosphere via measures such as carbon sequestration, biochar, direct air capture, enhanced mineralisation and afforestation/reforestation.
CRI	The Commercial Readiness Index (CRI) which begins at the early stage of technical readiness, extends to when the technology is being commercially deployed and has become a bankable asset class. A graphical representation of the TRL and CRI is in Figure 14.
CBD	Commercial Building Disclosure (CBD) program mandates disclosing information on the energy performance of a building when larger office spaces are being leased or sold.
Emissions Intensity	Emission intensity of an industry refers to the greenhouse gas emissions released per unit of production.
ESCs	Energy Savings Certificates (ESCs) are a part of NSW government's initiative to promote energy savings and one certificate represents a saving of one national MWh of energy.
Electrification	Electrification refers to a switch from fossil fuel-based equipment to an electricity powered equipment performing the same task.
Energy efficiency	Energy efficiency is an act of optimising a system's energy performance by implementing appropriate strategies to reduce the overall energy consumption of the system by reducing energy waste.
EnMS	Energy Management System (EnMS) is a framework that can be utilised within various energy consuming sectors to track, manage and improve their energy usage.
Green hydrogen	Green hydrogen refers to hydrogen produced from electrolysis of water.
Green Steel	Green steel refers to production of steel without using fossil fuels.
GEMS	Greenhouse and Energy Minimum Standards (GEMS) act was introduced in 2012 as a national framework to improve energy efficiency of products in Australia.
Hard-to-abate	Hard-to-abate refers to emissions that are either impossible or too costly to abate with current technology.
HVAC	Heating Ventilation and Air Conditioning systems

MVR	Mechanical Vapour Recompression (MVR) is an evaporative concentration technology that has been proven to reduce energy consumption of various industrial processes.
Renewable electricity	Renewable electricity refers to electricity generated via renewable sources such as solar energy, wind energy, biomass and hydropower.
Renewable fuels	Renewable fuels refers to renewable fuel sources such as hydrogen, biomass, biogas and biofuels.
SAF	Sustainable Aviation Fuel (SAF) has similar chemistry as aviation jet fuel, however, is produced from sustainable feedstocks such as cooking oil and solid waste.
SMCs	Safeguard Mechanism Credits (SMCs) are an alternative to ACCUs, which Australia's largest emitters can sell or purchase from the Commonwealth Government to meet their Safeguard Mechanism obligations.
TRL	The Technology Readiness Level (TRL) index is an indicator for tracking progress and supporting development of a specific technology through early stages to actual system demonstration over a full range of expected conditions.
VEECs	Victorian Energy Efficiency Certificates (VEECs) are part of the Victorian Energy Efficiency Target program and one certificate represents a saving of one tonne of greenhouse gas emissions.
VSD	A Variable Speed Drive (VSD) is a type of an adjustable speed drive that controls the motor speed and torque by varying the motor input frequency and voltage.

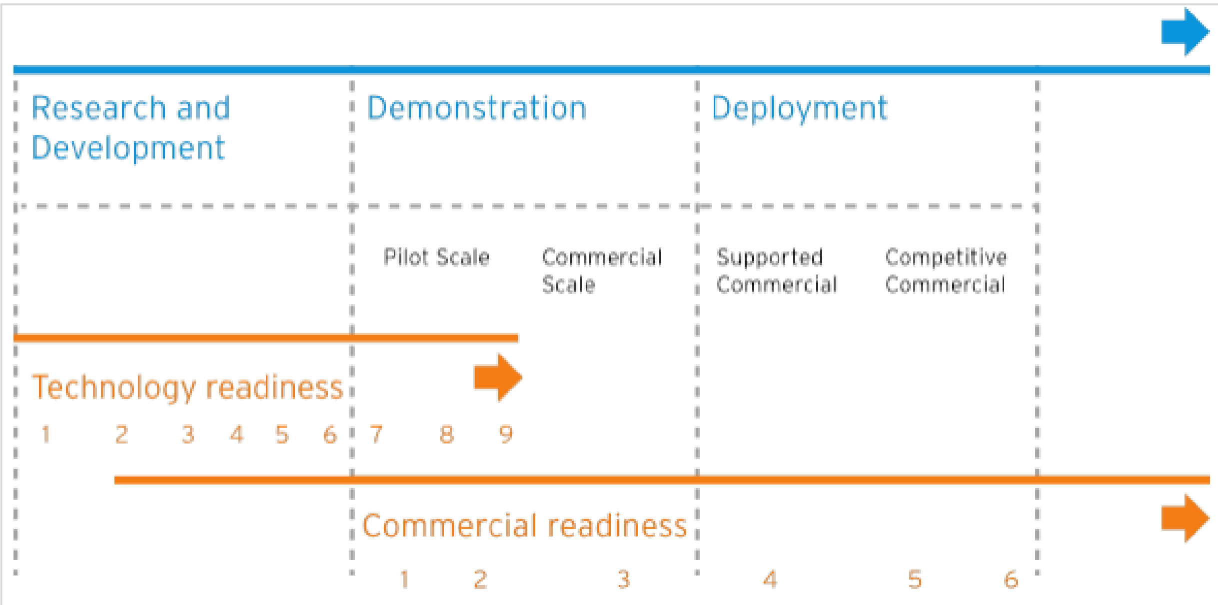

Figure 14. TRL and CRI mapped on the Technology Development Scale[59]

[59] https://arena.gov.au/assets/2014/02/Technology-Readiness-Levels.pdf

Appendix A – Technologies Considered

Energy Management / Energy Efficiency

Energy efficiency opportunity analysis considered the following technology/improvement methods, including:

- ***Compressed Air Systems:***
  - Controls and compressor allocation
  - Compressor sizing
  - Variable speed drives
  - System pressure
  - Remote pressure sensing
  - Air receiver capacity
  - Leakage
  - Dryer technology
  - Reticulation system improvements
  - Boosters and/or weekend usage
  - Heat recovery
  - Compressor service
  - Actuator air usage
  - Economiser regulators
  - Regulator and actuator tuning
  - Wasted air in vacuum systems
  - Inappropriate usage

- ***Refrigeration Systems:***
  - Controls and compressor allocation
  - System pressure including head pressure control
  - Compressor sizing
  - Condenser sizing
  - Primary vs secondary refrigerant circuits
  - Variable speed drives on compressors, fans, pumps
  - Heat recovery and desuperheating
  - Reticulation system improvements and insulation
  - Water and air purging from ammonia systems
  - Variable defrost timing and termination
  - Variable cold storage temperatures
  - Condensate sub-cooling with economisers or town water supply
  - Oil feed control and oil cooling of screw compressors
  - Fluid chiller selection based on application
  - Variable chiller fluid temperatures
  - Variable cooling water temperatures
  - Application including heat exchanger design and stream matching

- ***Boiler and Steam Systems (and Hot Water Generation):***

- Boiler and burner controls, including O_2 trim
    - Economisers and air preheating
    - Deaerator operation
    - Water quality improvement
    - Condensate return / optimization
    - Blowdown management and heat recovery
    - Steam pipework improvements and insulation
    - Steam leakage including steam trap management
    - Process heating optimization, process integration and heat exchanger improvements

- ***Motors and Drives:***
    - VSD applications
    - Motor controls
    - Unnecessary operation
    - Motor efficiency
    - Notched belts
    - Appropriate motor sizing
    - Rewinding vs new

- ***Pumps and Fans:***
    - Sizing
    - Optimal efficiency point
    - Impeller selection
    - Controls
    - Unnecessary usage

- ***Lighting:***
    - Unit selection
    - Controls
    - Lighting layout
    - Dimming
    - Use of skylights/natural light

- ***Other Considerations:***
    - Vacuum pumps (selection, sizing, controls, vacuum settings, tightness, etc.)
    - HVAC (selection, sizing, controls, tightness, etc.)
    - Technology improvements (of electrification solutions)
    - Mechanical Vapour Recompression (MVR) and absorption chilling
    - EnMS (Improve management and control)
    - Building standards (BMS, glazing, insulation, etc.)

Electrification Technologies

The following electrification opportunities were considered in the analysis:

- ***Residential Sector:***
    - Use of existing reverse cycle air conditioners for space heating instead of natural gas heaters

- Installation of reverse cycle air conditioners for space heating and cooling in homes that utilise fossil fuel-based energy sources
    - Replacing natural gas and LPG based hot water units with thermal heat pumps or solar thermal units
    - Replacing gas cooktops with induction cooktops

- ***Commercial and Services Sector:***
    - Replacing conventional HVAC systems with reverse cycle heat pumps in buildings
    - Replacing natural gas and LPG based hot water units with hot water heat pumps for domestic usage in buildings
    - Replacing conventional water heating systems with thermal heat pumps in aquatic centres
    - Electrification of diesel based transport

- ***Manufacturing Sector:***
    - Replacing fossil fuel-based systems with thermal heat pumps for low temperature heating applications
    - Replacing fossil fuel steam systems with high temperature heat pumps or electric boilers for steam generation
    - Replacing fossil fuel-based systems with electrification technology, e.g., induction, microwave, etc., for process heating applications

- ***Mining Sector:***
    - Replacing fossil fuel based heavy mining vehicles (such as trucks, excavators, loaders, diggers and trains) with electric vehicles
    - Replacing fossil fuel based light mining vehicles with electric vehicles
    - Renewable sources for electricity generation instead of fossil fuel based on-site electricity generation
    - Replacing fossil fuel-based pumps and lights with electric pumps and electric lights, respectively
    - Electrification of process heating applications

- ***Transportation Sector:***
    - Replacing fossil fuel-based vehicles with electric vehicles for both personal cars and freight transport
    - Electrification of water, rail and air transport

- ***Agriculture Sector:***
    - Electrification of agriculture vehicles, pumps and other fossil fuel based equipment

Renewable Electricity

This study assumes that all electricity generation would be converted to renewable electricity by 2050. The sources may include:

- Solar energy
- Wind energy
- Biomass
- Hydropower

Renewable Fuels

This study assumes that renewable fuels will play a role in carbon emissions reduction. The sources may include:

- Hydrogen generated by renewable electricity – utility scale or individual use scale (via fuel cell)
- Hydrogen as a vehicle fuel via fuel cell
- Biogas for injection into the natural gas grid
- Biomass fueled boilers for industrial heat generation
- Biofuels for:
    - Liquid Fuels used in road & offroad transportation
    - Sustainable Aviation Fuels (SAF) – biojet fuels used in air transport
    - Biofuels as an additive transitional fuel for diesel freight and off-road transport, assumed to be all electrified by 2050 in high electrification scenario.

CO_2 Removal

The study assumes that any remaining carbon emissions will have to be removed from the atmosphere to meet the 2030 and 2050 targets via the following measures[60]:

- Permanent plantings
- Plantation and farm forestry
- Human induced regeneration of native forest
- Savanna fire management
- Soil carbon
- Blue carbon (coastal)
- Biochar
- Carbon Capture & Storage (CCS)
- Bioenergy with Carbon Capture and Storage (BECCS)
- Direct Air Capture (DAC)
- Mineral Carbonation

[60] Extracted from CSIRO's *Australia's Carbon Sequestration Potential* report: https://www.csiro.au/en/research/environmental-impacts/emissions/carbon-sequestration-potential