Climate Action Tracker

Scaling up climate action

Key opportunities for transitioning to a zero emissions society

FULL REPORT

CAT Scaling Up Climate Action series

AUSTRALIA

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CLIMATE ANALYTICS

CAT Scaling Up Climate Action series

The Climate Action Tracker (CAT) strives to support the enhancing of climate action in the context of the Paris Agreement implementation. This analysis contributes to revisions of mitigation targets, and aims at spurring an increase in climate mitigation actions, to close the gap between current emissions projections and required Paris-compatible pathways.

As part of this, we have been researching the potential for countries to scale up climate action in different focus areas. The analysis in this report is relevant to governments considering revisions to their Nationally Determined Contributions (NDCs) to be submitted under the Paris Agreement by 2020, and also to their submission of long-term low greenhouse gas development plans, also due by 2020.

The result is our **Scaling Up Climate Action** country series, which identifies options for increased sectoral action that would move a country towards a pathway compatible with the Paris Agreement's long-term temperature limit and estimates the impact of those actions on emissions and other benefits.

The first round of our analysis covers **South Africa**, the **European Union**, **Argentina**, **Indonesia**, **Turkey**, and **Australia**.

The consistent method and similar structure for all six reports allows for country-specific insights, while enabling a cross-country comparison to draw general research findings and lessons learnt on global potentials.

climateactiontracker.org/publications/scalingup

Executive summary

Introduction and objectives

Under the Paris Agreement, governments have committed to holding temperature increase well below 2°C above pre-industrial levels and pursuing efforts to limit it to 1.5°C. According to Climate Action Tracker (CAT) estimates, emission reduction targets put forward by governments in aggregate will, even if fully implemented, fall short and will lead to an estimated warming of around 2.9°C globally by 2100.

The 1.5°C limit in the Paris Agreement is of critical importance for Australia. The continent is highly exposed to climate change impacts like sea level rise, coral reef loss, wildfires and extreme weather events. All of these effects can already be observed today and will be much worse in a 2°C world, compared to 1.5°C. Especially for tropical coral reefs, including the Great Barrier Reef, the difference between 1.5°C and 2°C is likely to be decisive if any reefs are to survive.

To stay below the globally-agreed limit, the IPCC Special Report on 1.5°C (SR15) finds that a massive increase in effort is required to peak global GHG emissions as soon as possible, reduce total global greenhouse gas emissions, including CO_2 emissions, to 45% below 2010 levels by 2030 and to reach net-zero emissions around 2050 for CO_2 emissions and net-zero total GHG emissions around 2070.

In recent years, measures to reduce GHG emissions have, in many cases, become more attractive to policy makers and private investors in many countries, both because of falling technology costs, as well as increased awareness for other benefits, such as air quality improvements and job creation in low-carbon-oriented sectors, in addition to the avoided climate change damages and related costs. These socio-economic benefits of climate change mitigation unfortunately are not yet in the centre of the climate policy debate in Australia.

We no longer live in a world where climate change mitigation is a burden *per se*, but one where it is increasingly the most feasible, cheapest option when considering all socio-economic aspects. For cost-efficient global mitigation, it will be essential to overcome remaining barriers in all countries including Australia.

This report, the sixth country assessment in the Climate Action Tracker's Scaling Up Climate Action Series, shows where Australia can accelerate its climate action. The report illustrates GHG emission reductions from these actions, along with employment and other benefits and the policies across all sectors that will bring emissions down fast enough.

Our analysis starts with an in-depth review of Australia's current policy framework and sectoral developments and compares them with the comprehensive policy packages and the progress of the kind of sector indicators required under Paris Agreement-compatible pathways.

It then focuses on a scenario analysis showing how to scale up climate action in Australia to levels consistent with the Paris Agreement. This analysis shows the huge gap between Australia's present sectoral emission trajectories under the Current Development (reference) scenario and the sectoral transformations that the country can undertake to align with the Paris Agreement's temperature limit.

Additionally, we investigate the sectoral transformations that can be undertaken in Australian by following the benchmarks set by the international frontrunners ('best-in-class'). In particular take the specific characteristics of Australia's industry sector and the importance of extraction and export of fossil fuels, as well as the key role of the power sector to decarbonise end-use sectors through (direct and indirect) electrification, and show what can be done to decarbonise these sectors by 2050, or earlier.

We focus on the potential to increase mitigation efforts in the electricity supply, transport, industry, and buildings sectors, while providing an integrated energy system approach and a pathway for greenhouse gas emissions reductions across all sectors consistent with the Paris Agreement.

The report identifies Australia's options for accelerated climate action in each sector, informed by insights from three different scenario categories: (1) National scenarios, (2) Scenarios applying sectoral best-in-class levels, and (3) 1.5°C Paris Agreement-compatible scenarios, the results of which have all been compared to the common baseline of (4) the Current Development Scenario.

	Scenario categories	Definitions
1	NATIONAL SCENARIOS	Scenarios based on national research and country-specific studies (analysed for some sectors)
2	BEST IN CLASS SCENARIOS	Scenarios based on best practices implemented by regional or international frontrunners (analysed for some sectors)
3	1.5°C PARIS AGREEMENT COMPATIBLE SCENARIOS	Scenarios based on sectoral developments in line with the Paris Agreement's temperature limit.
4	CURRENT DEVELOPMENT SCENARIO	Reference scenario used for comparison purposes. The scenario is based on the continuation of current trends and policies until 2050.

KEY FINDINGS

- Australia's 2030 Paris Agreement target and its domestic policies are not compatible with the Paris Agreement's 1.5°C limit. Australia will need to accelerate its climate action across all sectors of the economy and ratchet up the 2030 climate target to put the country on a path towards net zero GHG emissions by 2050.
- Increased climate action in Australia will achieve a wide range of benefits and can build on existing technologies and current market developments to achieve cost reductions, particularly for wind, solar and storage technologies by taking advantage of the country's extraordinary renewable energy resources.

2030 targets need major improvement

- Accelerated climate action in line with the Paris Agreement-compatible scenarios across all sectors allows Australia to achieve emission reductions of about 50% below 2005 emission levels by 2030, and 90% reductions by 2050, excluding the uncertain and volatile Land use, land-use change and forestry (LULUCF) sector.
- To achieve net zero by 2050 Australia's 2030 GHG reduction target (including LULUCF) needs to be about 66% below 2005 levels. This is very close to the high end of the 2030 target range recommended by the Climate Change Authority in 2014 of 47-65% below 2005 emission levels.

Achieving net zero by 2050

- Australia can achieve net zero GHG emissions by 2050 if it takes action to halt deforestation by 2030, and if it maintains the storage of carbon in forests projected for 2030 until 2050. This would be needed to outweigh remaining greenhouse gas emissions from hard-to-abate sectors, particularly agriculture.
- Achieving net zero GHG emissions by 2050 will require a whole of economy approach, with mitigation in the non-energy sectors alongside decarbonising electricity and electrification of industry and transport, the roll-out of renewable hydrogen and a balanced approach in the land-sector that protects biodiversity, water resources and avoids relying on carbon storage in the land sector beyond sustainable limits.

Major Employment generation by decarbonising the power sector

- The key to decarbonising Australia's energy system is decarbonising the electricity sector.
- Accelerating the transition towards a zero carbon, renewables-based electricity supply by the 2030's will bring large domestic employment opportunities to Australia
  - 46,000 additional jobs between 2021-2030 compared to the current trajectory
  - If combined with a policy to incentivise more local manufacturing of wind turbines, solar panels and batteries would reach 76,000.
- Australia can decarbonise its domestic energy system by 2050 by scaling up action in the electricity supply, and energy end use sectors (manufacturing industry, transport and building sectors) —which cover around 70% of the Australia's current greenhouse gas emissions.
- Electrification of end-use sectors is central to decarbonising the Australian economy, including electric mobility and green hydrogen for industry and transport, with benefits for the electricity system.
- Australia needs to urgently prepare for the global transition away from fossil fuels as the world implements the Paris Agreement with many countries now aiming for zero emissions by 2050 and can develop alternatives to exporting fossil fuel energy.
- By building on its extraordinary renewable energy resource and high skills base, Australia can become a regional and international frontrunner in successfully transitioning its energy system to zero carbon. The result will be more sustainable employment, reduced levels of air pollution, water demand and new manufacturing value chains and export opportunities based on zero emissions energy carriers including renewable electricity offshore, green hydrogen and energy intensive products such as green steel.

Electricity generation

- The electricity supply sector in Australia can be fully decarbonised, reaching 100% renewable energy by the mid to late 2030s given Australia's prime renewable energy resources and technology developments for wind, solar, and storage already underway
- Coal can be phased out of the power sector by 2030 using renewables and advanced storage without additional gas generation needs, consistent with what is needed globally to meet the Paris Agreement's goals.
- Coal phase-out plans are needed that will enable a smooth and just transition.
- Gas can be phased out of power sector by the mid to late 2030s using renewables and advanced storage. This study confirms that there is no role for an increase in gas use for power generation in a Paris Agreement-compatible pathway.

Renewable Energy and Green Hydrogen is a major opportunity for Australia

- Green hydrogen and other renewable energy-based fuels can be used to decarbonise industry processes to produce zero emissions steel or ammonia, and be used for aviation, shipping and freight transport through fuel cell trucks.
- Australia can benefit from its unique and abundant resources, both in renewable energy and the range of minerals and materials needed for a global transition to 100% renewable energy, but needs clear strategy and plan. It has the opportunity to become a global leader through, for example, exporting zero emissions energy carriers and products such as green steel.

Electric Mobility

- The phasing in of electric vehicles (EVs) can happen rapidly so that there would be no new fossil-fuel based vehicles sold from 2035 onwards.
- EVs will reduce air pollution and overcome fuel security concerns, with significant benefits to the economy.
- The need for imported fuel oil presently imposes an import cost burden of 1.5% of GDP (in 2018) with import dependency expected to increase under present policy settings.
- By accelerating EV market development fuel oil usage would be reduced by 24% by 2030 from 2005 levels and 100% by 2050, resulting in an entirely decarbonised transport sector.
- Integration of EVs into the Australian power grid will also provide substantial benefits for the electricity system, lowering costs and contributing towards integrating higher shares of variable renewables like wind and solar.

Reducing emissions from the LNG sector

- Natural gas will need to phased out globally for power generation by the 2040s to meet the Paris Agreement goals, however the domestic LNG industry will need to substantially reduce its own emissions well before that time.
- Emissions from the LNG industry can be substantially reduced by capturing and storing carbon dioxide that would otherwise be emitted in very large volumes from natural gas reservoirs, using renewable energy for the process of liquifying natural gas and upstream pumping and transport of gas rather than use the gas itself, and, as well, reducing fugitive emissions from LNG plant and related processes.
- Renewable electrification of LNG processing plant can play a key role in phasing out emissions from LNG processing industry in Australia. Transitioning the LNG manufacturing process away from gas to renewable electricity will also add significantly to the renewable energy market in Australia with opportunities for regional Australia.

Sectoral transitions towards zero-carbon

This report shows that Australia, has tremendous potential to scale up climate action in all sectors. Here we focus on the key sectors: electricity supply, industry (including LNG production), transport, and buildings.

Increasing climate action would initiate sectoral transitions towards a zero-emissions society relying on existing and, in some sectors, emerging technologies. This would come with the additional benefits of reducing air pollution, and creating additional employment including through new manufacturing value chains and new export opportunities based on renewable energy.

Electricity supply

Australia has no targets nor plans to increase the share of renewable energy beyond 2020. Under existing policies, Australia would likely reach a share of renewable energy in electricity generation nationally of around 50% by 2030 depending on state targets to be achieved.

The policy void at federal level is creating investment uncertainty and there is an urgent need to plan for a fast transition to 100% renewable energy in the 2030s with corresponding transmission and storage planning and investments. Current developments and the lack of targets and planning are leading to reduced investments, where acceleration is necessary.

For Paris Agreement compatibility the uptake of renewable energy in electricity supply needs to, and can, be accelerated, to reach a share of almost 97% in 2030, 99% by 2035 and 100% by 2040, with an increase in electricity generation by 32% in 2030 above 2019 levels and further 23% in 2040 above 2030 levels to enable electrification of end use sectors, including EVs in transport and green hydrogen for domestic use. An additional increase would be needed to allow for new export opportunities, such as green hydrogen or direct export of electricity to South East Asia, but has not been analysed in this study.

This accelerated uptake of renewable energy is more ambitious than the step-change scenario in the 2020 Integrated System Plan (ISP) for the National Electricity Market by Australian Energy Market Operator (AEMO) which reaches 94% renewables share in electricity generation in 2040. The AEMO scenarios do not account for the scale of increase in electricity generation needed to decarbonise all end use sectors by 2050, nor any additional increase to enable new export opportunities such as green hydrogen.

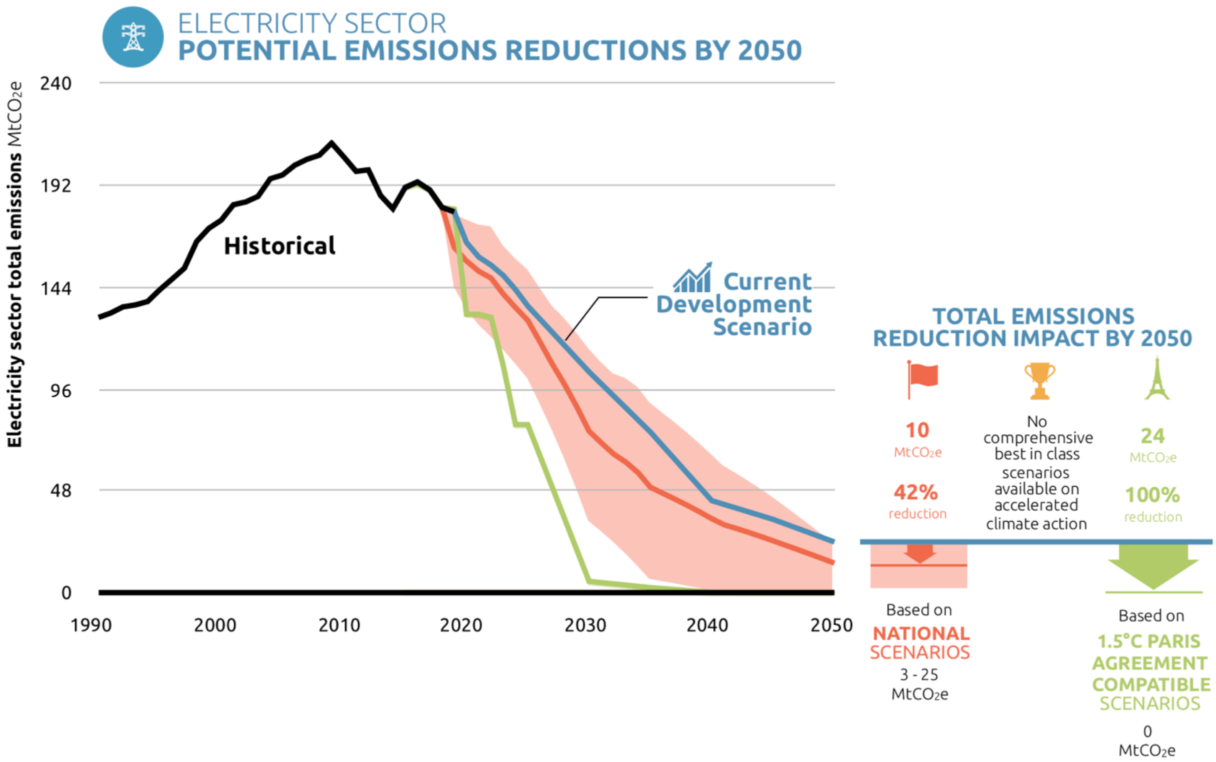
Table 1: Identification of indicator levels for scaling up climate action in the Australia's electricity supply sector. Shown is the share of Renewable energy in total power generation resulting from the scenarios under the assumptions for the two scenarios categories.

	Reference Scenario (REF)	National scenarios	1.5°C Paris Agreement Compatible scenario
Share of renewables in total electricity generation	**13% by 2015**	**-**	**-**
	53% by 2030	**59-84% by 2030**	**95-97% by 2030**
	79% by 2040	**82-99% by 2040**	**99% by 2035 and 100% by 2040**
	89% by 2050	**92-100% by 2050**	**100% by 2050**
References	*Based on AUSeMOSYS developed by Climate Analytics* (Tino Aboumahboub, Brecha, Shrestha, et al., 2020)	*Based on 'Advanced Renewables' Scenario by (Teske et al. 2016) for the High ambition case and 'Fast Change Scenario' by* (AEMO, 2018a) *for the Low ambition case. Other published national scenarios fall within this range.*	*Based on AUSeMOSYS developed by Climate Analytics* (Tino Aboumahboub, Brecha, Shrestha, et al., 2020)

Planning for renewable energy expansion needs to include grid transmission systems and electricity market adjustments.

An essential step to decarbonising electricity generation is a planned phase-out of coal-fired power generation by 2030. This needs to be a planned and regulated process to enable a just transition particularly for regions currently highly dependent on coal-fired power generation and coal mining.

This transition does not require an increase in gas for power generation due to the increasing cost efficacy of battery storage, pumped hydro systems, demand-side management measures and later the integration of hydrogen and EV storage systems into the grid.



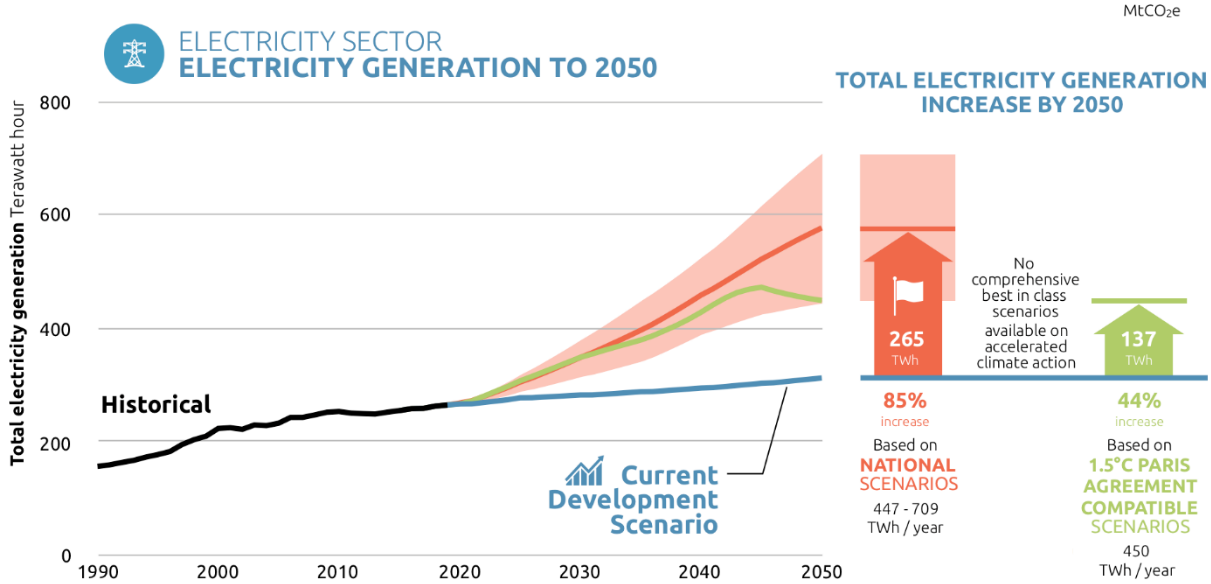


Figure 1: Overview of sectoral emission pathways under reference scenario projections and different levels of accelerated climate action in the Australia's electricity supply (top). The projected electricity demand considers accelerated climate action in the Australia's end-use sectors which leads to higher electricity generation (bottom). Based on AUSEMOSYS energy model developed by Climate Analytics (Tino Aboumahboub, Brecha, Shrestha, et al., 2020).

Note: In the Australia's electricity supply figure (top) the CO_2 emissions begin reducing from 2019 reflecting the model output. With action starting a year or two later a similar level of emissions reductions would still be achieved by the mid-2020s as coal plant are phased out. This adds about 0.1GtCO_2 to the cumulative emissions from 2018-2050.

In our modelling using the optimization approach in Australian Energy Modelling System (AUSeMOSYS), the share of gas for power generation decreases from today's level of about 20% to around 3% by 2030, 1% by 2035 and is completely phased out by 2040. This is contrary to statements by the government that more gas will be needed as a transition fuel or as a partner for renewable energy, and contrary to government plans to subsidise new gas-fired power plants.

Renewable energy-based power generation leads to reduced electricity prices and reduced health impacts avoiding air pollution from coal and gas fired power generation.

Transport

The upward trends of GHG emissions from the transport sector in Australia highlights the urgent need to accelerate action to fully decarbonise this sector by mid-century to be compatible with the Paris Agreement.

The CAT Paris Agreement-aligned benchmark requires Australia to increase its share of electric vehicles (or other emissions-free vehicles) in new vehicle sales from less than 1% today for personal cars, light duty vehicles and buses to 95% in 2030 to reach 100% in 2035.

This would translate into about a 38% EV share in the total fleet of cars and buses on the road in 2030 and, combined with the decarbonisation of the power sector, would result in full decarbonisation of this fleet by the middle of the century. In order to achieve this, Australia would need to apply stringent standards for CO_2 emissions intensity of new vehicles and increase the share of public transport.

A similar approach will be needed for trucks so that zero-emissions trucks would constitute 100% of newly sold trucks by around 2035-2040, leading to an almost 100% zero-emissions truck fleet by 2050. Options for zero-emission trucks at present include battery and fuel cells powered by Green Hydrogen.

For domestic aviation, technologies are also emerging in zero emissions fuels, such as synthetic jet fuel made from renewable energy using power to liquid technologies (P2L). We assume full decarbonisation of domestic aviation by 2050, which might imply the need for negative CO_2 emissions to compensate for remaining fossil fuel use.

Full decarbonisation of Australia's passenger and freight transport sector by 2050 is possible and requires a substantial modal shift for passenger and freight transport, introducing zero-emission vehicles, CO_2 fuel economy standards for cars, light duty vehicles, buses and freight vehicles. Internal combustion engine vehicle sales would need to be banned from 2035 at the latest.

Transport decarbonisation would build on the decarbonisation of the electricity supply sector, which would be decarbonised by the mid to late 2030s. This pathway reduces air and noise pollution and their harmful effects on health, and significantly reduces and eventually remove reliance on oil imports.

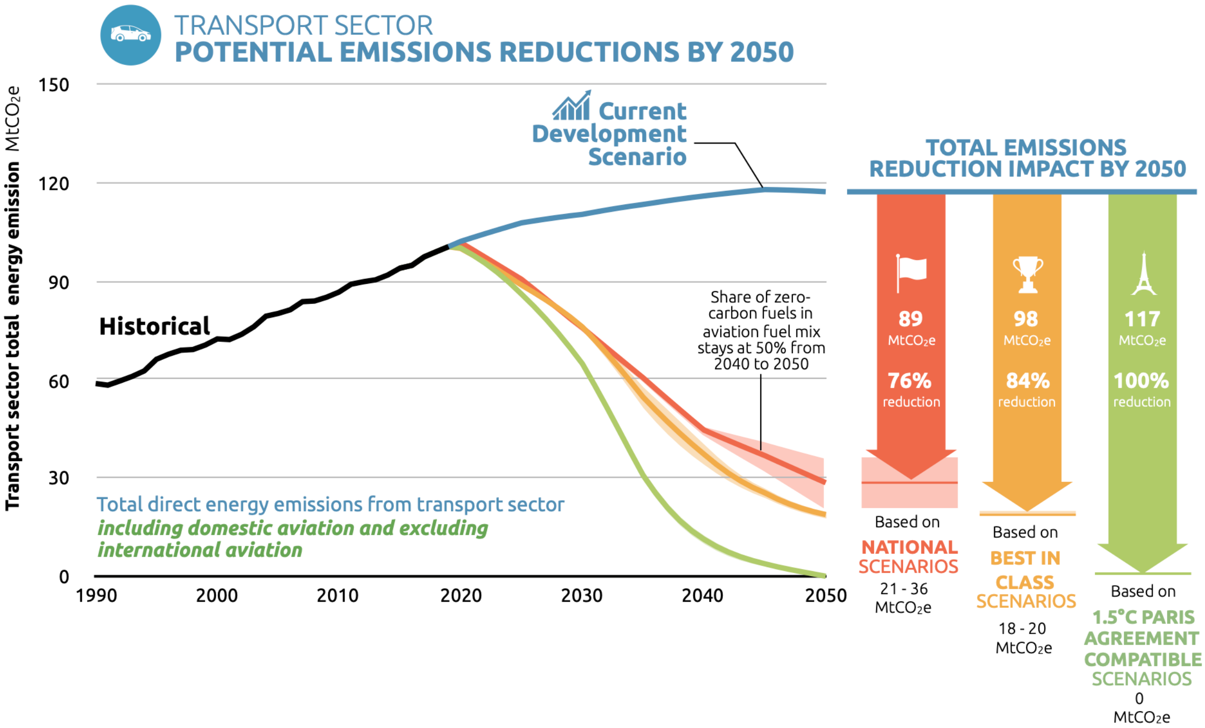


Figure 2: Overview of sectoral emission pathways under current policies and different levels of accelerated climate action in passenger and freight transport including domestic aviation. The CAT PROSPECTS Australia scenario evaluation tool has been used to estimate sectoral projections towards 2050. Historical emission levels have been harmonised to national inventory data. Shown are total direct emissions from the transport sector excluding electricity related emissions.

Buildings

Australia lacks a strategy to reach a 1.5 °C consistent benchmark in the residential and commercial buildings sector. There is widespread undercompliance with the present minimal energy efficiency standards, which are not due to be updated until 2022. Slow policy responses for long-lived assets mean that renovation rates will need to be scaled up, but there is no policy at all that focuses on increasing building renovation rates. Australian efficiency standards are behind other countries with similar climates. Failure to ensure adequate levels of energy efficiency in buildings places further pressure on the electricity grid to decarbonise.

The Paris Agreement-compatible trajectories almost fully decarbonise the buildings sector by 2050. Energy savings would need to be achieved through a deep retrofit of existing buildings at a 5% renovation rate per year from 2020 to 2050. In parallel to construction of zero-emissions new buildings, energy efficiency improvement of lighting and appliances as well as strong electrification (e.g. heat pumps) or other technological shifts to renewable energy in space/water heating can fully decarbonise the Australian buildings sector by mid-century. Decarbonising this sector critically relies on decarbonising the electricity supply sector.

There are direct benefits to households and businesses in decarbonising this sector, from thermal comfort to the financial savings by reducing electricity usage and installation of onsite renewables. Effective management of energy in buildings can reduce grid peak demand, reducing capital costs for further generation. Energy efficiency in buildings has been linked to improved health and productivity, improved air quality, economic growth and job creation.

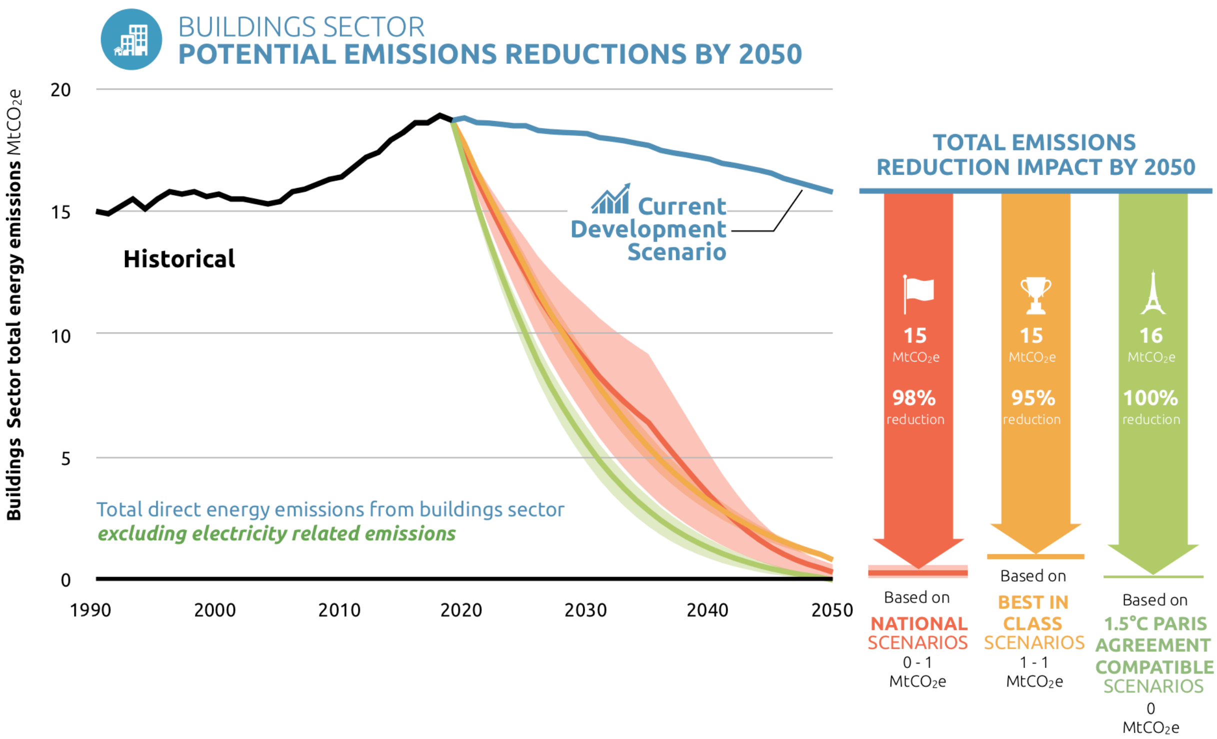


Figure 3: Overview of sectoral emission pathways under current policies and different levels of accelerated climate action in the buildings sector (domestic and commercial). The CAT PROSPECTS Australia scenario evaluation tool has been used to estimate sectoral projections towards 2050. Historical emission levels are harmonised to latest inventory data. Shown are total direct emissions from the residential and commercial building sector excluding electricity related emissions.

Industry

Australia's emissions from industry (direct combustion, fugitives, and industrial processes) account for 30% of total emissions (excl. LULUCF), making it the second largest emitting sector.

However, there is no strategy in Australia to achieve decarbonisation in the industry sector. Implementing energy efficiency policies across all industry sectors are key steps in reducing emissions and saving money.

Many heating processes in industry can be replaced to use electricity which can be produced 100% from renewable energy sources, mainly wind and solar. In other processes such as high-temperature heating or ammonia production, fossil fuel gas can be replaced by hydrogen or other fuels based on 100% renewable energy power. Australia's abundance of solar and wind energy can prompt international trade in renewables through hydrogen-rich chemicals and fuels or new zero emissions production.

Decarbonising Australia's industry sector needs to go beyond incremental improvements through increased energy efficiency. This needs to build on fuel switching and innovation leading to material efficiency, and process and product changes. This needs policy intervention through regulation, removal of barriers and concerted RD&D efforts by government and industry.

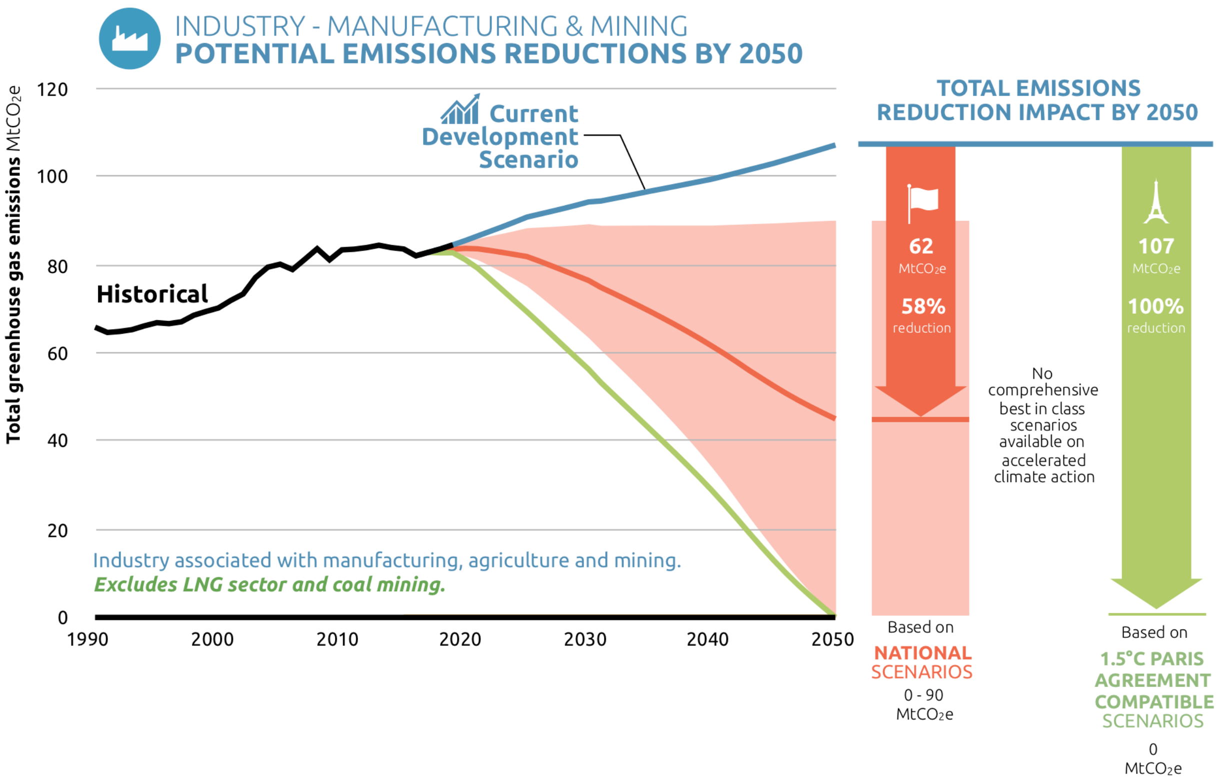


Figure 4: Overview of sectoral emission pathways under current policies and different levels of accelerated climate action in the industry manufacturing and mining sector (including steel and cement). The CAT PROSPECTS Australia scenario evaluation tool has been used to estimate sectoral projections towards 2050. Historical emission levels are harmonised to the latest inventory data. Shown are total direct combustion emissions and process emissions as well as emission from product use from the industry manufacturing sector excluding electricity related emissions. This includes the mining sector, but does not include the energy/fossil fuel extraction sector.

The industry sector is varied, and challenges differ significantly, but technologies with significant decarbonization potential are available as well as emerging across the industry sector. Electrification and green, renewable, hydrogen technologies with zero-emissions power are the key. A concerted effort guided by policy and targets is needed, to achieve transformational change including in sectors such as steel and cement where technologies to decarbonise these processes exist or are emerging.

Long lead times of investments in industry infrastructure mean these efforts need to start as soon as possible to enable the transition to zero emissions by 2050. A well-managed and planned transition can lead to large benefits for employment and growth through innovation and new manufacturing value chains and export opportunities based on zero emissions energy carriers including green hydrogen, energy intensive products such as green steel and aluminium.

Industry – the Liquefied Natural Gas sector

Australia contributed to around one-fifth of total global LNG capacity in 2018, most of this from Western Australia. In 2019, Australia overtook Qatar to become the largest exporter of LNG in the world. The future trend of LNG export volumes will have a major effect on Australia's domestic emissions.

Australia's LNG export volumes are forecast to increase from 62 million tonnes in 2017–18 to 82 million tonnes in 2019–20; the export volumes are forecasted to 81 million tonnes by 2023 (DIIS 2019). Here, we project the LNG export volumes under the "Reference Scenario" to reach to 87 million tonnes by 2025 and further rise to 97 million tonnes by 2030, and that volumes remain constant beyond 2030.

LNG manufacture is very energy-intensive, with about 10% of the feedstock gas being used to manufacture LNG. As a consequence, CO_2 emissions from gas used for energy in LNG plant during the period 2017-2019 comprised about 41 to 44% of the total emissions from the sector. Fugitive emissions from production and liquefaction can also be significant and have been estimated here at 11 to 12% of the total during the same period.

Natural gas reservoirs contain large amounts of carbon dioxide, which we estimate account for 16 to 21% of emissions in this period.

There is also significant energy use in upstream production of natural gas, estimated here in the range of 16 to 18% of total emissions in the sector. Coal Seam Gas (GSC) production in Queensland also consumes a significant amount of electricity which, based on the states' present energy mix, amounts to 9% to 12% of total LNG emissions nationally.

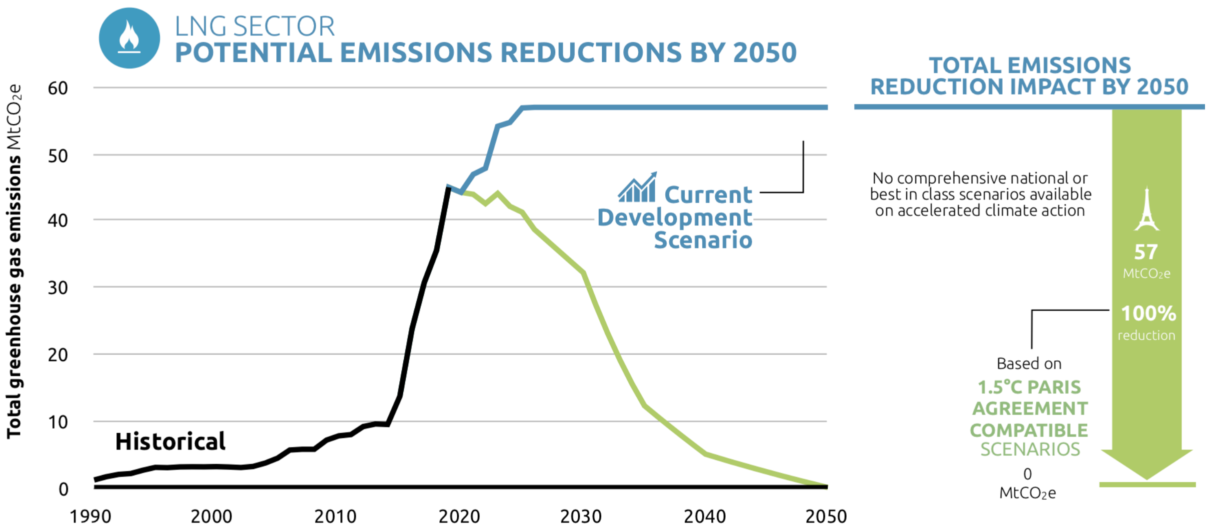


Figure 5: Overview of sectoral emission pathways under current policies and different levels of accelerated climate action in the LNG sector. Shown are total LNG related emissions – CO_2 venting, direct combustion emissions from upstream production and LNG manufacturing, fugitive emissions.

An essential option for abatement in the LNG sector is to ensure that reservoir CO_2 is captured and stored, rather than released into the atmosphere. In Western Australia this is a very significant component of the overall emissions from LNG production. The LNG production process must capture the CO_2 in the natural gas reservoir from the gas stream, and it should be well within the means of industry to achieve its storage and transport to an appropriate geological storage reservoir. In this study we assume that the 80% CCS capture rate planned for the Gorgon plant from 2019 is phased in to all LNG plants from around 2023.

Processes in the LNG plant themselves require electricity and energy for refrigeration. The corresponding CO_2 emissions can be avoided by using renewable electricity in the LNG manufacturing process, which in large part is essentially driven by aeroderivative gas turbines. This would also assist in reducing fugitive emissions from the LNG plant.

Renewable electrification of LNG processing plant can play a key role in phasing out emissions from LNG processing industry in Australia. Where electricity is used in upstream gas production, this can also be transitioned to renewable sources.

In the '1.5°C Paris Agreement-compatible' scenario in this study, Asian gas demand declines continuously from 2030 onwards. We assume that LNG export volumes would follow this decline towards an 80%-96% reduction of export volumes by 2050 below 2030 export levels. The basic options mentioned above - carbon capture and storage of reservoir CO_2, introducing renewable energy quickly into the upstream gas production and LNG manufacturing process and reducing fugitive emissions are all deployed in the Paris Agreement-compatible scenario shown in the figure below. If the assumed decline in LNG export volumes does not occur – and LNG exports follow the reference case (with constant export volume assumed after 2025), all of the above options would be needed, but at a larger scale.

Industry – other energy/extraction industry

The 1.5°C Paris Agreement-compatible pathway substantially reduces emissions and leads to the full decarbonisation of the mining industry by 2050. This is mainly driven by the strong electrification of the mining sector and use of decarbonised electricity from grid as a replacement to fossil fuel-based onsite generation.

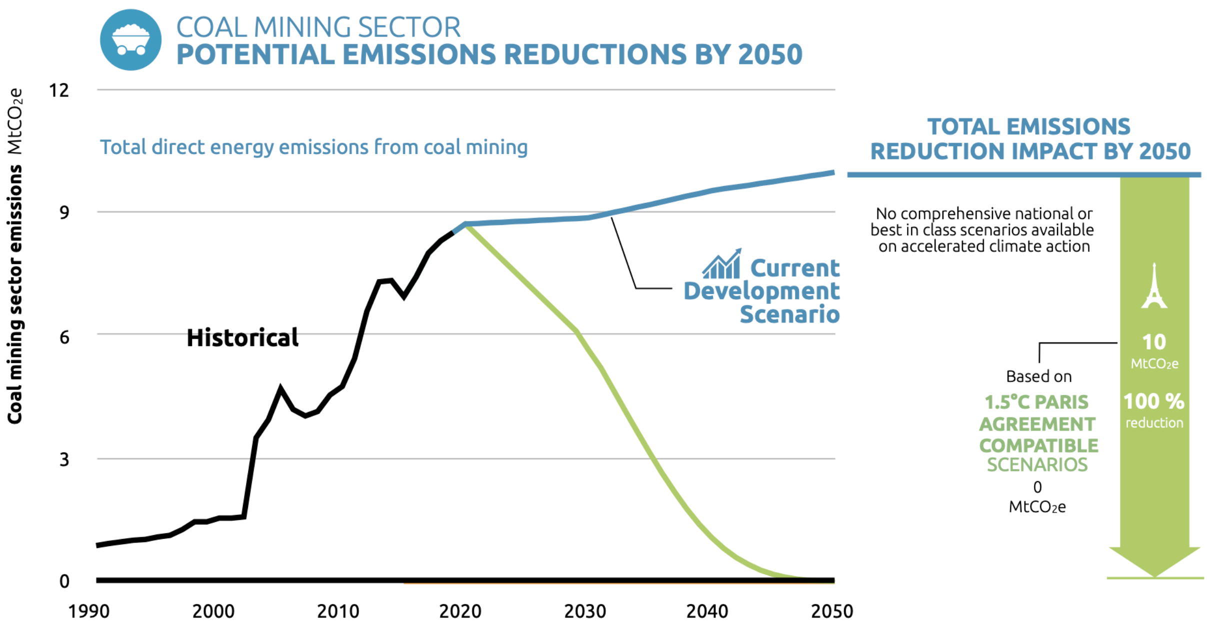


Figure 6: Overview of sectoral emission pathways under Reference scenario projections and accelerated climate action in Australia's coal mining sector.

One major mitigation strategy for mining companies is the use of decarbonised renewable electricity from the grid instead of onsite fossil-fuel based generation. This is already being deployed in some cases. Further complementary strategies to increase energy efficiency as well as electrification of energy end uses that have been so far powered by fossil fuels would yield further reductions.

In the **1.5°C Paris Agreement-compatible pathway,** coal mining declines from 2020 onwards towards a complete phase out of coal production by 2050, due to the replacement of thermal coal in the domestic power sector by 2030 and globally by 2040, and as metallurgical coal is gradually replaced by zero carbon alternatives, such as green hydrogen in steel manufacture.

Agriculture

At present in Australia there are few specific policies to reduce emissions from the agriculture and forestry sectors.

In general, reductions of non-energy emissions in the agricultural sector, particularly of methane and nitrous oxide, are expected to be much slower than in all other sectors. Key mitigation options include enhanced agricultural management (e.g. manure management, improved livestock feeding practices, and more efficient fertiliser use), as well as demand side measures such as dietary shifts to healthier, more sustainable, low-meat, low-dairy diets and measures to reduce food waste.

The 1.5°C Paris Agreement-compatible pathways for the agriculture sector project a 35% reduction of methane and nitrous oxide emissions relative to 2005 levels by 2050.

Waste

State and national policies do not provide a pathway to emissions reductions in this sector, as they do not focus on emissions. **Australia needs to scale up its national waste policy with more ambitious targets to tackle emissions, focusing on organic material waste.** Under the 1.5°C Paris Agreement-compatible pathway, emissions from the waste sector show an immediate and drastic reduction, declining to approximately 73% in 2030 below 2005 levels and about 3 $MtCO_2e/a$ in 2050.

Mitigation in the waste sector in particular is focused on reducing landfill emissions as this is highly cost effective and could even return a net profit. Key options in the short term to reduce emissions are lower landfill levels and an increase in methane capture. In the longer term, there is a need to move towards a circular economy, prioritising collection, recovery and re-use of products.

Accelerated climate action and Australia's inadequate 2030 emissions reduction target

Accelerated climate action in line with the Paris Agreement-compatible scenarios across all sectors would allow Australia to achieve emission reductions of about 50% below 2005 emission levels by 2030 (excluding LULUCF).

Assuming the 2019 Federal Government's projections for land use change and forestry (LULUCF) of a net sink in 2030 of 10 $MtCO_2e$, the reductions in the Paris agreement-compatible pathway here translates into a reduction including LULUCF of about **59% by 2030 below 2005 emission levels. A strategy to halt deforestation by 2030 would increase this to a 66% reduction in all greenhouse gases, including the land sector, by 2030 below 2005 levels. This would be the appropriate Paris Agreement-compatible target for Australia to update its NDC in 2020, as agreed in Paris in 2015 and the appropriate milestone towards net zero emissions by 2050.**

An important conclusion from these findings is that it is beneficial for Australia to considerably ratchet up its 2030 target to be consistent with the Paris Agreement. Increased climate action will achieve a wide range of benefits, it can build on existing technologies and current market developments and achieve cost reductions, particularly for wind, solar and storage technologies as well as take advantage of the country's extraordinary renewable energy resources.

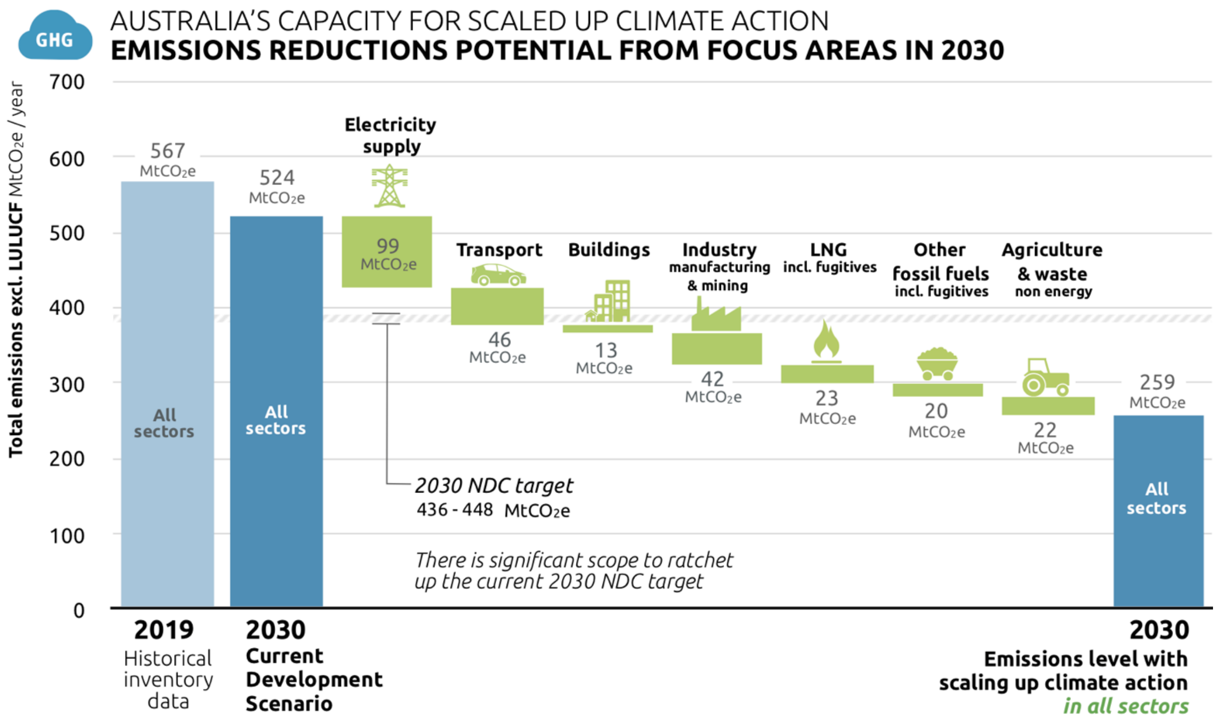


Figure 7: Overview of total emission levels (excl. LULUCF) under historical inventory data in 2019 (left bar), under a Reference Scenario in 2030 (middle bar), and most ambitious levels of accelerated climate action by 2030 in all sectors.

A strategy towards net zero emissions in 2050

When determining its long-term strategy by mid-century, Australia needs to act quickly on a fast decarbonisation of the power sector and recognise this sectors role in decarbonising end use sectors, including industry and transport. It will need to define sectoral targets and roadmaps, and implement more ambitious and stringent policies across all sectors to initiate and steer these sectoral transformations, given long lead times for infrastructure in industry, transport, and buildings.

Emissions from agriculture and waste cannot be reduced to zero, and some of the processes - especially in heavy industry, aviation and shipping - will likely need a bit longer to decarbonise than other sectors (Figure 8). Figure 9 provides and overview and summary of the sectoral results from this study.

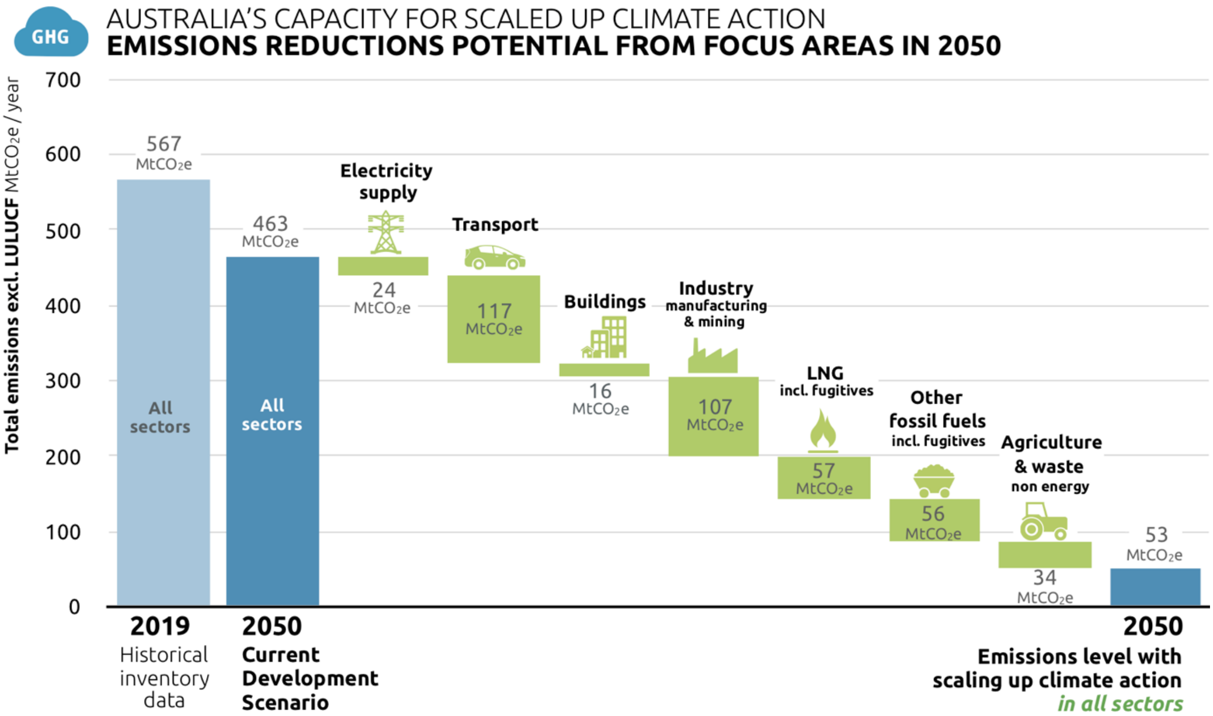


Figure 8: Overview of total emission levels (excl. LULUCF) under historical inventory data in 2019 (left bar), under a Reference Scenario in 2050 (middle bar), and most ambitious levels of accelerated climate action by 2050 in sectors (right bar).

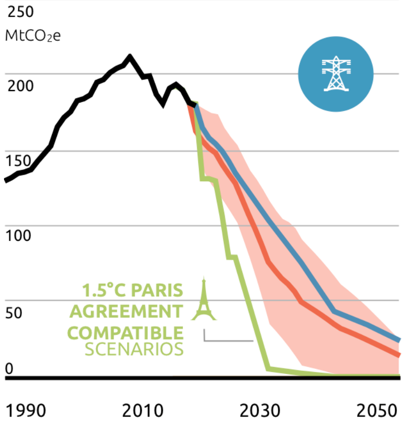
The 1.5°C scenario for Australia developed here, with all options considered, gets to a 90% reduction in overall greenhouse gas emissions (excluding LULUCF) by 2050, with about 50 $MtCO_2e$ per year remaining (Figure 10).

Net zero GHG emissions by 2050 cannot be achieved even with this ambitious strategy unless there is a significant increase in the amount of CO_2 stored in the land sector. With the government's 2019 land-use change and forestry projections to 2030 extrapolated until 2050 GHG emissions of 93% from 2005 levels may be achievable by 2050. Net-zero greenhouse gas emissions would not occur until the 2070s, at the earliest assuming that there are slow reductions in the non-CO_2 emissions from hard to abate sectors.

Achievement of net-zero GHG emissions needs a significant increase in the storage of carbon in Australia in the land sector.

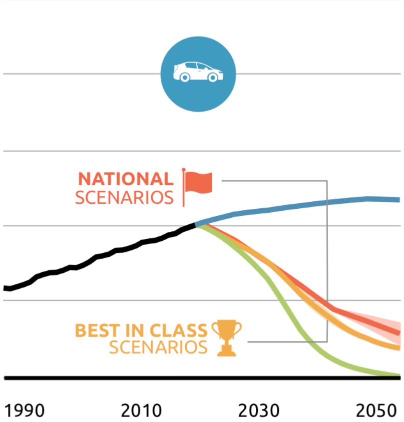
SCALING UP CLIMATE ACTION IN AUSTRALIA
POTENTIAL EMISSIONS REDUCTIONS IN FOCUS AREAS BY 2050

ELECTRICITY SUPPLY



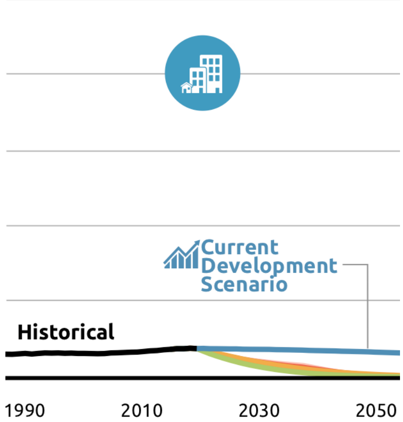
- Policy continuity and targets to support accelerated uptake of renewable energy.
- Phase out coal from power generation by 2030, with a strategy to ensure a just transition from coal mining and electricity generation.
- Grid infrastructure investment and energy market reforms to support uptake of demand management and storage at all scales (household to industrial).

TRANSPORT



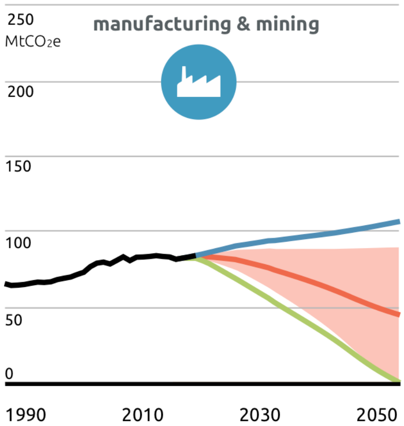
- Set ambitious greenhouse gas emission standards (at least as ambitious as the EU) both for passenger and heavy transport.
- Announce ban on sales of internal combustion cars and LDVs by 2035.
- Programmes to transition the truck fleet to renewable energy sources.
- Concerted initiatives with industry to decarbonise aviation and maritime shipping and develop market for carbon free fuels including bio jet fuel, and P2L technologies.

BUILDINGS



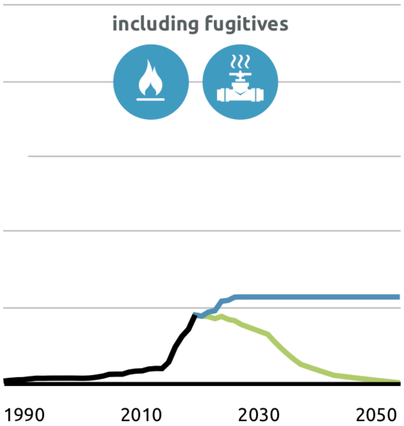
- Commit to national zero carbon ready building code and ensure compliance.
- Progressive requirements and incentives for buildings to include renewables and storage with EV re-charging capabilities.
- Increase awareness and information about energy efficiency benefits, ensure transparency through disclosure schemes, and introduce incentives.
- Energy rating requirements on property transfer and sale.
- Ban fossil fuels for heating from 2030 onwards.

INDUSTRY



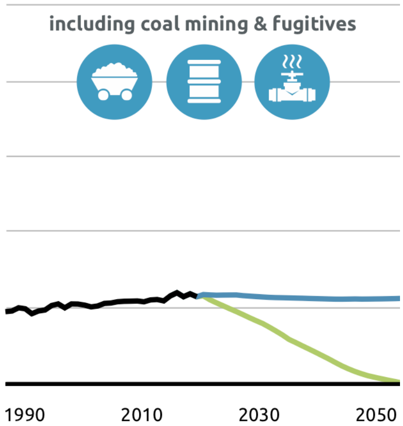
- Replace the ineffective safeguard mechanism with an effective carbon pricing system
- Implement best practice policies such as incentives for Energy management, mandatory energy audits.
- Programmes and incentives for zero carbon mining and metal production
- Establish a defined Paris-compatible decarbonisation pathway and strategy, and targeted sectoral R&D
- Hydrogen strategy needs to focus on renewable hydrogen

LNG



- Carbon pricing or regulation to ensure electrification and phasing in of renewable energy.
- Mandatory capture and storage of reservoir CO_2.
- Mandatory reduction targets and independent MRV for fugitive emissions
- Approval process for LNG projects takes into account consistency with a global Paris Agreement pathway.
- Development of transition strategy for LNG industry to renewable hydrogen
- Develop new markets for green hydrogen for a transition away from exporting LNG.

OTHER FOSSIL FUELS



- Effective carbon pricing system
- Regulation to ensure electrification and phasing in of renewable energy.
- Monitoring and regulation for mitigation measures to reduce fugitive emissions.
- Work towards international Agreement for a moratorium for new fossil fuel extraction projects.
- Federal support for a planned regional just transition process with participation of all relevant stakeholders for regions affected by transition.

Figure 9: Overview of emissions levels under different scenarios for different sectors, and policy recommendations.

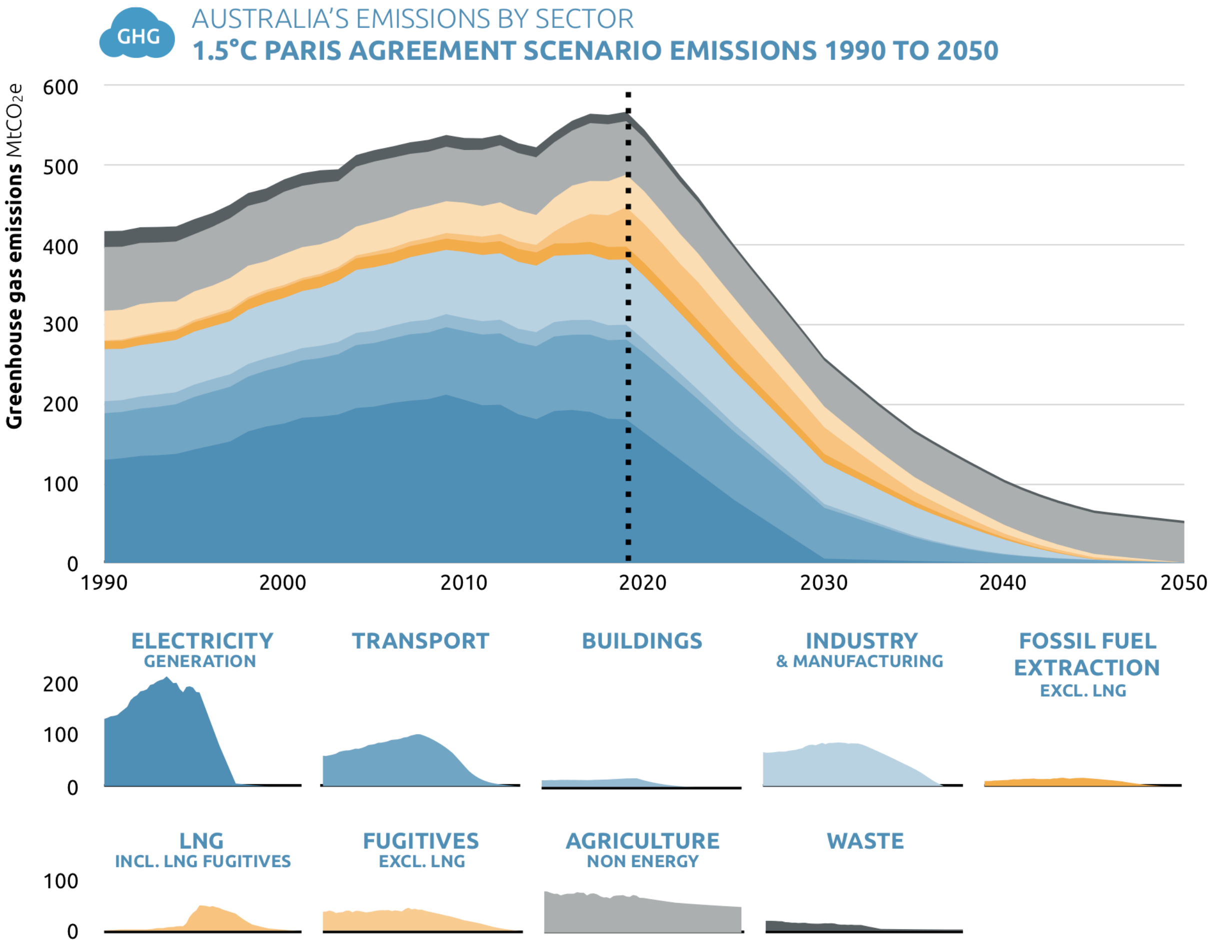


Figure 10 Australia's Paris Agreement-compatible greenhouse gas emissions pathway (not including LULUCF) for all of the sectors analysed in this study.

Net zero GHG emissions by 2050 can be achieved by phasing out deforestation by 2030 and maintaining the rate of carbon storage projected for forests by 2030 until 2050 (Figure 11). This would reduce total GHG emissions including LULUCF by 66% below 2005 (Table 3).

Factoring out the non-CO_2 emissions from the land use change and forestry sector, this would have Australia's net-CO_2 emissions reach zero by about 2038, with net negative CO_2 emissions prevailing thereafter (see Figure 12 for land use scenarios). If the rate of carbon storage projected for forests by 2030 can be doubled by 2040 net-CO_2 emissions would reach zero a few years earlier by about 2035, and net zero GHG emissions would be achieved about ten years earlier in 2040 compared to 2050 in the case where the rate of carbon storage projected for forests is maintained at 2030 levels.

The analysis here does not assume offsets between land sector carbon sequestration and greenhouse gas emissions from any other sector. This study also takes into account limits to how much we can rely on increasing carbon removal, as well as inertia in the land sector that limits the available update by 2030, and important trade-offs between a focus on carbon uptake and biodiversity and water values. Policies that focus on carbon storage alone do not generate significant benefits for biodiversity, and policies that favour environment and biodiversity values will result in lower levels of carbon storage. There is a significant trade-off between a focus on carbon uptake and water values, with a high focus on carbon reducing available water significantly.

Building on its extraordinary renewable energy resources as well as essential mineral resources and high skills, Australia can become a regional and international frontrunner in successfully transitioning its energy supply and demand sectors. This will benefit sustainable employment generation, reduce levels of dangerous air pollution, water demand, socially just housing, and new manufacturing value chains and export opportunities based on zero emissions energy carriers including renewable electricity offshore, green hydrogen and energy intensive products such as green steel.

Our findings emphasise that Australia will need to undertake additional mitigation actions in all other remaining non-energy sectors, in particular agriculture and waste, as well as decrease deforestation and sustain a carbon sink in the land use sector to align its economy-wide emissions pathway with the Paris Agreement's temperature limit and achieve net zero emissions by 2050.

A strategy towards net zero emissions needs to take into account the different starting points, trends and mitigation potential in different sectors (Table 3). Some sectors such as agriculture cannot reduce emissions to zero, and others, such as electricity generation, can be rapidly decarbonised. All energy-related emissions can be reduced to zero by 2050, thus minimising the need to rely on carbon dioxide removal of remaining emissions.

The path to get to net zero emissions matters both in terms of the cumulative emissions and their impact on temperature, as well as in terms of the technical and economic transition pathways and policy implications for the near future. This is why targets for 2030 matter: unless governments have believable pathways backed by policies to reduce emission levels, and energy transformations consistent with achieving zero emissions by 2030, then 2050 promises of net zero emissions lack any real credibility.

Sectoral strategies and policies, such as those outlined above, need to be embedded in an overall strategy, ideally with climate legislation to ensure a transparent and effective process to reach consistent overall and sectoral midterm targets.

In summary analysis shows that Australia can reduce overall GHG emissions excluding LULUCF by 90% below 2005 levels by 2050 that net-zero GHG emissions including LULUCF can be achieved in 2050 provided the LULUCF sector is a sink of -53 $MtCO_2e$ or greater by 2050 (Figure 11) or if other carbon dioxide removal options not analysed in this study are introduced.

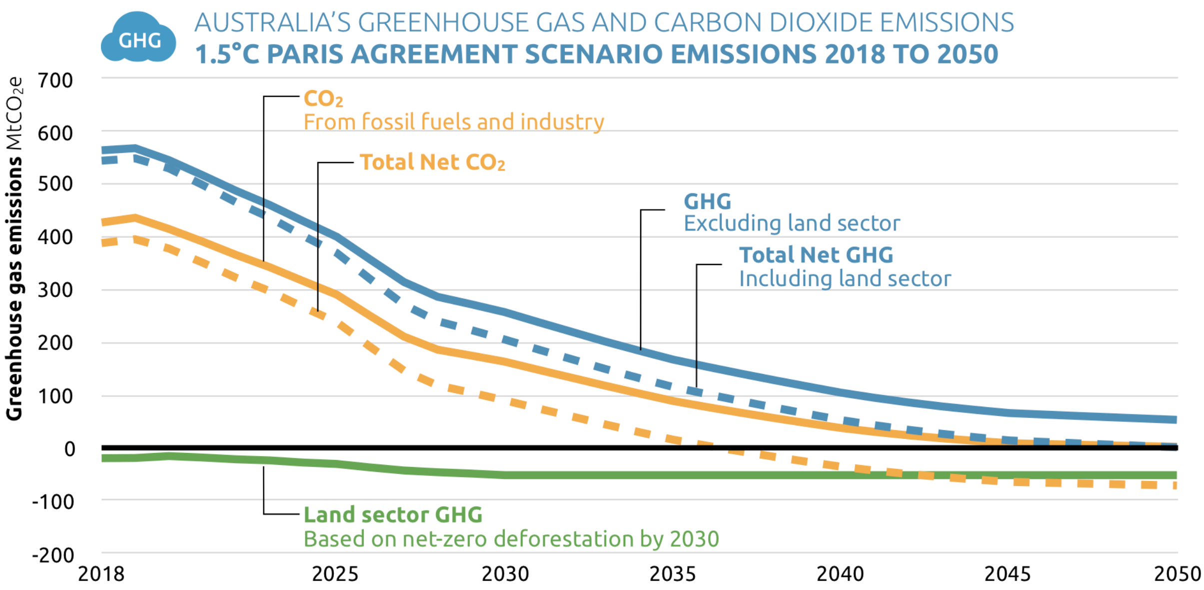


Figure 11 Net greenhouse gas and CO_2 emissions pathway for Australia to reach net zero by 2050.

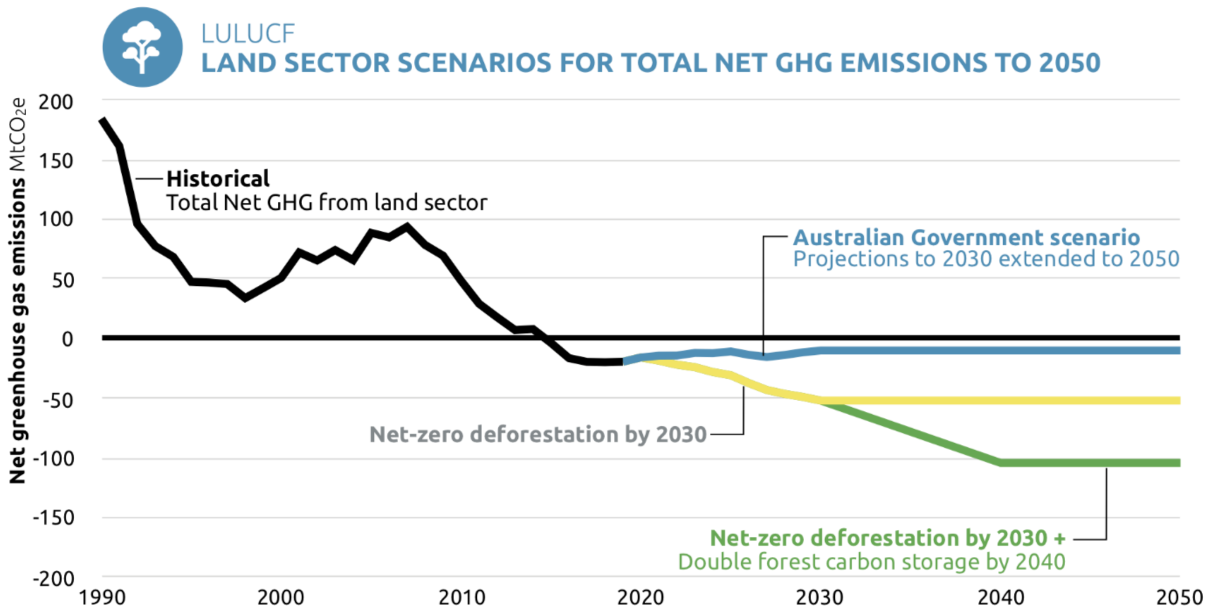


Figure 12 Land use emissions and removals scenarios used in this study.

Carbon budgets and cumulative emissions

Australia's cumulative CO_2 and GHG emissions from this study fit within a range of different perspectives on the carbon and greenhouse gas budgets consistent with limiting warming to 1.5°C. Carbon budgets for warming limits have a very large uncertainty and because of the need for negative CO_2 emissions[1] can be confusing and hard to interpret.

Carbon budgets are subject to very large uncertainties, including first and foremost from non-CO_2 GHG gases. In addition, this kind of budget obscure some key features of the technically and economically feasible pathways of energy system transformation that could meet the 1.5°C warming limit in practice. The CO_2 emissions from 1.5°C compatible scenarios can exceed the carbon budgets identified in IPCC SR1.5 above by 2050, and any excess will have to be compensated for by negative CO_2 emissions post 2050. Part of the reason for this is due to historically high emissions which need to be compensated with negative CO_2 emissions. In addition, ongoing non-CO_2 GHG emissions from hard to abate sectors including agriculture also need to be compensated, so there will likely be a need for negative CO_2 emissions for this purpose.

Two broad perspectives are used here as a cross check on Australia's cumulative emissions.

The IPCC SR1.5 has estimated the remaining carbon budget from 2018 to limit warming, after accounting for an estimated 100 $GtCO_2$ of carbon release from geophysical feedbacks, to below 1.5 °C with 50% chance to be 480 $GtCO_2$ and 320 $GtCO_2$ with a 67% probability (IPCC 2018a). If Australia's share of this were equivalent to its current contribution to global CO_2 emissions of 0.9%[2] its budget would be 2.9-4.3 $GtCO_2$. As this budget corresponds to the time at which 1.5°C is reached this correspond to the period 2018-2050 and can be compared with the cumulative Australian total CO_2 emissions from this study of around 2.8 $GtCO_2$ for the same period. It should be noted that the cumulative fossil fuel and industry CO_2 emissions from this study until 2050 are around 5 $GtCO_2$.

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1 To achieve zero emissions there is a need to compensate for remaining emissions using carbon dioxide removal options (CDR), including either large-scale afforestation and reforestation, bioenergy with carbon capture and storage (BECCS) or other options such as direct air capture (DAC). In our analysis, we have not analysed the deployment options for carbon dioxide removal, via BECCS or DAC. We have focused on analyses of options for emission reductions across all sectors with the aim to minimise the reliance on CDR options in the period to 2050. This will also have the benefit of minimising, but not eliminating, the need for CDR options post 2050, a timeframe not considered in this report

2 A broader range of share of global budgets in the literature are explored in the main report.

Whilst on the surface the cumulative Australian CO_2 emissions would appear to be consistent with the 1.5°C carbon budget above the picture is more complex due to the ongoing emissions of non-CO_2 GHGs, and the related need for negative CO_2 emissions.

Another way to derive an appropriate greenhouse gas and carbon budget for Australia is to look at the cumulative GHG and CO_2 emissions from 1.5°C compatible scenarios using integrated assessment models (IAM) assessed in the IPCC SR1.5. The full range of emissions including air pollutants are assessed using reduced complexity climate models to produce probabilistic assessment of the global warming consequences to evaluate how these pathways meet the climate goals. This is the way the IPCC SR1.5 evaluated these pathways for 1.5°C compatibility.

The total cumulative global CO_2 budget for limiting warming to 1.5°C based on the integrated assessment model (IAM) scenarios assessed in the IPCC SR1.5 is about 200 $GtCO_2$ for the entire century, and for the period to 2018-2050 about 560 $GtCO_2$. If Australia's share of this were equivalent to its current contribution to global CO_2 emissions of 0.9% its budget would be around 5 $GtCO_2$ to 2050 and about 1.8 $GtCO_2$ for the full century (2018-2100), implying a need for negative CO_2 emissions at scale to compensate post 2050. The cumulative Australian CO_2 emissions from this study from 2018-2050 are around 2.8 $GtCO_2$, which implies a need for ongoing negative CO_2 emissions post 2050.

Looking at fossil fuel and industry CO_2 emissions, the CO_2 budget for limiting warming to 1.5°C based on IAM scenarios assessed in the IPCC SR1.5 is about 350 $GtCO_2$ for the entire century, and for the period to 2018-2050 about 540 $GtCO_2$. This is quite close to the total CO_2 budget above for 2018-2050 as these scenarios generally assume the land sector is close to balance in this period as deforestation is reduced and carbon storage on land is ramped up. Post 2050 these budgets diverge as carbon storage on land increases (negative CO_2 emissions) so that the total negative emissions are around 360 $GtCO_2$ with about 190 $GtCO_2$ from measures to take CO_2 from the atmosphere using the energy system, and the remainder in the land sector.

If Australia's share of the fossil fuel and industry CO_2 emissions budget were equivalent to its current contribution to global CO_2 emissions its budget would be around 4.9 $GtCO_2$ to 2050 and about 3.2 $GtCO_2$ for the full century (2018-2100), also implying a need for negative CO_2 emissions at scale post 2050. The cumulative Australian fossil fuel and industry CO_2 emissions from this study until 2050 are around 5 $GtCO_2$, implying a need to be negative CO_2 emissions of order to 2$GtCO_2$ post 2050 to compensate for high historical emissions and for remaining emissions that cannot be reduced to zero.

Finally, the total global GHG budget for limiting warming to 1.5°C based on IAM scenarios assessed in the IPCC SR1.5 is about 830 $GtCO_2$ for the entire century, and for the period to 2018-2050 about 860 $GtCO_2e$. If Australia's share of this were equivalent its current contribution to global CO_2 emissions its budget would be around 7.7 $GtCO_2e$ to 2050 and about 7.5 $GtCO_2e$ for the full century (2018-2100). Australia's cumulative GHG emissions from this study from 2018-2050 are around 6.4 $GtCO_2e$ (7.8 $GtCO_2e$ before counting land sector carbon storage estimated here at 1.5 $GtCO_2e$). See Table 2 for an overview of these results.

This analysis shows that in general the 1.5°C compatible pathways assessed in the IPCC SR1.5 rely significantly on negative CO_2 emissions to limit warming to 1.5°C or below. The amount of negative emissions ultimately required is linked to near-term emission reduction actions. Higher emissions than should otherwise be the case entail obligations for the future deployment of negative emissions to compensate. The amount of land sector carbon storage assumed in some studies is high and may be infeasible or can raise concerns from a sustainability perspective. Similarly the scale of technologically based negative CO_2 emissions is also large.

What this means for policy is that all efforts need to be taken to minimise the need for negative CO_2 emissions, and this means reducing the cumulative emissions by 2050 as much as possible. Apart from economic costs this is another reason why the substantial emission reductions by 2030 are critical, and hence why the pathway to zero emissions is very important for ultimately achieving the Paris Agreement's long-term temperature goal.

Table 2 Australia's cumulative CO_2 and greenhouse gas emissions for 1.5°C scenario compared to carbon budget estimates

Australia emissions	**Scenario emissions** 2018-2050	**IAM Budget** 2018-2050	**IAM Budget** 2018-2100
Total GHG emissions GtCO₂e	6.4	7.7 [6.2–8.5]	7.5 [6.3–8.2]
Fossil fuel and industry CO_2 emissions $GtCO_2$	5.0	4.9 [4.4–5.6]	3.3 [1.7–4.7]
Total CO_2 emissions $GtCO_2$	2.8	5.0 [4.3–5.5]	1.8 [0.9–2.9]
		IPCC SR1.5 budget 2.9–4.3	

Notes: Australia's share of carbon budget assumed here is 0.9%. IAM median budgets are shown and range is [25th – 75th percentile]. The IPCC SR1.5 range is from a 67% (lower budget) to a 50% likelihood (higher carbon budget). It is located in the period to 2050 as the budget is calculate to the point at which the temperature limit is reached and CO_2 emissions reach zero at this time.

Table 3 Sectoral emissions and overall reductions in 2030, 2040, 2050 as compared to 2005 for a Paris Agreement consistent pathway as outlined in this study.

Sector	**2005 baseline** $MtCO_2e$	**2019 value** $MtCO_2e$	**2030 reduction** compared to 2005 baseline	**2040 reduction** compared to 2005 baseline	**2050 reduction** compared to 2005 baseline
Electricity generation	197	180	-97%	-100%	-100%
Buildings	15	19	-69%	-94%	-100%
Transport	80	100	-20%	-87%	-100%
Manufacturing and mining Industry	80	82	-35%	-78%	-100%
Agriculture (non-energy)	76	67	-24%	-30%	-35%
Waste (non-energy)	14	12	-73%	-77%	-78%
Coal mining, Petroleum refining, Oil and Gas extraction (excluding LNG)	15	16	-28%	-84%	-100%
LNG (including fugitive emissions)	4	50	+664%	+14%	-100%
Fugitives from coal, oil and domestic gas	38	41	-31%	-71%	-100%
Total excluding LULUCF	**520**	**567**	**258 (-50%)**	**105 (-80%)**	**53 (-93%)**
LULUCF	**90**	**-19**	**-53**	**-53**	**-53**
Total including LULUCF	**608**	**549**	**105 (-66%)**	**53 (-91%)**	**0 (-100%)**

Note: Totals may not add due to rounding errors

The status of sectoral transitions: opportunities for accelerating climate action

The transitions towards zero-emissions in Australia across sectors have shown very little progress, with the notable exception of electricity generation from renewable energy – despite the attempts by the federal government to stop it.

Progress in the electricity sector was driven by the renewable energy target, which effectively expires in 2020 and will not be replaced. Recent data from the Reserve Bank of Australia that there is a decline in investment in the sector (De Atholia, Flannigan, & Lai, 2020). Australia is lagging behind despite its large opportunities.

Below is an overview of this study's evaluation across all sectors compared with sector-specific benchmarks. These benchmarks represent the most important short-term steps for limiting global warming to 1.5°C identified by the Climate Action Tracker (Kuramochi et al., 2018), as well as more recent analysis of 1.5°C benchmarks based on the scenarios assessed by the IPCC in its Special Report on 1.5°C (Yanguas Parra et al., 2019).

Table 4: Policy Gap Analysis: Sectoral policy activity and gap analysis in Australia across the three largest ghg emitting sectors, electricity, transport and Industry. The 1.5°C compatible benchmarks relate to most important short-term steps for limiting global warming to 1.5°C identified by the Climate Action Tracker (Kuramochi et al., 2018) as well as recent analysis of benchmarks based on IPCC SR 1.5 (Yanguas Parra et al., 2019).

Sector	1.5 °C-consistent benchmark	Australia specific 1.5 °C benchmark	Overall evaluation based on policy activity and gap analysis	Policy rating
Electricity supply sector	*Sustain the global average growth of renewables and other zero and low-carbon power until 2025 to reach 100% by 2050*	*100% renewable electricity generation achieved by 2030s*	• Australia is not on track to meet the benchmark, with government projections indicating renewables will represent just 50% of electricity generation by 2030 if state targets are met. • Australia does not have a renewable energy target beyond 2020. The 2020 target was met, and there has been no new target set (CER, 2019a). • Investment in renewable energy has decreased since 2018 (Clean Energy Council, 2020b). Policy uncertainty and lack of long-term planning of transmission grids is leading to curtailment and delays in grid connections for large scale projects. • Government funding for the national renewable energy agency (ARENA) has decreased and funding is soon to be exhausted (Mazengarb, 2020a). • The government has indicated ARENA's funding will likely continue, but also intends to alter ARENA and the Clean Energy Finance Corporation's (CEFC) remit to be 'technology neutral' and could include coal and gas with carbon capture and storage forcing renewable projects to compete with fossil fuel interests (Mazengarb, 2020d). • Out of the eight states and mainland territories in Australia, six have committed to renewable energy targets and some states have committed to ambitious 100% renewable energy targets. Tasmania plans for 200% renewables.	

Sector	1.5 °C-consistent benchmark	Australia specific 1.5 °C benchmark	Overall evaluation based on policy activity and gap analysis	Policy rating
	No new coal plants, reduce emissions from coal power by at least 30% by 2025	*Phase out coal by 2030*	• There is no plan to phase out coal, which will continue to represent the largest share of electricity generation to 2030 (DEE, 2019a). • The Paris Agreement benchmark of phasing out coal by 2030 would imply an earlier retirement of the fleet of coal fired power stations. • The government has encouraged utilities to extend the lifespan of coal fired power generation beyond the shutdown dates scheduled (Taylor, 2019), generating further investment uncertainty for renewables. • The government continues to incentivise fossil fuel electricity generation, offering incentives through a power subsidy ("Underwriting New Generation Investments") scheme, where a coal generation upgrade has been shortlisted and is likely to be funded (DEE, 2019n; Sydney Morning Herald., 2019a) with additional funding for a feasibility study into a new coal-fired power plant that would require government subsidies. • The Federal Government and New South Wales state government made a deal to supply coal to a coal power station to operate to at least 2042 (RenewEconomy, 2020b).	No Action
Transport sector	*Last fossil fuel car sold before 2035*		• There are no targets to end the sales of fossil fuel cars. The government has announced the development an electric vehicle strategy, but this has not been published (Australian Government, 2019a). • Australia is one of the few countries in the world without any emissions or fuel efficiency standards for light duty vehicles, and the current government has not indicated any intention to introduce these, despite five years of deliberations in the Ministerial Forum on Vehicle Emissions (MFVE). • The current piecemeal policies are ineffective. Recent auctions for the Emissions Reduction Fund have not seen projects in the transport sector. The Safeguard Mechanism only applies to a small portion of transport emissions.	No Action
	Freight trucks need to be almost fully decarbonised by approximately 2050		• Despite the projected increase in road freight transportation emissions (DEE, 2019a), there is an absence of plans to decarbonise freight trucks in Australia. • Unlike the EU, Canada, USA and Japan, Australia has no emissions or fuel efficiency standards for heavy duty vehicles (Climate Analytics, 2019e). • The National Hydrogen Strategy could be used to decarbonise heavy long-range road transport, (plus rail and shipping) if the hydrogen is derived from renewable energy. As the strategy takes a 'technology neutral' approach, this may not be the case.	No Action

Sector	1.5 °C-consistent benchmark	Australia specific 1.5 °C benchmark	Overall evaluation based on policy activity and gap analysis	Policy rating
	Aviation and shipping: Develop and agree on a 1.5°C compatible vision		• Government projections indicate aviation and shipping emissions will increase (DEE, 2019a). • There is no 1.5°C compatible vision or emissions reduction policy for domestic aviation and shipping. • Commitments for reducing emissions of aviation and shipping are limited to international transport through the Carbon Offsetting and Reduction Scheme for International Aviation and as a member of the UN International Maritime Organisation (DFAT, 2019).	
Industry sector	*All new installations in emissions-intensive sectors are low-carbon after 2020, maximise material efficiency*		• The industry sector does not prioritise decarbonisation. Australia's long-term plan to decarbonise the industry sector was abolished with the "carbon tax." • Policies do not ensure low carbon installations nor maximise material efficiency. • Government figures show a decline in emissions in the subsectors of industrial processes, direct combustion and fugitives, despite increases in the past year (DEE, 2019a). • Industrial processes emissions are projected to decline as a consequence of the phase down of hydrofluorocarbons (DEE, 2019a). • Fugitive emissions are projected to decrease (DEE, 2019a), but government figures rely on the Gorgon CCS project to meet its emissions obligations. • There are only a few industry projects in the Emission Reduction Fund portfolio. • ERF and Safeguard Mechanism achieve marginal amounts of emissions abatements (Reputex 2019a). Yet the ERF has been supported with a financial top-up, and renamed the Climate Solutions Fund (CSF). • The federal government takes an increasingly "technology neutral" approach to industry policy without linking it to climate targets in line with the Paris Agreement: - Appointing a Covid-Commission with gas industry stakeholders, which produced recommendations for a gas-led economic recovery (Parkinson, 2020). - Appointing an expert panel with fossil fuel stakeholders to review the ERF/CSF (Australian Government, 2020a, 2020b). - The government intends to change the remit of the CEFC, ARENA and the ERF to take a "technology neutral" approach, and wants to support CCS but not renewable energy (Australian Government, 2020a, 2020b).(Australian Government, 2020c). - The National Hydrogen Strategy is at risk of supporting the fossil fuel industry, as it follows a technology neutral approach. • The National Energy Productivity Plan (NEPP) is not effective, impact policies have not been implemented (Climate Analytics, 2018a). • Australia's LNG related emissions have soared in recent years with large-scale expansion plans.	

Co-benefits of upscaled climate action: employment

Accelerated climate action in Australia can generate significant employment benefits and needs to be a focus for a green recovery out of the economic crisis due to the COVID-19 pandemic.

This study's quantification of employment impacts indicates that the scenario heavily relying on renewable capacity additions supports substantially more jobs compared to the Current Development Scenario driven by the investments into renewable energy and storage technology. Moreover, assuming efforts to increase Australian manufacturing of solar and wind and local sourcing of all related services further increases job prospects considerably.

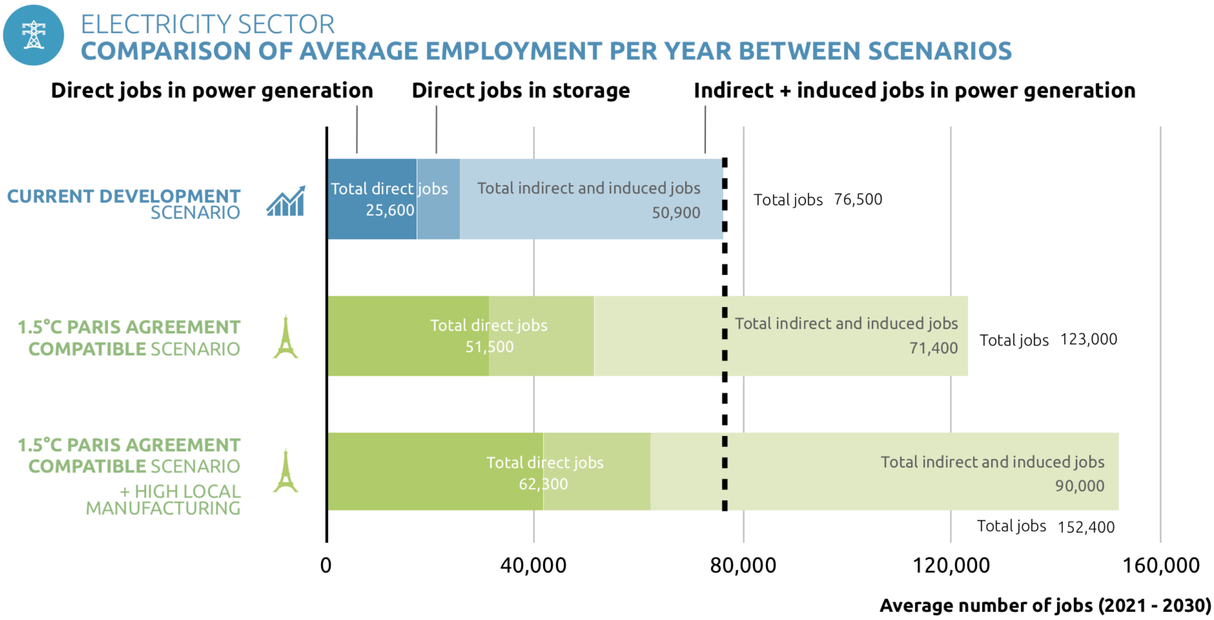


Figure 13: Average direct employment per year between 2021–2030 and average total employment per year between 2021–2030 in Australia for different electricity generation scenarios. Employment impacts related to power generation are estimated with the Economic Impact Model for Electricity Supply (EIM-ES)[3]. Direct jobs related to storage have been approximated based on employment factors from the literature (Ram, Aghahosseini, & Breyer, 2020; Rutovitz, Briggs, Dominish, & Nagrath, 2020) *using approximated storage capacity needs. No indirect jobs related to storage have been estimated. Due to a thinner existing empirical basis regarding storage, the presented numbers for storage are only indicative. Direct jobs include jobs in manufacturing, construction and installation and operation and maintenance. Indirect jobs are jobs further down the supply chain and induced jobs are created by spending of wages throughout the economy. A scenario variant of the Paris Agreement scenario has been added to demonstrate the relevance of local sourcing for local jobs. This PA variant is based on the same emissions pathway and technology mix as the Paris Agreement-compatible Scenario, but it assumes higher shares for local manufacturing of technology components and services being provided within Australia for wind and solar. More information can be found in the methodological annex.*

Under the Current Development Scenario (CDS), approximately 17,000 people per year, on average, are directly employed in the development of new capacity for power generation and the operation and maintenance (O&M) of total capacity (existing and new capacity) over the period between 2021 and 2030. We estimate the investments would stimulate a further 51,000 indirect and induced jobs per year, on average. In addition, over 8,000 jobs related to batteries (distributed and utility scale) and pumped hydro storage (PHS) could be expected in the CDS.

The 1.5°C Paris Agreement-compatible scenarios with accelerated transition to renewable energy have higher employment benefits. Applying the same assumptions on local shares as the CDS scenario supports about 46,000 more jobs compared to the CDS (on average between 2021 and 2030), including about 31,000 direct jobs and 71,000 further indirect and induced jobs in electricity generation stimulated by investments through the supply chain as well as induced economic impacts driven by the spending of wages throughout the economy.

[3] The general EIM-ES tool including a documentation of the tool is available here https://newclimate.org/2018/11/30/eim-es-economic-impact-model-for-electricity-supply/.

The higher storage needs due to the higher share in renewable energy could more than double the number of direct jobs related to storage, mostly batteries (approximately 20,000 jobs per year on average). A variant of the Paris Agreement-compatible scenario, which assumes higher local shares for wind and solar, indicates that efforts to increase Australian manufacturing and local sourcing of services could double total estimated jobs compared to the Current Development Scenario, supporting about 75,000 more jobs, with about 62,000 direct (including storage jobs) and 90,000 indirect and induced jobs.

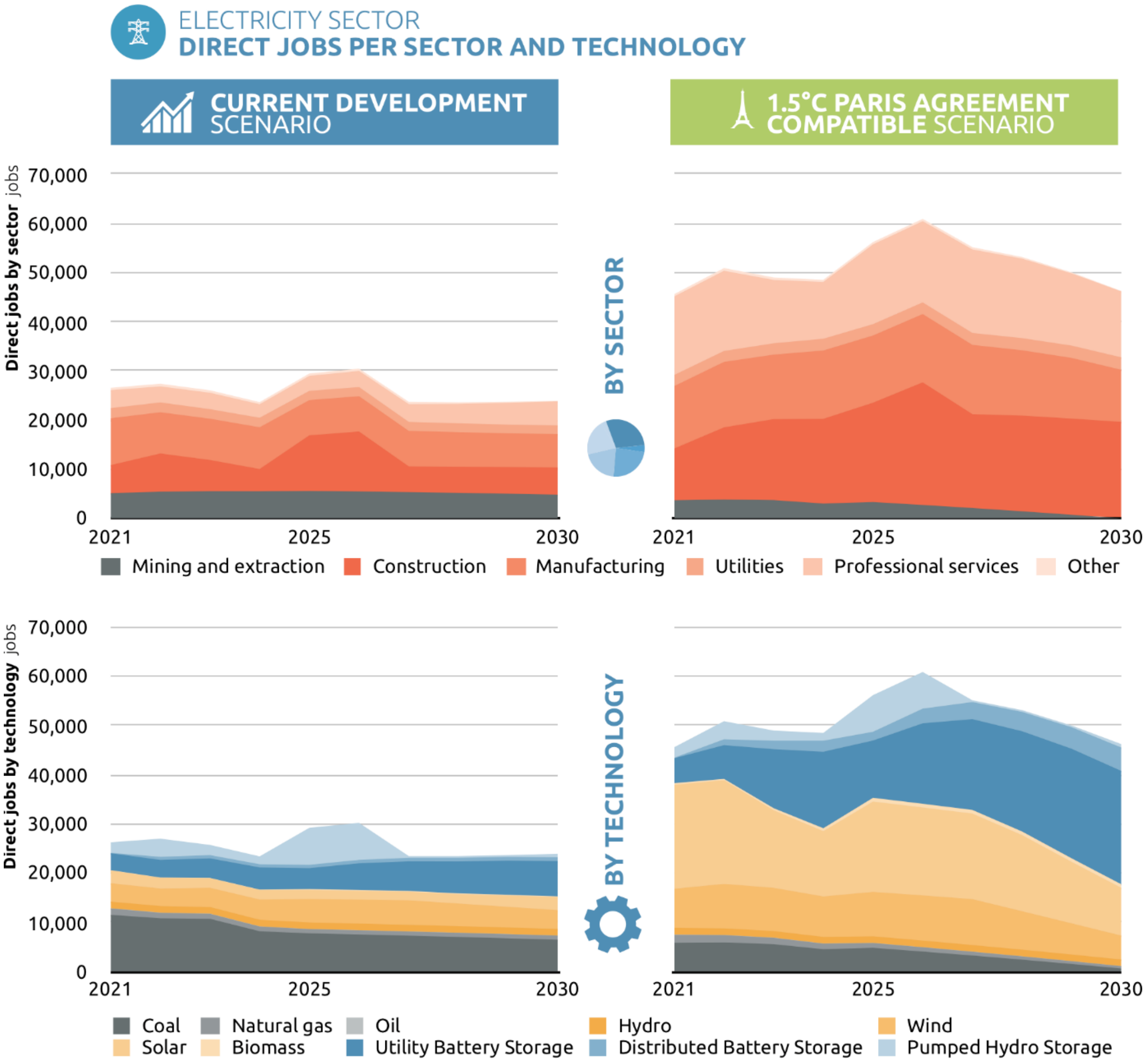


Figure 14: Direct jobs per employment sector' and 'Direct jobs per generation technology' between 2021-2030 for the Current Development Scenario (CDS) (graphs on left) and the 1.5°C Paris Agreement compatible scenario (same assumptions on local shares, graphs on right) for the Australian electricity supply sector Direct employment estimates reflect energy supply sector investments linked to planning, construction, manufacturing of component parts, operation (including fuel supply such as oil and gas production, where relevant) and maintenance of power plants. Note employment impacts for mining and extraction only relate to the fuels used in the Australian electricity supply sector and do not include jobs supported to supply other sectors or the export market. Employment impacts related to power generation are estimated with the Economic Impact Model for Electricity Supply (EIM-ES)[4], jobs related to storage are approximated based on employment factors from the literature (Ram et al., 2020; Rutovitz et al., 2020), *both based on Input from AUSMOSYS (see methodological annex). Note that the optimization period in AUSMOSYS starts in 2017 with the model suggesting that it would have been optimal to install substantial capacities for wind and solar already in the years before 2021 not shown in this figure, which have however not been installed to this extent in reality. As a consequence, the job impact especially for the Paris Agreement compatible pathway can be considered to even underestimate the job potential in renewable energy for the period shown.*

[4] The general EIM-ES tool including a documentation of the tool is available here https://newclimate.org/2018/11/30/eim-es-economic-impact-model-for-electricity-supply/.

Employment in electricity supply sector scenarios with accelerated renewables deployment is focused on the construction and manufacturing sectors and increasingly in the development and operation of renewable energy sources, notably solar PV and onshore wind as well as related storage capacities.

These jobs are in technologies and sectors that are more likely to form the core of future electricity supply, both in Australia and globally. Fossil fuel-based jobs do not have a promising future in any of the scenarios. In contrast, jobs related to energy storage could potentially provide large and long-term job opportunities.

In the 1.5°C Paris Agreement-compatible scenario, the mining and extraction sector (for local use) accounts for only about 8% of jobs in 2021 and no more jobs in 2030 (see Figure 14, right hand side). Instead, employment opportunities are focused in the construction and manufacturing sectors and increasingly in the development and operation of renewable energy sources, notably, solar PV, onshore wind and hydropower.

The higher number of jobs supported in the construction and manufacturing sectors in the 1.5°C Paris Agreement-compatible scenario by far outweighs the reduction in employment opportunities in the extraction sector, compared to the Current Development Scenario.

The Paris Agreement-compatible scenario assuming higher local shares stimulates the highest local investments in Australia and also supports the highest number of jobs per unit of investment. Both Paris Agreement Scenarios support more jobs per unit of local investment compared to the Current Development Scenario, with the PA scenario with higher local shares showing higher jobs per local investment than the PA scenario with lower local shares.

These findings emphasise how accelerating climate action in the electricity generation sector has the potential to support higher overall employment. They also highlight the need for Australia to prepare a just transition - not only in the electricity sector but across all sectors, to be prepared with skills and jobs for new export opportunities based on the abundant potential for clean energy.

A well-managed transition should start now by reducing the incentives to expand the natural gas sector and building on and increasing opportunities to develop skills in future-proof technologies.

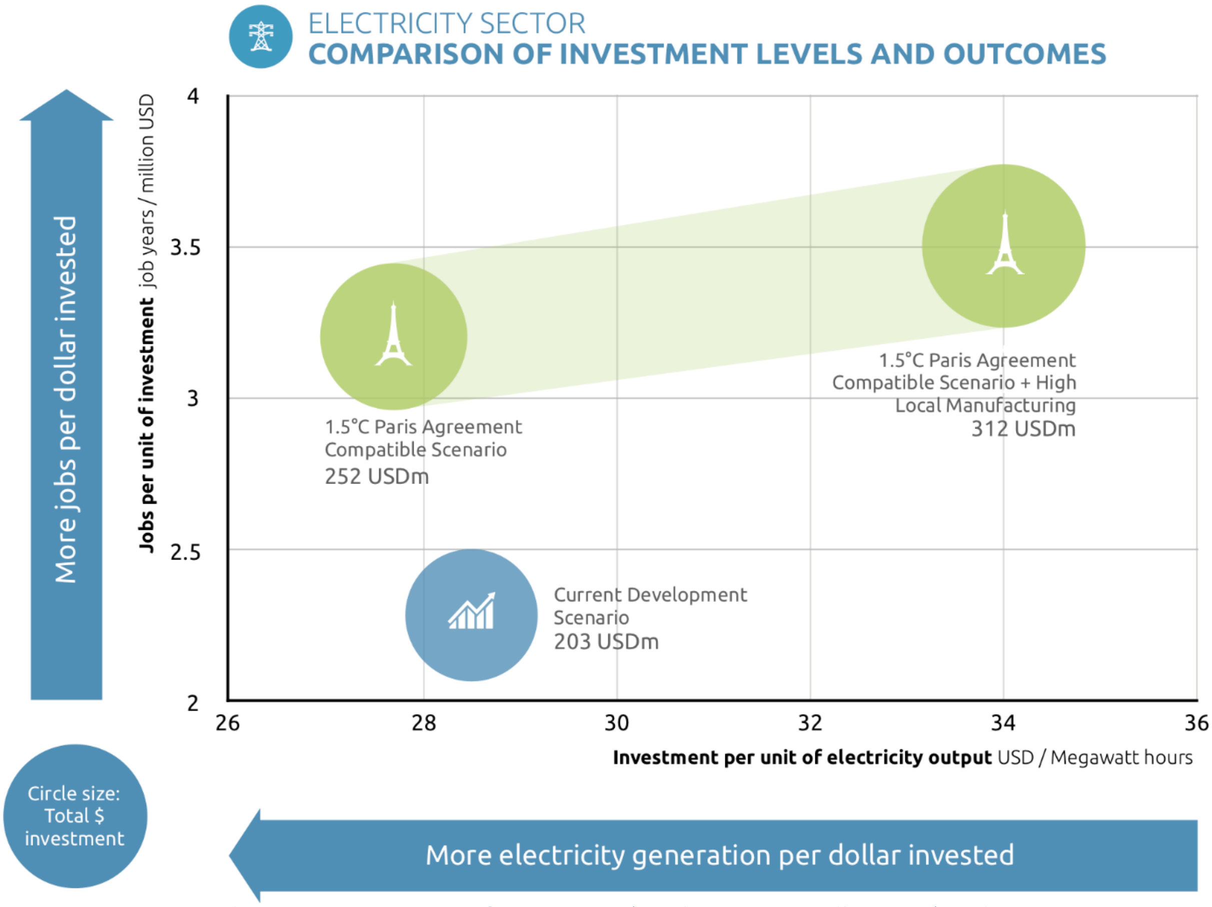


Figure 15: Average job generation per unit of investment (in job years per million USD) and average investment per unit of electricity generation (in USD per MWh) in the Australian electricity supply sector for selected electricity generation scenarios between 2021–2030. Note the figures reported here relate exclusively to investments in Australia and do not reflect the overall cost of scenarios, which also include investments on imported products and services.

Abbreviations

AEMO	Australian Energy Market Operator
AFOLU	Agriculture, Forestry and Other Land Use
ARENA	Australian Renewable Energy Agency
B2DS	Beyond 2 ℃ Scenario
BECCS	Bioenergy with Carbon Capture and Storage
BEV	Battery Electric Vehicles
BZE	Beyond Zero Emissions
CAT	Climate Action Tracker
CCS	Carbon Capture and Storage
CEFC	Clean Energy Finance Corporation
CER	Clean Energy Regulator
CSF	Climate Solutions Fund
CSIRO	Commonwealth Scientific and Industrial Research Organization
DEE	Department of the Environment and Energy of Australia
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EIM-ES	Economic Impact Model for Electricity Supply
EPBD	Energy Performance of Buildings Directive
ERF	Emissions Reduction Fund
ETP	Energy Technology Perspective
EV	Electric Vehicles
F-gases	Fluorinated Gases
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GPG	Gas Powered Generator
GWP	Global Warming Potential
ICCT	International Council on Clean Transport
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	Fifth Assessment Report by the IPCC
IPCC SR 1.5	IPCC’s Special Report on Global Warming of 1.5 ℃
IRENA	International Renewable Energy Agency
ISP	Integrated System Plan
kfW	Kreditanstalt fuer Wiederaufbau
LCOE	Levelized Cost of Electricity
LED	Light-emitting diode
LNG	Liquified Natural Gas
LPG	Liquefied Petroleum Gas
LULUCF	Land Use, Land-Use Change and Forestry
MEPS	Minimum Energy Performance Standards
NDC	Nationally Determined Contribution
NEM	National Electricity Market
OECD	Organization for Economic Cooperation and Development
OSeMOSYS	Open Source Energy Modelling System
PHEV	Plug-in Hybrid Electric Vehicles
PtG	Power to Gas
PtL	Power to Liquid
PV	Photovoltaic
RD&D	Research Development and Demonstration
RES	Renewable Energy Source
RES-E	Renewable Electricity
RET	Renewable Energy Target
SIAMESE	Simplified Integrated Assessment Model with Energy System Emulator

Contents

Introduction

Background and objectives

Under the Paris Agreement, governments have committed to holding temperature increase well below 2°C above pre-industrial levels and to pursue efforts to limit this to 1.5°C. Current efforts globally are by far insufficient: aggregate mitigation targets, according to Climate Action Tracker (CAT) estimates, result in global warming of about 2.8°C. Implementation of the targets is falling short, with greenhouse gas (GHG) emissions under implemented policies leading to an estimated warming of around 3°C (CAT, 2019b).

To stay below the globally agreed limit, the IPCC Special Report on 1.5℃ finds that an increase in effort is required to peak global GHG emissions as soon as possible, reduce all greenhouse gas emissions, including CO_2 emissions to 45% below 2010 levels by 2030 and to net-zero around 2050 for CO_2 emissions and total GHG emissions around 2070 (Intergovernmental Panel on Climate Change (IPCC), 2018; Schaeffer, Hutfilter, Brecha, Fyson, & Hare, 2019).

This Paris Agreement 1.5°C limit is of critical importance for Australia: A continent that is exposed to climate change impacts like sea level rise, coral reef loss, and extreme weather events. All of these effects can already be observed today and will be much worse in a 2°C world, compared to a 1.5°C (IPCC, 2018b; Schleussner, Pfleiderer, & Fischer, 2017). Especially for tropical coral reefs, the difference between 1.5°C and 2°C is likely to be decisive if any reefs are to survive (Schleussner et al., 2016).

Rapidly falling technology costs, as well as increased awareness for other benefits, such as air quality improvements and employment benefits in zero and low-carbon-oriented sectors, have made measures to reduce GHG emissions more attractive to policy makers and private investors across the globe, in addition to the avoided costs from climate change impacts, and need to be in the centre of the Australian discussion on climate policy.

We no longer live in a world where climate change mitigation is a burden per se, but where it increasingly becomes the most feasible option when considering all socio-economic aspects. For cost-efficient global mitigation, it will be essential to make those mitigation actions accessible to all countries and overcome remaining barriers.

This report, the sixth country assessment in the Climate Action Tracker's Scaling Up Climate Action Series, analyses areas where Australia could accelerate its climate action. The report illustrates GHG emissions reductions from such actions, along with other benefits.

Approach

The analysis starts with an in-depth review of Australia's current policy framework and sectoral developments, comparing them with the comprehensive policy packages and the progress of the kind of sector indicators required under Paris-compatible pathways.

The report then presents a scenario analysis supporting scaling up climate action in Australia focusing on the energy sector, in particular electricity supply, as well as electrification of end use sectors, in particular buildings, transport, and industry. The analysis also focuses on further mitigation potential in the industry sector, taking into account the specific challenges of Australia's industry with the importance of the mining sector and extraction and export of fossil fuels, in particular coal and gas.

The scenario analysis looks at sectoral transformations required to be compatible with the Paris Agreement's long-term temperature goal, as well as sectoral transformations demonstrated by international frontrunners and existing national scenarios, and quantify resulting emissions reductions. With an integrated energy system approach, we account for the increasing importance of sector coupling and decarbonisation through electrification of key demand sectors.

For the quantification of sectoral and total emission trajectories and corresponding electricity demand until 2050, the Scaling Up Climate Action series uses the CAT's PROSPECTS scenario evaluation tool. We then apply the energy system model AUSeMOSYS to develop an optimal pathway for the electricity sector that meets the increasing electricity demand through (direct or indirect) electrification for all sectors and is constrained by a cumulative CO_2 emissions budget of about 1100 $MtCO_2$ over 2018-2050 consistent with the Paris Agreement long-term temperature goal (Tina Aboumahboub, Brecha, Gidden, Geiges, & Shrestha, 2020; Tino Aboumahboub, Brecha, Gidden, et al., 2020).

1 Context for scaling up climate action in Australia

While the scientific community is continuously highlighting severe risks related to climate change, and despite Australia's unprecedented bushfire crisis enveloping several states in 2019/2020, the translation into actionable targets and policies to effectively reduce emissions in Australia remains highly inadequate. Australia's emissions from energy and industry have been increasing by 1% on average each year since 2014, when the federal government repealed the carbon pricing system target (Climate Action Tracker, 2019).

The Climate Action Tracker rates Australia's nationally determined contributions target as "insufficient" and current policies as "highly insufficient". Australia ratified the Paris Agreement on 6 November 2016. In its nationally determined contributions (NDC), Australia committed to a 26–28% reduction of greenhouse gas emissions by 2030 below 2005 levels, including land use, land-use change, and forestry (LULUCF). The "insufficient" rating indicates that Australia's climate commitment is not consistent with holding warming to below 2°C, let alone limiting it to 1.5°C as required under the Paris Agreement, and is instead consistent with warming between 2°C and 3°C. The highly insufficient rating indicates that with current policies, Australia's emissions are consistent with warming between 3°C and 4°C: This implies that more ambitious climate policy across all sectors is required. Australians emit more than twice as much per person as the average person in the "Group of Twenty" (G20) in terms of greenhouse gas emissions.

Warming in Australia is projected to continue, with increasingly frequent hot days, shifting weather systems, intensifying rain events, more frequent severe droughts, more intense cyclones, harsher fire weather, sea level rise, and warmer and higher acidity of oceans (CSIRO, 2016). The IPCC Special Report on Global Warming of 1.5°C highlights the global impact of increased temperature on land and in oceans, hot extremes, heavy precipitation and drought (Masson-Delmotte et al., 2018). The report underlines the benefits of limiting warming to 1.5°C compare to 2°C. Impacts to biodiversity and ecosystems will be lower both on land and in the ocean. Limiting global warming will also reduce the risks to health, livelihoods, food security, water supply, human security and economic growth associated with climate change.

Despite the risks, the Australian government continues to prop up the fossil fuel industry and abandon efforts to reduce emissions. The government has encouraged utilities to extend the coal-fired power generation lifespan (Taylor, 2019), supports fossil fuel electricity generation, offering incentives through a power subsidy scheme, considering future support for a new coal fired power plant, and locking in coal supply to a coal fired power plant for at least two decades (Coorey, 2019; DEE, 2019n; RenewEconomy, 2020b). Australia has dismissed the findings of the IPCC Special Report, and backtracked on funding the Green Climate Fund target (Climate Action Tracker, 2019). Australia continues to subsidize fossil fuel extraction and export, despite the global need to phase out fossil fuels, and especially coal but also gas (UNEP, 2019). The government ignored the Finkel (2017) report and downgraded the Renewable Energy Target. Australia is ramping up its Liquified Natural Gas (LNG) production and aims to have 10 plants in operation producing over 80Mt of LNG annually by 2020 (DEE, 2019a). The government ignores the need to ramp up climate action and the need to ratchet up the 2030 target to close the ambition and action gap, as mandated by the Paris Agreement framework, as recalled by the latest UN climate meeting in 2019 (UNFCCC, 2020).

The government has shown no sign of scaling up climate action. The government's projections show that Australia is not on track to achieve its insufficient NDC target. Instead of scaling up action, the current government plans to carry over surplus emissions from the Kyoto Protocol to meet the abatement task of the current NDC (DEE, 2019a). The government has announced a so-called 'Climate Solutions Package' to achieve one third of the remaining abatement task, relying on adding $2 billion AUD to the Emissions Reductions Fund (renamed Climate Solutions Fund) over 15 years (effectively cutting the funds per year) (Australian Government, 2019b; DEE, 2019e). Only one third of the Climate Solutions Package abatement task as defined by the government is claimed to be specified with some measures (grants for efficiency projects, developing further labelling, investment in electricity grid and storage) and plans to develop an electric vehicle strategy (Australian Government, 2019b). The remaining third of the abatement task is claimed to be achieved with largely unspecified "further technology changes, improved economic efficiency and other sources of abatement" (Australian Government, 2019b).

The government is taking an increasingly 'technology-neutral' approach supporting the fossil fuel industry. The government appointed a National Climate Change Commission comprised of oil and gas industry stakeholders, allowing the fossil fuel industry to plan their own policy future, producing recommendations for a gas led recovery (Mazengarb, 2020c; Parkinson, 2020). The government seems to have noticed the 'centrepiece' emissions reduction fund policy is failing to achieve emissions reductions, and called upon fossil fuel industry stakeholders to conduct a non-transparent review of climate policies (Mazengarb, 2019; Morton & Murphy, 2019). The government has indicated they will follow the review recommendations to change the remit of the CEFC and ARENA to take a 'technology neutral' approach, add CCS to the CSF, in addition to add an incentive scheme to the safeguard mechanism rewarding large emitters that manage to reduce emissions despite the ineffectiveness of the mechanism (Australian Government, 2020a, 2020b). The Technology Investment Roadmap discussion paper indicates support for gas and CCS, without ruling out coal and nuclear (Australian Government, 2020d).

States and mainland territory governments have committed to either aspirational or legislated commitments toward zero-emissions, and some states have strong renewable energy targets in place (CAT, 2019a). Two million Australian households are reaping the benefits of small scale solar increasingly in combination with battery storage. In 2018, small scale solar accounted for 4.2% of total electricity generated, and 19.6% of renewable energy (Clean Energy Council, 2019b).

Current policy projections show Australia's emissions will decrease 16 per cent below 2005 by 2030 (DEE, 2019a) which translates into an increase by 8% without the uncertain LULUCF sector. The latest government data differs from previous years as historical emissions were adjusted, which coincides with the Coalition's narrative of a decrease since 2013 emissions levels, the same year they were in elected (DEE, 2019a; The Guardian, 2019). Yet, Australia's Paris current inadequate commitment requires a decrease of 26-28 per cent below 2005 levels. The government claims the 26 percent target will be "overachieved" using the Kyoto carryover units rather than through action (DEE, 2019a). Meeting the upper end of the target (of a 28 percent reduction) will require a further 51 $MtCO_2e$ in cumulative emissions reductions.

Figure 16 provides an overview of the share of emissions by sector according to recent government data and Table 2 provides an overview of the currently implemented policies. The so-called centrepiece policy, the Emissions Reduction Fund (ERF) has been widely criticised as ineffective and does not set Australia on a path towards meeting its NDC target (Climate Action Tracker, 2019). The government is not intending to continue the renewable energy targets beyond 2020 nor to replace it with any other instrument to reduce emissions in the power sector. None of the policies that have proven effective in other countries are implemented in Australia e.g. emissions standards in transport, energy auditing or energy management systems in industry (Climate Analytics, 2018c).

AUSTRALIA
EMISSIONS BY SECTOR EXCL. LULUCF

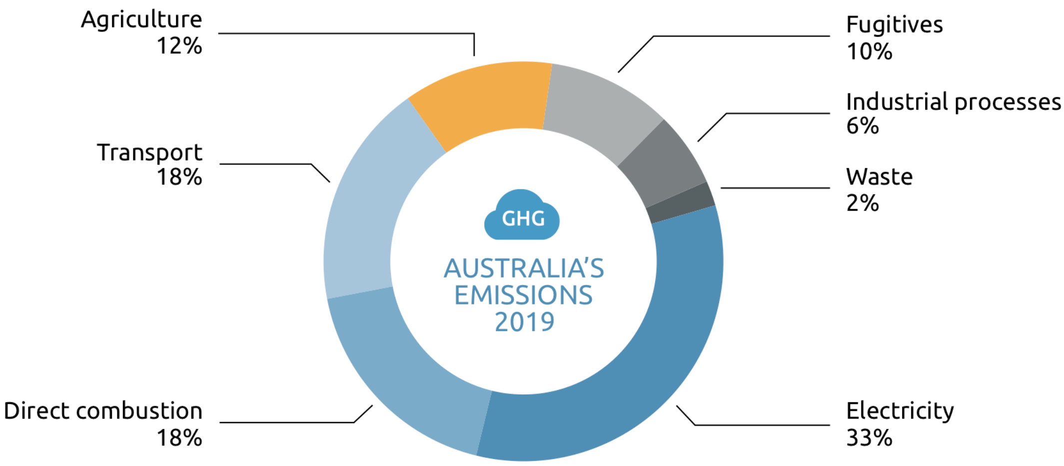


Figure 16: Australia's emissions by sector, excluding LULUCF, (historical data for 2019) Source: (DEE, 2019a).[5]

Table 5: Overview of existing and planned overarching climate change policies in Australia

OVERARCHING CLIMATE CHANGE POLICIES OF AUSTRALIA				
Changing activity	**Energy efficiency**	**Renewables**	**Nuclear or CCS or fuel switch**	**Non-energy**
Climate Strategy **There is no overarching Climate Strategy**. **Climate Solutions Fund (Emission Reduction Fund or ERF)** The ERF is a reverse auction mechanism designed to reduce emissions, through organisations and companies voluntarily abating greenhouse gases for carbon credits purchased by the government. The fund had an initial total volume of AUD 2.55 billion over 5 years. The government has budgeted a further $2 billion AUD in funding over a period of 15 years effectively cutting the fund to $133m AUD per year (DEE, 2019e). **The Safeguard Mechanism** The Safeguard Mechanism places limits (baselines) on the emissions of large industrial facilities (emitting more than 100,000t per year). These baselines cover around half of Australia's emissions, including facilities in the manufacturing, electricity, mining, oil and gas, transport and waste sectors. A single sectoral baseline applies to grid-connected electricity generators (DEE, 2019g). **The Technology Investment Roadmap** The government released a Technology Investment Roadmap Discussion Paper in May 2020 for public consultation (Australian Government, 2020d). The government releases the first Low Emissions Technology Statement to specify the government's technology investment priorities, and will produce a Long Term Emissions Reduction Strategy before COP26 (Australian Government, 2020d). The discussion paper indicates a technology neutral approach to investment, with support for gas and CCS (as well as renewables), without ruling out coal and nuclear power.				
GHG reduction targets ▪ **Copenhagen Accord 2020 target:** Unconditional: 5% below 2000 by 2020. [27% above 1990 by 2020 excl. LULUCF]. Conditional: 15-20% below 2000 by 2020. ▪ **Paris Agreement:** 26-28% below 2005 by 2030 (including LULUCF) (17-19% below 2010 levels excluding LULUCF). The Government intends to use carry-over credits, thus effectively reducing the target to a reduction of 17-18% (Climate Analytics, 2019f). ▪ **Long Term:** No target The Government has not set a target, but instead proposes a Technology Investment Roadmap as part of a emissions reduction strategy (Australian Government, 2020d).				

[5] The Buildings sector emissions are part of the direct combustion emissions.

Coordinating body for climate change

- **Department of Industry, Science, Energy and Resources** is responsible for climate change policies and GHG reporting and monitoring, including Emission Reduction Fund policy development, and legislation and methods for activities that reduce emissions under the ERF.
- **Clean Energy Regulator** (CER) is an independent statutory authority, responsible for administering schemes legislated by the government, for measuring, managing, reducing, or offsetting emissions. This relates to the National Greenhouse and Energy Reporting Scheme, the Renewable Energy Target (RET), the ERF and Safeguard mechanism.
- **Climate Change Authority** (CCA) was established in 2012 under the Climate Change Authority Act 2011. It is an independent institution with an objective to advise the Minister responsible for climate change and the Australian Parliament on climate change policy (CCA, 2018). The CCA is mandated to undertake reviews and makes recommendations on the National Greenhouse and Energy Reporting system, and for the Carbon Farming Initiative (CCA, 2018). Reviews on other matters can be requested by the Minister responsible for climate change or the Australian Parliament (CCA, 2018). The CCA can also commissions its own independent research (CCA, 2018). As an advisory body, the Authority is not responsible for administering regulation or programs (CCA, 2018).

Support for low-emission R&D

- **Australian Renewable Energy Agency** (ARENA) provides funding for renewable energy projects.
- **The Clean Energy Finance Corporation** (CEFC) is a government-owned corporation designed to co-invest with the private sector to spur investment in renewable energy, energy efficiency, and low-emissions technology.
  - **The Advancing Hydrogen Fund** was established with the National Hydrogen Strategy with existing funding commitments from ARENA and CEFC. The fund has up to $300 million AUD (CEFC, 2020). The National Hydrogen Strategy refers to a “technology-neutral” approach and defines “clean hydrogen” as “hydrogen produced using renewable energy or using fossil fuels with substantial carbon capture” (COAG Energy Council 2019).
  - **The Sustainable Cities Investment Program** aims to develop and deploy clean energy in cities, with a total investment of $8.8 billion AUD committed by the CEFC in addition to private sector funds (CEFC, 2020).
- **The Clean Energy Innovation Fund** (CEIF) was launched by the Australian Government to invest in clean and renewable technologies for commercial deployment. It uses CEFC capital and the technical expertise from the ARENA. For example, 2017 to 2018 projects included clean energy business incubators, cloud-based electricity monitoring ($2m AUD), electric vehicle batteries ($750k), and energy management system ($5m) (CEFC, 2018a). Since its inception, the fund had a total budget of $200m and has used $56.2m to finance 10 projects, with $143.8 remaining in the fund (CEFC, 2018a).
- R&D for a number of projects and initiatives for fossil fuel technology: the National Low Emissions Coal Initiative; the Carbon Capture and Storage Flagships; the Low Emissions Technology Development Fund; Coal Mining Abatement Technology Support Package; and the Hydrogen Energy Supply Chain Pilot Project (Department of Industry, 2019).

	National Energy Productivity Plan (NEPP) (launched December 2015) aims at improving energy productivity by 40% between 2015 and 2030 (Australian Government 2019). **Energy Efficient Communities Program** Announced in February 2019, and will deliver $50 million AUD in grants to businesses and community organisations to improve energy efficiency (DEE, n.d.).	**National renewable energy target** 33,000GWh by 2020 **No target beyond 2020** **Large Scale and Small Scale Renewable Energy Target Schemes (RET)** The schemes allow for renewable energy certificate trading, with a number of certificates surrendered per year.	Despite the government promoting the use of Carbon Capture and Storage (CCS) for fossil fuels, there is no operational use of CCS in the power sector, and none is projected. There is no nuclear power generation in Australia, and none is projected. It is currently banned by law (Australia Government, 1999). The Technology Investment Roadmap Discussion paper does not rule out nuclear power (Australian Government, 2020d).	**Legislation to phase-down hydrofluorocarbons (HFCs)** HFCs will be phased down -85% from 2019 to 2036. The phase-down will be implemented through the Ozone Protection and Synthetic Greenhouse Gas Management Act 1989 and its amendment (Australian Government, 1989) and associated regulations (DEE, 2019i) to gradually reduce annual import quotas over 18 years.

		The large scale renewable energy target was already met in 2019 (CER, 2019a) with **no further incentives for after 2020.**		**Information program for owners of refrigeration and air conditioning equipment on benefits of maintenance** (Australian Government, 2019b)**.** **Grants for local communities** The National Landcare Program provides governments, industry, communities and individuals with grants from projects that conserve water, soil, plants animals and ecosystems (Australian Government, 2019f). **Carbon Neutral Certification** A measure to support products, services, organisations, events, precincts and buildings to voluntarily measure, reduce and offset GHGs (DEE, 2019d)**.**

No policies currently exist and a similar policy gap exists in all other countries

No policies currently exist however Australia could adopt policies from other countries

Existing and planned policies in Australia

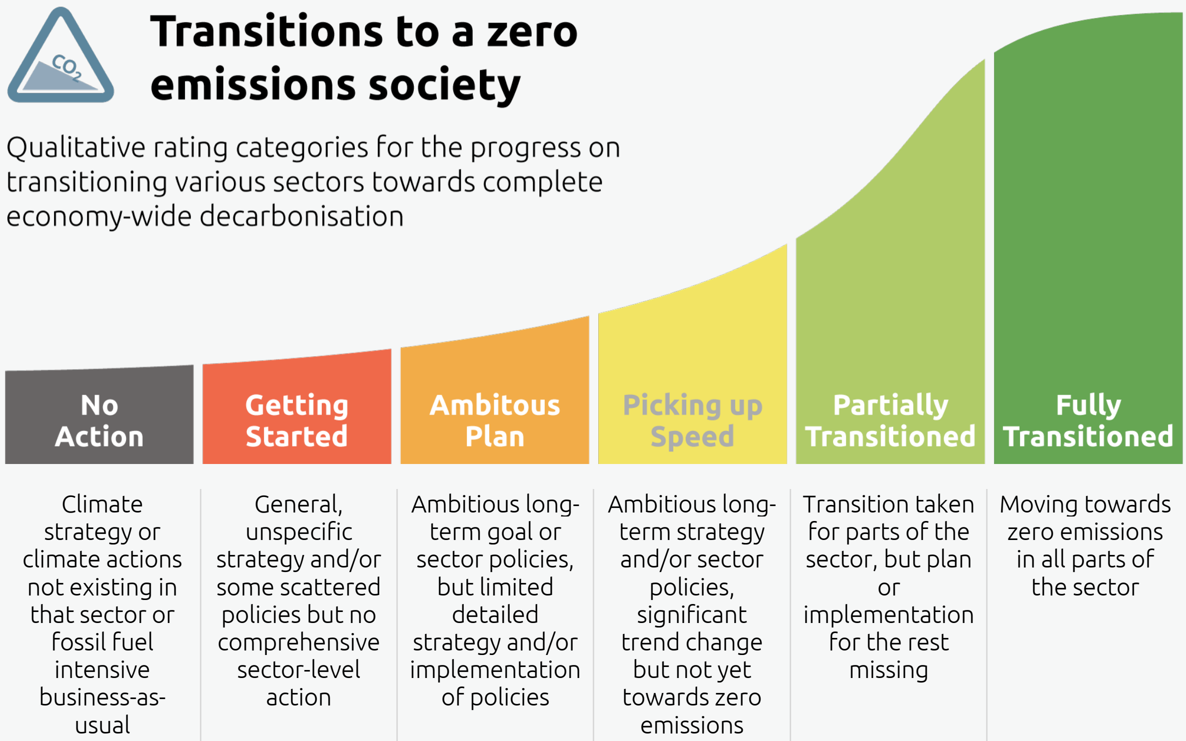
2 Overview of national climate policy actions and gaps

This chapter provides a comprehensive overview of existing and planned climate policies in Australia. The chapter is divided into 6 subsections based on the following sectors: electricity, transport, buildings, industry, agriculture and forestry, and waste. Each of the sectoral subsections is further divided into four parts (1) actionable benchmarks, (2) recent policy developments, (3) comparisons of recent developments and projections, (4) followed by a section conclusion.

The first part of each of the subsections presents the most important short-term steps for limiting global warming to 1.5°C identified by the Climate Action Tracker for a specific sector (Kuramochi et al., 2018) and discusses relevance for Australian context. The second part investigates the most important policies aiming at emissions reduction in a given sector. Subsequently, the benchmarks and policies are compared for each sector. This comparison is complemented with some recommendations for further emissions reduction in a specific sector.

Box 1 Qualitative policy rating for sectoral transition to zero-emissions society

The qualitative analysis of policy activity and its ambition results in a rating for each sector. The rating aims to reflect the sector's current transition state towards 1.5°C Paris Agreement compatibility. For this purpose, the rating accounts for existing sectoral long-term strategies and/or policies, their status of implementation, as well as the general state of transition of the sector under analysis.



The policy ambition analysis compares historical and projected developments under current policies to the global or in some cases regional or national indicators. The policy ambition analysis mainly provides an indication to which degree current trends in each sector align with required steps and presents a standardised approach for all countries analysed in the CAT Scaling Up Climate Action series.

Key findings of policy activity and policy ambition analysis

Table 6 summarises the key findings of the policy activity and gap analysis for each of the focus areas and the respective sectoral benchmarks. The qualitative rating evaluates the current sectoral status in transitioning to 1.5°C Paris Agreement compatibility. Policy rating focuses on the federal level.

Table 6: Summary table for sectoral policy activity and gap analysis in Australia

Sector	1.5 °C-consistent benchmark	Australia specific 1.5 °C benchmark	Overall evaluation based on policy activity and gap analysis	Policy rating
Electricity supply sector	*Sustain the global average growth of renewables and other zero and low-carbon power until 2025 to reach 100% by 2050*	*100% renewable electricity generation achieved by 2030s*	• Australia is not on track to meet the benchmark, with government projections indicating renewables will represent just 50% of electricity generation by 2030 relying on state targets to be met. • Australia does not have a renewable energy target beyond 2020. The 2020 target was met, and there has been no new target set *(CER, 2019a)*. • Investment in renewable energy have decreased since 2018 (Clean Energy Council, 2020a). Policy uncertainty and lack of long-term planning of transmission grids is leading to curtailment and delays in grid connections for large scale projects. • Government funding for the national renewable energy agency (ARENA) has decreased and funding is soon to be exhausted *(Mazengarb, 2020a)*. • The government has indicated ARENA's funding will likely continue, but also intends to alter ARENA and the Clean Energy Finance Corporation's (CEFC) remit to be 'technology neutral' and could include coal and gas with carbon capture and storage forcing renewable projects to compete with fossil fuel interests (Mazengarb, 2020d). • Out of the eight states and mainland territories in Australia, six have committed to renewable energy targets and some states have committed to ambitious 100% renewable energy targets, and Tasmania plans for 200% renewables.	

	No new coal plants, reduce emissions from coal power by at least 30% by 2025	*Phase out coal by 2030*	• There is no plan to phase out coal, and coal will continue to represent the largest share of electricity generation to 2030 (DEE, 2019a). • The Paris Agreement benchmark of phasing out coal by 2030 would imply a sooner retirement of the fleet of coal fired power stations. • The government has encouraged utilities to extend the coal fired power generation lifespan beyond shutdown dates scheduled (Taylor, 2019), generating investment uncertainty for renewables. • The government continues to incentives fossil fuel electricity generation offering incentives through a power subsidy ("Underwriting New Generation Investments") scheme, where a coal generation upgrade has been shortlisted and is likely to be funded (DEE, 2019n; Sydney Morning Herald., 2019a) with additional funding for a feasibility study into a new coal fired power plant that would require government subsidies. • The Federal Government and New South Wales state government made a deal to supply coal to a coal power station to operate to at least 2042 (RenewEconomy, 2020b).	No Action
Transport sector	*Last fossil fuel car sold before 2035*		• There are no targets to end the sales of fossil fuel cars. The government has announced the development an electric vehicle strategy, but this has not been published (Australian Government, 2019a). • Australia is one of the few countries in the world without any emission or fuel efficiency standards for light duty vehicles, and the current government has not indicated any intention to introduce these, despite five years of deliberations in the Ministerial Forum on Vehicle Emissions (MFVE). • The current piecemeal policies are ineffective. Recent auctions for the Emissions Reduction Fund have not seen projects in the transport sector. The safeguard mechanism only applies to a small portion of transport emissions.	No Action
	Freight trucks need to be almost fully decarbonised by approximately 2050		• Despite the projected increase in road freight transportation emissions (DEE, 2019a), there is an absence of plans to decarbonise freight trucks in Australia. • Unlike the EU, Canada, USA, Japan, Australia does not have any emissions or fuel efficiency standards for heavy duty vehicles (Climate Analytics, 2019e). • The National Hydrogen Strategy could be used to decarbonise heavy long-range road transport, (plus rail and shipping) if the hydrogen is derived from renewable energy. As the strategy takes a 'technology neutral' approach, this may not be the case.	No Action

	Aviation and shipping: Develop and agree on a 1.5°C compatible vision	• Government projections indicate aviation and shipping emissions will increase (DEE, 2019a). • There is no 1.5°C compatible vision or emissions reduction policy for domestic aviation and shipping. • Commitments for reducing emissions of aviation and shipping are limited to international transport through the Carbon Offsetting and Reduction Scheme for International Aviation and as a member of the UN International Maritime Organisation (DFAT, 2019).	No Action
Buildings sector	*All new buildings fossil free and near zero energy by 2020*	• There are no policies to ensure new buildings are fossil free, or for buildings to be near zero energy by 2020. • The National Construction Code has minimum building efficiency standards, with many stakeholders calling for the standards to be improved (ClimateWorks Australia, 2018a; COAG Energy Council, 2018a, 2018b; Harrington, Zhang, Bloomfield, Johnston, & Shen, 2018). • The next update to the National Construction Code is scheduled for 2022 (ABCB, 2019b), and therefore new measures on building efficiency are unlikely to be implemented by 2020. • The Council of Australian Governments (COAG), the peak intergovernmental forum in Australia, is considering expanding the Commercial Building Disclosure program to other buildings (DEE, 2019f), which would reduce emissions, but no action has been taken to date. • A new Energy Efficient Communities Program begin in 2020 to support energy efficiency in buildings. • Market mechanisms have been put in place by state/territory governments to increase energy efficiency (Climate Change Authority, 2019, p. 12). • Australian building efficiency standards are behind other countries (Energy Efficiency Council, 2019). • There is evidence of widespread under compliance in meeting building energy efficiency requirements (Energy Efficiency Council, 2019)	Getting Started
	Increase building renovation rates from <1% to 3% by 2020	• There is no data on building renovation rates nor policy on increasing building renovation rates.	No Action

Industry sector

All new installations in emissions-intensive sectors are low-carbon after 2020, maximise material efficiency

- The industry sector does not prioritise decarbonisation. Australia's long-term plan to decarbonise the industry sector was abolished with the "carbon tax."
- Policies do not ensure low carbon installations or maximise material efficiency.
- Government figures show a decline in emissions in the subsectors of industrial processes, direct combustion and fugitives, despite increases in the past year (DEE, 2019a).
- Industrial processes emissions are projected to decline as a consequence of the phase down of hydrofluorocarbons (DEE, 2019a).
- Fugitive emissions are projected to decrease (DEE, 2019a), but government figures rely of the Gorgon CCS project to meet its emissions obligations.
- There are only a few industry projects in the Emission Reduction Fund portfolio.
- Evidence suggests the ERF and Safeguard Mechanism achieve marginal amounts of emissions abatements (ABC News, 2019; Reputex, 2019a; RepuTex, 2020; Sydney Morning Herald., 2019d). Yet, the ERF has been supported with a financial top-up, and renamed the Climate Solutions Fund (CSF).
- The federal government takes an increasingly technology neutral approach to industry policy:
  - Appointing a Covid-Commission with gas industry stakeholders, which produced recommendations for a gas-led economic recovery (Parkinson, 2020).
  - Appointing an expert panel with fossil fuel stakeholders to review the CSF CSF (Australian Government, 2020a, 2020b).
  - The government intends to follow recommendations of the panel to include CCS in the remit of the CEFC, ARENA and the ERF, and add an incentive scheme to the safeguard mechanism to reward large emitters that manage to reduce emissions despite the ineffectiveness of the ERF CSF (Australian Government, 2020a, 2020b).
  - The recently released Technology Investment Roadmap discussion paper includes gas, CCS and does not rule out coal and nuclear (Australian Government, 2020d).
  - The National Hydrogen Strategy is at risk of supporting the fossil fuel industry, as it follows a technology neutral approach.
- *The National Energy Productivity Plan (NEPP) is not effective, as high impact policies have not been implemented* (Climate Analytics, 2018a).
- Australia's LNG related emissions have soared in recent years, and Australia plans to have 10 plants in operation to export over 87 Mt of LNG in 2030 (DEE, 2019a).
- There are further emissions at fossil fuel export destination countries that are not accounted for in Australia's national level greenhouse gas accounts.

LULUCF sector	*Reduce emissions from forestry and other land use to 95% below 2010 by 2030, stop net deforestation by 2025*	• Australia has high deforestation rates by global standards (Slezak 2018; WWF 2018b). • Government emissions projections indicate the benchmark will be met, however the national level data is inconsistent with state level data. • The government has been criticised for adjusted historical emissions accounts in line with their political narrative (The Guardian 2019). • Recent and unprecedented bushfires will have made a negative impact on this sector, as the scale and intensity of fires affect the rate at which carbon will be reabsorbed (Sydney Morning Herald 2020).	Getting Started
Agriculture sector	*Keep emissions in 2020 at or below current levels, establish and disseminate regional best practice, ramp up research*	• Emissions are projected to decrease marginally by 0.1 $MtCO_2e$ from 2019 to 2020, meeting part of this benchmark (DEE 2019a). • Emissions are projected to increase from 2020 to 2030 (DEE 2019a). • Research and dissemination of best practise at the national level has been scaled down, as the Carbon Farming Futures Program ended in 2017 (Department of Agriculture and Water Resources 2017). • The Australia government demonstrates a degree of participation in international research initiatives such as the Global Research Alliance on Agricultural Greenhouse Gas and the Global Methane Initiative.	No Action

2.1 Electricity sector

The power sector is the single largest contributor to greenhouse gas emissions, and contributes 33 per cent of Australia's total emissions (excluding LULUCF, see Figure 1). Emissions are expected to slightly decline through to 2030 (DEE, 2019a), in contrast to the faster downward trajectory needed to honour the Paris Agreement commitment. For 2020, the government projections indicate the electricity generation mix to be 54% coal, 16% gas, 11% wind, 10% solar, 7% hydro, and 2% liquid fuel (DEE, 2019a).

Rooftop solar installations are booming, and 1.5 GW of capacity was added in 2018, creating a total capacity of over 8.1 GW (Clean Energy Council, 2019a) and have further increased in 2019 to over 10 GW (CER, 2020). Rooftop PV accounts for 22% of total renewable energy and 6% of Australia's total energy generation (DEE, 2019a). 100% renewable energy can be achieved cost effectively, due to the disruptive cost decrease of solar and wind technology combined with battery storage (Australia Energy Networks & CSIRO, 2016; Sven Teske, Dominish, Ison, & Maras, 2016b). A number of studies show that 100% renewable energy share can be achieved in the 2030s (Blakers, Lu, & Stocks, 2017b; Diesendorf, 2018; Gulagi, Bogdanov, & Breyer, 2017; Howard, Hamilton, Diesendorf, & Wiedmann, 2018; Riesz, Elliston, Vithayasrichareon, & MacGill, 2016; Sven Teske et al., 2016b) (ClimateWorks Australia, 2020b).

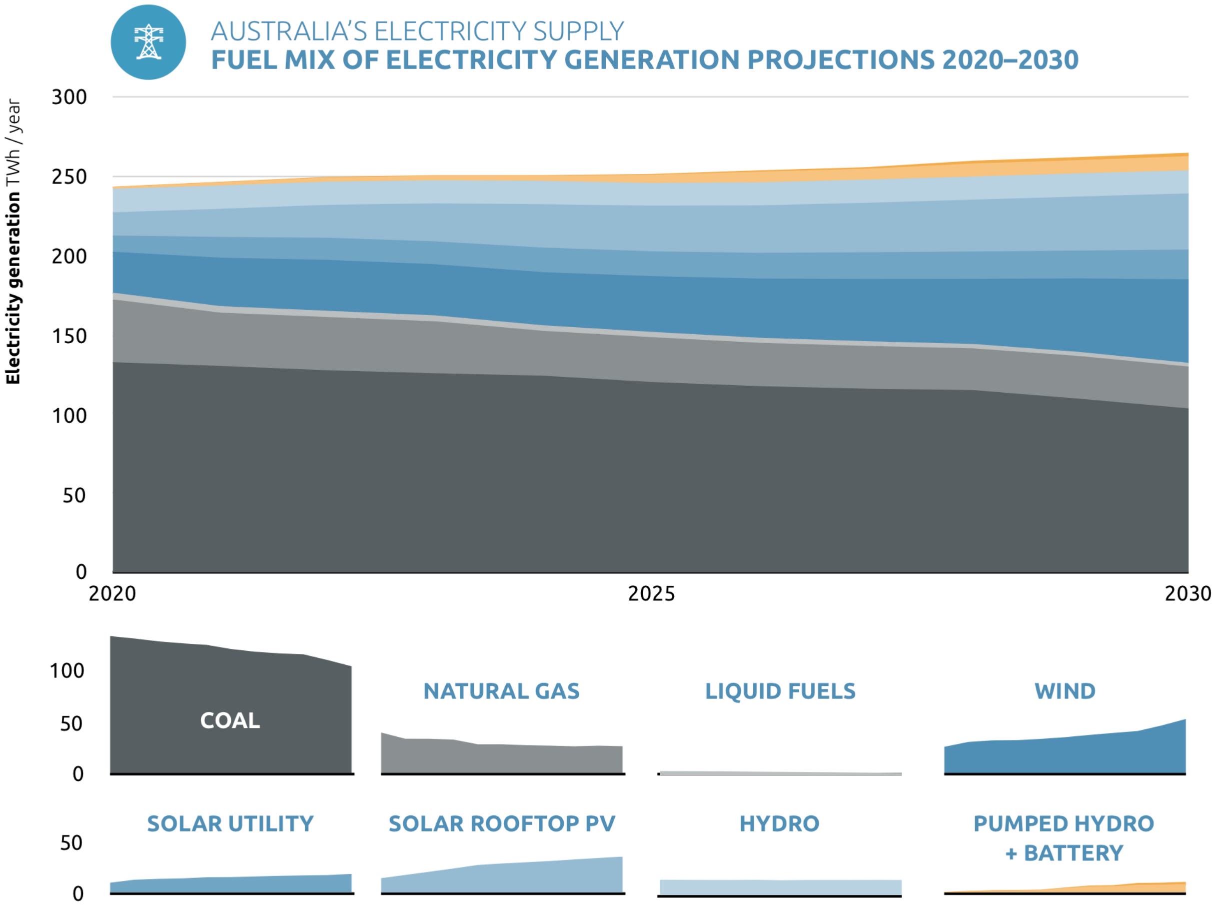


Figure 17 - Australia's Fuel generation mix, Projected data 2020 to 2030 (GWh). Source: (DEE, 2019a)

Table 7 summarises Australia's progress – or lack thereof - on the most important steps to decarbonise the electricity sector.

Table 7: Progress on the most important steps in the electricity supply sector to limit temperature increase to 1.5°C

Sector	1.5 °C-consistent benchmark	Projection(s) under current policies	Gap assessment (qualitative)	Policy rating
Electricity sector	Sustain the global average growth of renewables and other zero and low carbon power until 2025 to reach 100% by 2050 **Australia specific benchmark:** 100% renewable electricity generation achieved by 2030s	• *In 2030, electricity sector emissions are projected to be 131 $MtCO_2e$, which is 23% below 2020 levels of 170 $MtCO_2e$* (DEE, 2019a). • *The government projects renewables and storage to represent 50% of electricity generation by 2030* (DEE, 2019a). *This relies on state government targets (e.g. Victoria, Queensland) being achieved.* • *This is supported by another study finding that with current policies, Australia could achieve about 50% share of renewable energy by 2030, with state targets and schemes being the dominant signal for investment (Reputex, 2019b).* • *Despite the government promoting the use of Carbon Capture and Storage (CCS) for fossil fuels, there is no operational use of CCS in the power sector, and none is projected.* • *Australia does not have any nuclear power and there are no plans to introduce it. It is currently banned by law (Australia Government, 1999).*	- Current projections indicate Australia will only meet half of the Australia specific benchmark for renewable energy generation. +/– The large scale renewable energy target was achieved in 2019, but there is no target beyond 2020 (CER, 2019a). - Investment in renewable energy has declined since 2018 due to regulatory risk and uncertainty (Clean Energy Council, 2020b). - Government funding for ARENA has decreased and funding is nearly exhausted (Mazengarb, 2020a), and the CEFC's investments are lower than in previous years. - The government intends to change ARENA and CEFC policy to be technology neutral, which could include coal and gas generation with CCS, indicating renewable energy projects will have to compete with fossil fuel projects (Mazengarb, 2020d), despite being the cheapest and lower emissions option. + Six out of eight states and territories have renewable energy (RE) targets (Climate Council, 2019). • ACT: 100% RE by 2020 • Tasmania: 100% RE by 2022, 200% RE by 2040 • South Australia: net 100% RE by 2030 • Queensland: 50% RE by 2030 • Victoria: 45% RE by 2025, 50% by 2030 • Northern Territory: 50% RE by 2030 - Western Australia and New South Wales do not have a renewable energy target.	Getting Started

	No new coal plants commissioned, reduce emissions from coal power by at least 30% by 2025 and 80% below 2010 levels by 2030. Phase out coal globally by 2040, and by 2030 in OECD countries **Australia specific benchmark:** Phase-out coal by 2030	• Profitability prospects make refurbishment of the aging coal fleet or opening of new plants highly unlikely, despite the intent of the government to push for more coal-fired power generation. • Emissions are projected to overall decline from 2020 to 2030, due to coal plant retirement (DEE, 2019a). • Coal is projected to account for 54% of the fuel generation mix in 2020 and 39% in 2030 (DEE, 2019a).	- *There is no plan to phase out coal, and coal will represent the largest share of Australia's electricity generation in 2030 compared to other electricity sources based on government projections (DEE, 2019a).* - *Meeting the benchmark would require the retirement of the coal power plants before their planned closure.* - *Utilities are being forced to extend the lifespan of coal-fired power (Taylor, 2019) creating uncertainty for investments in renewable energy.* - *The government supports coal power generation. The government has encouraged electricity companies to apply for the power subsidy scheme to build new coal-fired power plants, resulting in a coal generation upgrade to be shortlisted* (DEE, 2019n; Sydney Morning Herald., 2019a). - *The government has agreed a deal with the New South Wales Government to ensure a coal fired power station can operate for at least two decades (RenewEconomy, 2020b) including a likely funding of 11 mil. AUD for the shortlisted upgrade of a coal fired power plant (Vales Point) (The Guardian, 2020) and a 4 mil. AUD funding for a feasibility study for a new coal fired power plant in Queensland (ABC News, 2020).*	

2.1.1 Actionable benchmarks in electricity sector

The Climate Action Tracker identified two short-term actionable benchmarks for the electricity sector to limit warming to 1.5°C at a global level (Kuramochi et al., 2018):

- Sustain the growth rates of renewables and other zero and low-carbon power until 2025, and reach a 100% share of electricity generation by 2050.

For Australia, many scenarios show that 100% share of electricity generation can be achieved as early as 2030 (Diesendorf, 2018; Sven Teske et al., 2016b(ClimateWorks Australia, 2020b).

- No new coal capacity to come online from 2018, emissions from coal combustion need to be reduced by at least 30% by 2025.

A more recent publication based on the recent IPCC assessment supports this direction, and suggests reducing the use of coal in electricity by 80% between 2010 and 2030 and phase out coal globally by 2040, and by 2030 in many regions including OECD (Yanguas Parra et al., 2019). This is in line with the IPCC Special Report on 1.5°C (IPCC, 2018c). For Australia, a complete coal phase-out is needed by around 2030 (Climate Analytics, 2017; Yanguas Parra et al., 2019).

The following gap analysis compares historical and projected developments in Australia's electricity to these benchmarks.

2.1.2 Recent policy developments

This section provides an overview of the main climate policies (or lack thereof) in the electricity sector. Australia abolished the carbon pricing mechanism (CER, 2015) and downgraded the Renewable Energy Target from 41 000 GWh to 33 000 GWh in 2020 (CER, 2018a), and has no target in place from 2020 onwards. Policies influencing the development of renewables and decarbonisation of the electricity sector are provided in Table 8. The current government has no plans for policies to increase the share of renewable energy beyond the 2020 target or to reduce emissions in the electricity sector. Rather, regulatory uncertainty has caused renewable energy investments to fall and the government continues to support the coal industry (Clean Energy Council, 2020b).

Table 8: Overview of existing and planned climate change policies in the electricity sector

OVERVIEW OF EXISTING, PLANNED AND POTENTIAL CLIMATE CHANGE POLICIES FOR THE ELECTRICITY SECTOR IN AUSTRALIA			
Changing Activity	**Energy efficiency**	**Renewables**	**Nuclear or CCS or fuel switch**
	Support for highly efficient power plants (none)	**Renewable energy target for electricity sector** ▪ **Renewable energy target (RET) (for 2020)** The RET aims to achieve 23.5% renewable energy generation by 2020 (DEE, 2019m). Australia committed to a Renewable Energy Target of 41,000GWh which was subsequently downgraded to 33,000GWh by 2020 which will remain at that level to 2030 (CER, 2018a).	▪ **Low Emissions Technologies for Fossil Fuels (LETFF) programs** The LETFF program includes the National Low Emissions Coal Initiative (NLECI) and the Carbon Capture and Storage (CCS) Flagships program. The NLECI has implemented numerous projects with the intention to reduce emissions from coal and has expended its $233 million AUD funding (Australian National Audit Office, 2017) and is no longer in the Department of Innovation, Science and Industry Budget 2019-20 (DIIS, 2019a). The Carbon Capture Storage (CCS) Flagship program supports the financing of CCS demonstration projects to capture emissions from industrial processes and storing emissions underground and is due to close in 2020 (Australian National Audit Office, 2017).
	Reduction obligation schemes (none)	**No Renewable Energy Target for post 2020: There is no new target planned beyond 2020.**	
		Support scheme for renewables • The Large Scale Renewable Energy Target Scheme (LRET) and the Small Scale Renewable Energy Target Scheme (SRET) both allow for renewable energy certificate trading, and a certain amount of certificates are surrendered per year. The target is set for 2020 but the scheme will continue to 2030 (CER, 2019a)	
		• The large scale renewable energy target was already met in 2019 (CER, 2019a) with **no further incentives for after 2020.**	
		Grid infrastructure development	

		▪ A Grid Reliability Fund was announced in October 2019, to support Australian Government investment in new energy generation, storage and transmission infrastructure, including eligible projects shortlisted under the Underwriting New Generation Investments (UNGI) program, to be administered by the CEFC. This policy is not directly targeted at increasing uptake of renewable energy. ▪ **Public investment into pumped hydro (electricity storage).** The government has supported the Snowy 2.0 pumped hydro-electric storage project. Snowy 2.0 is an expansion of an existing government owned hydroelectric facility aiming to provide largescale storage to support integration of high shares of variable renewable energy into the grid (Snowyhydro, 2019).	
		Sustainability standards for biomass use (no definite policy or regulations regarding biofuels production and environmental sustainability (Sasongko, Thorns, Sankoff, Chew, & Bista, 2017))	
Overarching carbon pricing scheme or emissions limit **None** **Note: The Safeguard Mechanism:** Aimed at ensuring large emitters keep emissions below a baseline level but does not provide any incentive to limit or reduce emissions: A single sectoral baseline applies for grid based electricity generation based on the high-point in annual emissions from the sector between 2009-10 and 2013-14 and therefore does not create any inventive to reduce emissions further. In 2017–18, total reported scope 1 emissions from grid-connected generators was 167 million tonnes.			
Fossil fuel subsidies ▪ Underwriting New Generation Investment (UNGI) programme includes fossil fuel generation (gas and coal). No policy that aims at reducing fossil fuel subsidies in electricity sector			

No policies currently exist and a similar policy gap exists in all other countries

No policies currently exist however Australia could adopt policies from other countries

Existing and planned policies in Australia

The carbon pricing mechanism provided Australia with a long-term goal to decarbonise, but lasted only two years. The mechanism involved reducing greenhouse gas emissions by 5% below 2000 levels by 2020 and 80% below 2000 levels by 2050. The carbon pricing mechanism was legislated under the Clean Energy Act by the Gillard Labor government (Australian Government, 2011a). The mechanism came into force in 2012 and by 2014 the Abbott Liberal government repealed the scheme (DEE, 2019e).

The Safeguard mechanism is ineffective for the electricity sector, as the sectoral baseline was defined based on the highest point in historical emissions between 2010 and 2014 and therefore does not create any inventive to reduce emissions.

The main remaining instrument to reduce emission from the electricity sector is the renewable energy target legislated in the Renewable Energy Act 2000 (Australian Government, 2000). The two schemes in motion are the Large Scale Renewable Energy Target Scheme and a Small Scale Renewable Energy Target Scheme: the former allows generators to trade renewable energy certificates, and obligates retailers to surrender a certain amount of certificates per year (DEE, 2019m); the latter allows individuals and businesses to trade certificates while operating small-scale renewable energy systems, and retailers are obligated to surrender a certain amount of certificates per year (DEE, 2019m).

The large-scale renewables target aimed to support the installation of 41,000 GWh of large-scale renewable energy by 2020. In 2015, this policy was downgraded to a lower target of 33,000 GWh (CER, 2018a), despite the Climate Change Authority's recommendations for no scale-back (CCA, 2014). The renewable energy target schemes will remain in place to 2030, but importantly, there is no renewable energy target beyond 2020 nor any other scheme to reduce emissions in the electricity sector, after the former Prime Minister Turnbull did not get support for a so-called National Energy Guarantee (NEG) aiming at reducing emissions and ensuring reliability of supply.

States and territories are stepping up and committing to their own targets. Six out of eight states and territories within Australia have committed to a renewable energy target to or beyond 2025 (Climate Council, 2019). Some states have set ambitious targets for 100% renewable energy. Tasmania and ACT meet the Australia specific benchmark of 100% renewables earlier. ACT has committed to 100% by 2020 and Tasmania aims to be 100% self-sufficient in renewable energy by 2022 (Climate Council, 2019). Tasmania has set a new ambitious target for 200% renewable energy by 2040 (Gutwein, 2020). South Australia has an ambitious target of net 100% renewables by 2030 (Climate Council, 2019). The state plans to export surplus renewable electricity to neighbouring grids and overseas (RenewEconomy, 2019b). Electricity generation will not be 100% renewable, as there will be gas generation too (RenewEconomy, 2019b). Queensland, Victoria, and the Northern Territories have committed to 50% renewables by 2030 (Climate Council, 2019). Western Australia and New South Wales do not have a renewable energy target. It is surprising Western Australia does not have a target, despite covering over 30% of Australia, with large potential for wind and solar, and having an independent energy system separated from other networks across the country. All states have a net-zero emissions target for 2050 or before (Climate Council, 2019; NT Government, 2019).

After the government did not get parliamentary support for abolishing the agencies funding renewable energy investments, it has decreased funding for both the Australian Renewable Energy Agency (ARENA) and the Clean Energy Finance Corporation (CEFC).

ARENA was created to support the development of renewable energy and related technologies to secure Australia's power supply (ARENA 2018). ARENA has given $1.347 billion AUD in grants to 441 projects (Australian Government 2019). ARENA began in 2013-14 with a budget of $581m AUD award by the Labor government, which significantly dropped during the budgets of the Abbott Government and beyond, consecutively decreasing $194m (2014-15), to $90m (2015-16), to $57m in 2016-17 (ARENA, 2019d). Financial year 2017-18 experienced a budget rise to $258m AUD and a drop to $235m the following year (ARENA, 2019d). ARENA's budget was affected by the repeal of the carbon tax in 2013 and the 2016 Budget Savings (Omnibus) Bill (ARENA, 2019d). ARENA was nearly scrapped in this bill, but survived with a reduced budget (The Conversation, 2016).

The current ARENA funding is $255m AUD (for the financial year 2019-2020), but with a significant decrease in funds for financial years 2020-21 and 2021-22, with budgets of $134m and $132m respectively (ARENA, 2019d). The latest annual report 2018-2019 indicates that ARENA's (2019a) investment priorities are delivering secure and reliable electricity ($86.9m AUD), improving energy productivity ($67m), accelerating solar PV innovation ($20m), exporting renewable energy ($18.7m) and other ($13m). Remaining funds are close to exhausted with AUD $200m left, and funding window ending in 2021/22, prompting calls for funding extensions (Mazengarb, 2020a). The government has suggested it will continue ARENA's funding following the recommendations of a review that was not initially disclosed to the public. ARENA and the CEFC will be funded but given a 'technology neutral remit" which could allow for coal or gas generation with CCS, and may force renewable projects to compete with the fossil fuel industry for projects (Mazengarb, 2020d).

The CEFC was created to mobilise investment in renewable energy, energy efficiency and low emissions projects with a $10b AUD budget. In 2018, the CEFC was given a ministerial direction to include investment activities focusing on developing a market for firming intermittent sources of renewable energy (CEFC, 2019). The CEFC was given its first new injection of capital of $1b from federal government for a Grid Reliability Fund (RenewEconomy, 2019a). The Fund is to include projects shortlisted for the Underwriting New Generation Investments (UNGI) program, but only projects that meet the CEFC's mandate (assumingly not the coal plant upgrade) (RenewEconomy, 2019a). Although, the CEFC's mandate may follow a technology neutral approach in future.

The CEFC includes a $1b AUD Sustainable Cities Investment Program, $1b Reef Funding Program, and $200m Clean Energy Innovation Fund (CEFC, 2019). The latest annual report suggests that every dollar invested was match by over two dollars over the six years of operation, with an improved 3:1 ratio for 2018/19 (CEFC, 2019). To date, the CEFC has driven $24b AUD in investment commitments in clean energy projects, and abated 260MtCO_2e (CEFC, 2019).

The Australian government has invested in Low Emissions Technologies for Fossil Fuels (LETFF) programs including: the National Low Emissions Coal Initiative (NLECI), the Carbon Capture and Storage (CCS) Flagships program; the Low Emissions Technology Development Fund; Coal Mining Abatement Technology Support Package; and Hydrogen Energy Supply Chain Pilot Project (DIIS, 2019c).

As an example, the National Low Emissions Coal Initiative (NLECI) aims to reduce greenhouse gas emissions from the use of coal, through low emission technology and carbon dioxide transport and storage (DIIS, 2019d). The initiative has so far completed several projects at substantial costs but with none of them leading to actual emissions reduction in the electricity sector.

Completed projects of the NLECI so far are the Hydrogen Energy Supply Chain Front End Engineering Design Project, to convert brown coal to hydrogen to export to Japan; the Mineral Carbonation Project, capturing carbon dioxide in mineral deposits as storage in rocks.

The National Carbon Dioxide Infrastructure Plan aimed to accelerate the development of long term carbon dioxide storage sites; the Post Combustion Capture (PCC) of Carbon Dioxide Technology project aimed to progress PCC technology; the Carbon Dioxide Infrastructure Assessment Project aided the identification of onshore and offshore pipeline routes to transport carbon dioxide to geosequestration storage areas; and the Callide oxyfuel combustion project demonstrated how oxyfuel and carbon capture technology can be implemented in power stations (see DIIS 2019f for further project details).

The Department of Industry, Innovation and Science suggests there are two ongoing research projects in the NLECI. One project is research and development on national low emissions coal to accelerate the feedback from demonstration projects to applied technology (DIIS, 2019d). The other project is bilateral cooperation on Clean Coal Technology between China and Australia (DIIS, 2019d). In 2017, the Australia National Audit Office (Australian National Audit Office, 2017) found the NLECI has expended its total funding of $233m AUD. The NLECI is no longer in the department's budget (DIIS, 2019a).

Another example of a Low Emissions Technologies for Fossil Fuels (LETFF) program is the Carbon Capture Storage (CCS) Flagship program. It supports several demonstration projects that capture carbon dioxide from industrial processes, arranging transport infrastructure such as pipelines and storing carbon dioxide underground (DIIS, 2019b). The program had expended $217 million AUD (in 2017) of the allocated $2 billion and is set to close in 2020 (Australian National Audit Office, 2017). The Australia National Audit Office concluded that after a decade of operation, it is not clear how the projects have achieved objectives to accelerate the deployment of technology to reduce emissions (Australian National Audit Office, 2017). Many studies have found fossil fuels with CCS are not viable as they cannot compete with renewable energy (Sgouridis, Carbajales-Dale, Csala, Chiesa, & Bardi, 2019; Viebahn, Vallentin, & Höller, 2012).

Despite the large levels of funding from the government to promote CCS, the operational use of CCS has only recently come online, but not for power generation. The Gorgon LNG Project was required to use CCS to reduce emissions from CO_2 venting (Chevron, 2019). The facility came online years late and captures lower levels of carbon then contractually agreed without penalty (Morton, 2019a).

Renewable energy-based hydrogen is an opportunity for integration of large shares of renewable energy and decarbonisation of end-use sectors where electrification is not feasible. The National Hydrogen Strategy was adopted by state and federal energy ministers in November 2019. The strategy is explicitly "technology neutral" with a small portion of funding dedicated to supporting electrolysers to produce (green) hydrogen from water (COAG Energy Council, 2019a) (see the Industry section below for further details).

In terms of hydro pumped storage projects, funding was committed to the "Snowy 2.0" pumped hydro-electric power storage project in February 2019 (Snowyhydro, 2019). The "Battery of the Nation" project was a AUD$2 million study, jointly funded by ARENA and Hydro Tasmania (2019). The project located the best locations for pumped hydro in Tasmania, finding that it is viable for Tasmania to more than double its current hydro capacity adding 2500 MW of storage potential (ARENA, 2019b; Hydro Tasmania., 2019). A feasibility study finds that the Battery of the Nation project is only financially viable under two conditions: the accelerated retirement of coal power; and the uptake of renewables needs to be accelerated, with a 52% emissions reduction target for 2030 (TasNetworks, 2019). Major economic and environmental concerns have been raised about the Snowy Hydro project, which is predicted to have damaging effects on the Kosciuszko National Park (Mazengarb, 2020b).

There are several other pumped hydro storage projects ARENA has helped finance in 2018. ARENA has funded AUD $500k of a $9m 'Cultana' hydro energy storage project, aiming to be capable of 225 MW of electricity for South Australia and offering eight hours of storage using seawater (ARENA, 2019c). Another $500k helped fund a pre-feasibility study for the Middleback Ranges Pumped Hydro Energy Storage Project, assessing the technical and commercial feasibility of 110 MW and six-hour storage capabilities with the possibility to increase capacity to 220 MW (ARENA, 2019f). ARENA financed $2m to help fund a $6m Origin Energy Shoalhaven Pumped Hydro Expansion Opportunity Feasibility Study to explore the option of expanding the existing scheme (ARENA, 2019g). In 2019 ARENA (2019e) financed $6m for the Hydrostor Angas A-CAES project which is an advanced compressed air energy storage facility.

Comparison of recent developments and projections to benchmarks

2.1.2.1 **Actionable indicator #1**: Growth of renewables and other zero and low-carbon power

This benchmark will be addressed in two parts, (1) growth in renewable electricity generation; (2) other zero-carbon power.

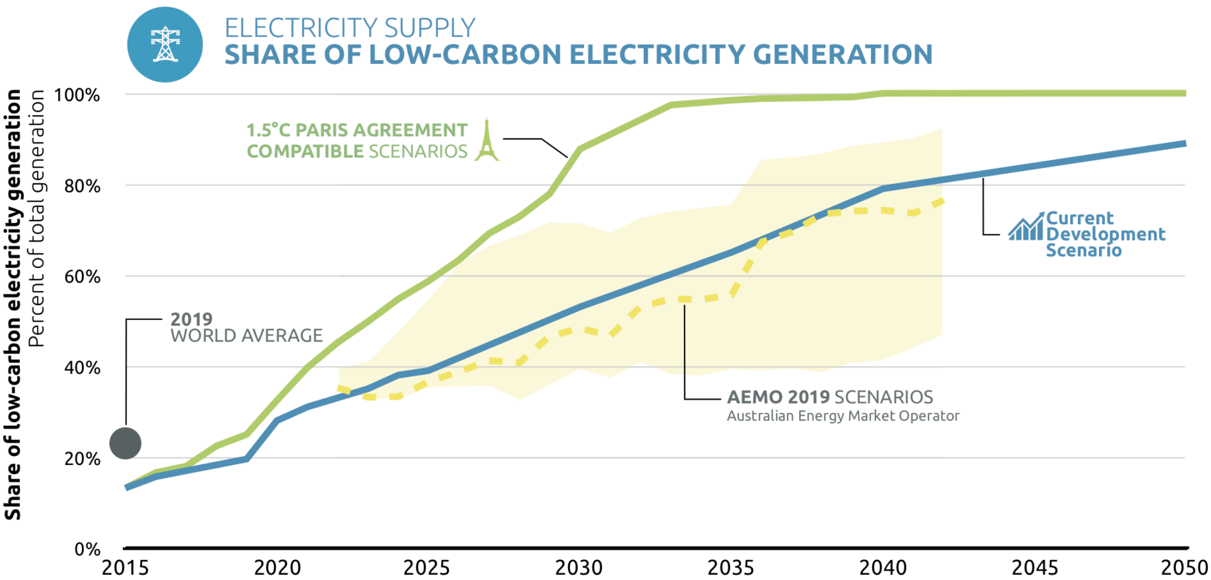


Figure 18 - Historical and projected share of low carbon electricity generation Australia. Source: AEMO data is from the Draft Integrated System Plan 2020 and Integrated System Plan 2019 for the NEM only (AEMO, 2018a; Australian Energy Market Operator, 2019) *(AEMO, 2020), IEA historical data is from IEA* (IEA, 2019a).

Growth in renewable electricity generation

The renewable energy sector has experienced growth but investments in renewables are declining and curtailment and delays to grid connections are becoming an increasing problem, increasingly referred to as a "grid connection and congestion crisis" (RenewEconomy, 2020a). Government projections indicates 27% (66,898 GWh) of electricity will be generated by renewable energy and storage technology in 2020 and 50% (132,638 GWh) by 2030 (DEE, 2019a). Similarly, Reputex found, with current policies, Australia could achieve around a 50% share of renewable energy by 2030, with state targets and schemes being the dominant signal for investment (Reputex, 2019b). The government projections show a year on year growth in renewable energy electricity generation and consequently there is a projected 23% decline in electricity sector emissions from 2020 to 2030 (DEE, 2019a). The cost of solar PV and wind power will continue to fall globally, ensuring the growth of wind power and the further proliferation of rooftop solar in Australia. Wind and solar will be the lowest cost option for electricity generation in Australia compared to any new build technology, including an additional six hours of storage (CSIRO, 2018).

However, recent analysis finds that investment in renewable energy is decreasing. Investment in renewable energy peaked in 2018, with over 100% increase in investment compared to the previous year (Clean Energy Council 2019a). Investment for large scale renewable energy dropped by 50% from 2018 to 2019 (Clean Energy Council, 2020b). Reasons for the decline in investment include policy uncertainty, enough capacity was approved to achieve the 2020 renewable energy target, regulatory risks, grid connector issues and lack of investment in the network (Clean Energy Council, 2020a; McConnell, 2019). The situation is therefore characterised by a lack of targets and planning at the federal level. The Clean Energy Regulator (CER) points at curtailment of renewable generation and delays in approvals for 2019 (CER, 2019f). Strong growth is continuing for small-scale renewable energy due to strong growth in uptake of rooftop solar by private households and small businesses. Some 2.2 gigawatts (GW) of capacity is expected to be installed in 2019 compared to 1.6 GW in 2018 (CER, 2019f).

A number of studies show the technical and economical feasibility of a transition to 100% renewable energy by the 2030s through simple and affordable policies, such as incentives for dispatchable renewables and storage, funding for transmission links, and incentives or legislation for retiring high polluting coal power (Blakers et al., 2017b; Diesendorf, 2018; Gulagi, Bogdanov, & Breyer, 2017; Howard et al., 2018; Riesz et al., 2016; Sven Teske et al., 2016b).

Growth of other zero and low-carbon technologies

The government's CCS programs and initiatives have supported several demonstration projects. Research and pilot studies are ongoing (CSIRO, 2019a). Research suggests fossil fuels with CCS are not viable compared to renewables (Sgouridis et al., 2019; Viebahn et al., 2012).

There are no nuclear power plants for electricity generation in Australia and nuclear energy is currently banned (Australia Government, 1999). There are currently no plans for nuclear power electricity generation.

Australia does not have any plans for application of biomass energy with carbon capture and storage (BECCS) to generate negative emissions.

2.1.2.2 **Actionable indicator #2**: Reduce emissions from coal power plants

Despite the clear need for a structured coal phase-out policy in Australia, there is currently no policy to phase out coal in Australia, and no systematic framework to ease the transition out of coal in regions where coal plays an important role. Coal is set to remain the main share of the fuel generation mix to 2030. Coal is projected to account for 54% of the electricity generation in Australia in 2020, and 39% in 2030 (DEE, 2019a).

The decrease in coal will contribute to the projected decrease in electricity sector emissions of 23% from 2020 to 2030 (DEE, 2019a). Coal power plant refurbishments will temporary reduce emissions from power plants, and the closure of the Liddel plant in 2022, unit 5 of the Muja C plant in 2023 and Yallourn plant in 2028-2030, but the rest of the coal fleet will be used at a higher capacity (DEE, 2019a). (RenewEconomy, 2020b)

The majority of Australia's coal fired power stations are old, inefficient and unlikely to be able to be retrofitted with carbon capture and storage (CCS) technologies, quite apart from the adverse economics of the latter technology. Currently, there are 19 grid-connected coal-fired power stations operating in Australia. Within a decade, around half of Australia's coal-fuelled generation fleet will be over 40 years old, with some currently operating stations approaching 60 years, all using obsolete sub-critical coal technology (Climate Council, 2014). These older plants will likely be too out-dated, inefficient and carbon-intensive to be candidates for retrofitting CCS technology (Climate Council, 2014, 2018a). These power stations are technically already obsolete and increasingly unreliable: faced with extreme heatwave events, these power stations already fail, on occasion leading to blackouts (Climate Council, 2018a). In addition, coal-fired power stations in Australia have extremely weak air pollution controls and there are substantial adverse health effects, particularly in Sydney (Sydney Morning Herald., 2018, 2019b, 2019c).

The government supports coal power through forcing power companies to extend coal-fired power plant lifespans or offering incentives to build new plants or securing coal supply.
The federal government has leveraged state support for renewables to prop up the coal sector. The federal government and New South Wales government agreed a deal to increase the supply of coal to the Mount Piper coal fired power plan to secure supply to at least 2042, in exchange for $2 billion AUD in funding for emissions reduction activities (RenewEconomy, 2020b).

The Energy Minister warned the new Retailer Reliability Obligation law will financially penalize retailers who do not provide power and uphold their contracts (Taylor, 2019). The government has also offered support to build new coal-fired power stations through a government power subsidy scheme (DEE, 2019n; Sydney Morning Herald., 2019a). Profitability prospects make refurbishment of the aging coal fleet or opening of new plants highly unlikely (Climate Council, 2018a), despite the intent of the government to push for more coal-fired power generation. One coal upgrade project has been shortlisted, along with hydro and gas projects (DEE, 2019n). Delaying coal power retirement inevitably slows the transition to renewables.

The study by the CSIRO and the AEMO (the energy market operator) found that renewables offer the lowest cost option to generate electricity, including storage, compared to coal-powered generation (CSIRO, 2018). The electricity sector will remain fossil fuel intensive with current policies, given there is no explicit emission reduction policy for the electricity sector, and instead an explicit push to support coal-fired power generation.

2.1.3 Conclusion

The conservative Liberal-National Coalition government has repealed the effective carbon pricing mechanism and back-tracked the now expired less than ambitious renewable energy target. There is no intention to continue the policy of renewable energy target setting nor introducing any policy whatsoever in the electricity sector to reduce emissions. Policy uncertainty and regulatory issues are causing renewable energy investments to plummet and are leading to curtailment and delays in grid connections. The government does not recognise the need for higher emissions reduction in the electricity sector compared to the overall emissions reduction target.

All but two of the state and territory governments have renewable energy targets to 2025 and beyond, with Western Australia and New South Wales being the exception. Tasmania, ACT and South Australia meet the Australia specific benchmark of 100% renewable energy generation by 2030s. Yet, national government support for coal continues and Australia is setting a path to take itself further away from meeting these benchmarks. Instead of phasing out coal, the government is promoting more coal through extending the lifespan of coal power plants and securing coal supply for current coal plants. Without a new renewable energy target, and without a reversal of policies, the sector will continue to be fossil fuel intensive business-as-usual.

Contrary to Australia's national-level actions of policy reversal, lack of targets and planning at federal level, and active support for fossil fuel based power generation, the state-level renewable energy targets and policies offer some action in Australia towards decarbonising the electricity sector building on the policies established by previous governments, therefore Australia is "getting started" in meeting the benchmark of growth in renewables, but has "no action" in reducing emissions of coal power plants and needs to urgently fill the policy void to create investment certainty and plan for a fast transition to 100% renewable energy with corresponding transmission and storage planning and investments.

2.2 Transport sector

The transport sector is the third largest source of emissions in the Australian economy (after electricity and industry), and emissions are growing fast. Transport emissions result from the combustion of fuels for transportation, whereas electricity for electric vehicles and other electric transport are not included here as they are accounted for in the electricity sector. In 2019, transport represented 18% of total emissions (see Figure 1) and has increased by 22% since 2005 (DEE, 2019a). Figure 4 demonstrates the emissions from different sources of transport. Road transport currently represent the largest source of transport emissions, accounting for 85% (DEE, 2019a). Car emissions have grown by 25% since 1990 (DEE, 2019a). Emissions are projected to stabilise, with only slight increase a 7% increase from 2020 to 2030 in the transport sector, despite economic growth, population growth and increase in transport activity, due to energy efficiency and rise of electric vehicles (DEE, 2019a). The projected rise of electric vehicles is shown in Figure 20.

Australia's combined vehicle fleet of 19.2 million vehicles is one of the world's most polluting and least efficient (Climate Analytics, 2019e), with the emissions performance of its car and truck fleet far behind the US, China, Japan, India, and the EU, and the projected improvement being smaller than for these countries, meaning it will continue to fall behind even further. The International Energy Efficiency Scorecard for transportation assesses a combination of policy and performance metrics related to energy efficiency in transport. The Scorecard rated Australia as one of the worst countries, with a score of 6.5 out of a total score of 25 (Castro-Alvarez, Vaidyanathan, Bastian, & King, 2018). Many other countries are far ahead in terms of policies regarding emissions standards and initiatives and targets for electric mobility.

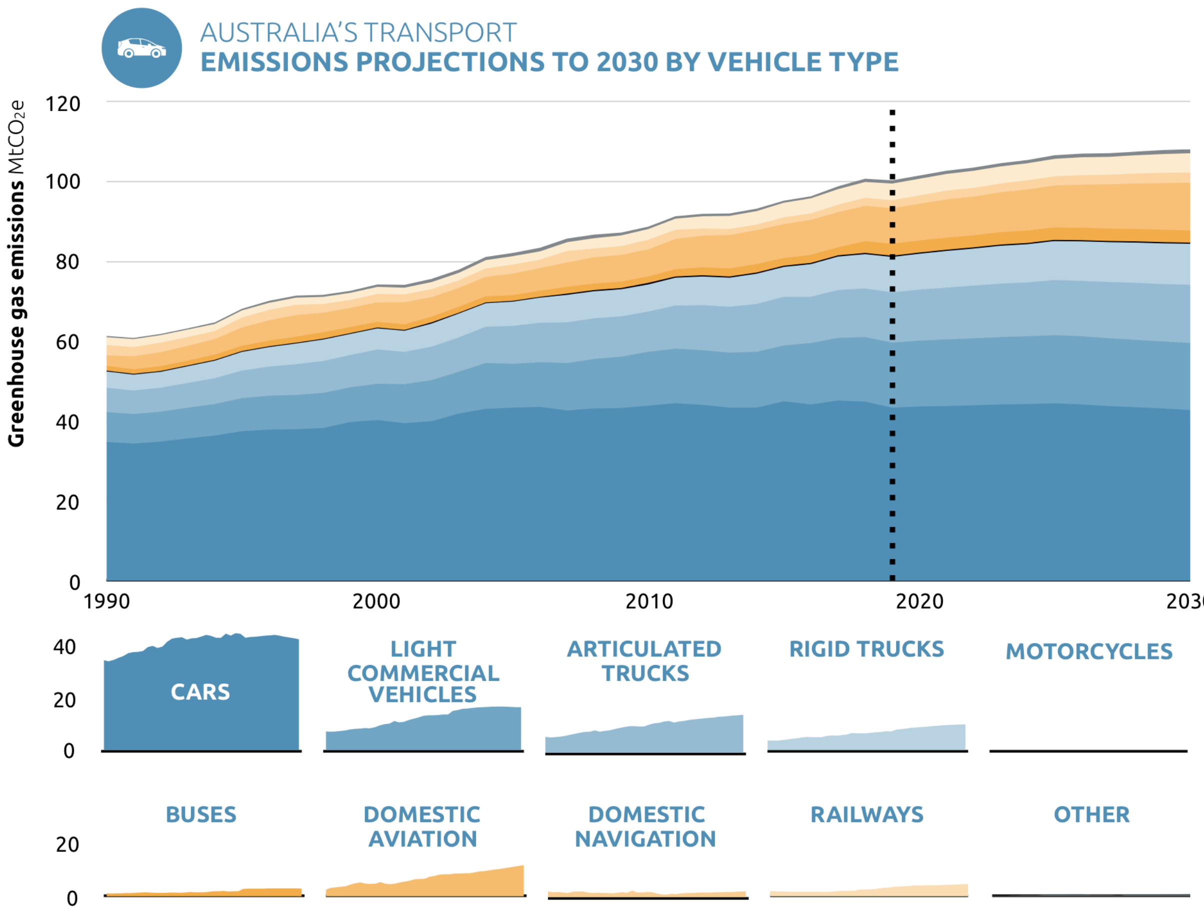


Figure 19. Australia's transport emissions, (historical data from 1990 to 2019, projected data 2020 to 2030) (LCVs = Light Commercial Vehicles). Source: (DEE, 2019a).

Nearly 80% of new light-duty vehicles sold globally are subject to some kind of emissions or fuel economy standard, and some countries such as Canada, China, Japan, and the United States have introduced efficiency standards for heavy-duty freight vehicles. The EU has mandatory emissions targets for new cars and heavy-duty vehicles (European Commission, 2019b). Australia does not have any efficiency or carbon emissions standards for passenger vehicles, let alone heavy-duty vehicles, leaving the country at risk of being a dumping ground for vehicles from countries with emissions standards. This is despite the Climate Change Authority (Climate Change Authority, 2014) recommending a cost effective policy for light vehicle emissions standards to achieve lower emissions and lower fuel bills for motorists in 2014.

In the absence of the introduction of CO_2 efficiency standards for motor vehicles, light duty vehicles trucks and buses, as well as modern air pollution standards it is increasingly likely that Australia will become the dumping ground for motor vehicles that cannot be sold in other markets due to increasing environmental standards[6].

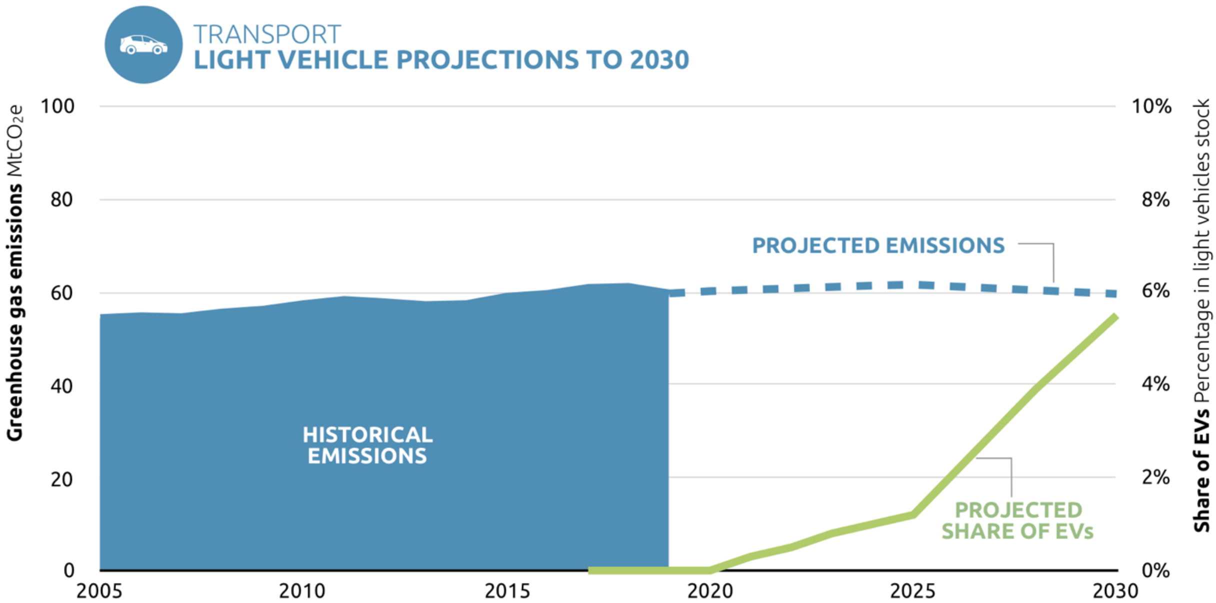


Figure 20 - Light vehicles emissions and the percentage of Electric Vehicles in the light vehicle fleet. Source: (DEE, 2019a).

6 https://reneweconomy.com.au/australia-risks-becoming-dumping-ground-for-worlds-most-polluting-cars-44012/

Table 9: Progress on the most important steps in the transport sector to limit temperature increase to 1.5°C

Sector	1.5 °C-consistent benchmark	Projection(s) under current policies	Gap assessment (qualitative)	Policy rating
Transport sector	Last fossil fuel car sold before 2035	• *Electric Vehicles (EVs, including plug-in hybrid are projected to represent 1% in 2025 and 6% in 2030* (DEE, 2019a) *(see Figure 5).* • *EVs will account for 0.5% of new light vehicle sales in 2020, 5% in 2025 and 19% in 2030* (DEE, 2019a). • *Another projection indicates that (without government intervention) EV sales would cover 22% of new car sales by 2030, and EVs would represent 73% of cars on the road by 2040 (CEFC, 2018b).*	- There are no targets to end the sales of fossil fuel cars. - It is unlikely the benchmark will be met as the latest government figures indicate EVs will account for 19% of light vehicles sales in 2030, fossil fuel cars will likely still represent the majority share of vehicle sales in 2035. - Australia is one of the few countries in the world without any emission or fuel efficiency standards for light duty vehicles. - The current piecemeal policies are ineffective. Recent auctions for the Emissions Reduction Fund have not seen projects in the transport sector. The safeguard mechanism only applies to a small portion of transport emissions. Token gestures such as the luxury car tax have small benefits compared to government support for fossil fuels through the fuel tax credit scheme. - The government has announced the development an electric vehicle strategy, but this has not been published (Australian Government, 2019a). - There are no plans to decarbonise passenger transport, nor emissions standards for the sector, and the current government has not indicated any intention to introduce these, despite five years of deliberations in the Ministerial Forum on Vehicle Emissions (MFVE)	
	Freight trucks need to be almost fully decarbonised by approximately 2050	• *Articulated and rigid trucks will represent 21% of transport emissions in 2020 and 23% in 2030* (DEE, 2019a). *Emissions from trucks will increase 14% from 2020 to 2030* (DEE, 2019a).	- There are no plans to decarbonise freight trucks in Australia, despite the projected increase in road freight transport emissions. - Australia does not have emissions or fuel efficiency standards for heavy duty vehicles, unlike other major economies (EU, Canada, China, Japan, USA) (Climate Analytics, 2019e). +/- The National Hydrogen Strategy could be used to decarbonise heavy long-range road transport, although it may also use hydrogen derived from fossil fuels and support the fossil fuel sector.	

	Aviation and shipping: Develop and agree on a 1.5°C compatible vision	• *Domestic aviation accounts for the majority of emissions, for the non-road forms of transport sources, accounting for a projected 9% of transport emissions in 2020 and 11% in 2030* (DEE, 2019a). *The government projects a 31% increase in domestic aviation emissions from 2020 to 2030 due to flight demand increases* (DEE, 2019a). • *Domestic shipping emissions are projected to represent 2% of transport emissions in 2020 and 2030* (DEE, 2019a). *Domestic shipping emissions are projected to increase by 26% from 2020 to 2030* (DEE, 2019a).	- There is no 1.5°C compatible vision, or any discussion under development for decarbonising the domestic aviation and shipping sectors in Australia, despite the projected increase in emissions. +/- Australia has committed to offsetting international aviation through the ICAO Carbon Offsetting and Reduction Scheme for International Aviation (DFAT, 2019). + Australia has committed to reducing GHG emissions from international shipping to 50% below 2008 levels by 2050, as a member of the UN International Maritime Organisation (DFAT, 2019).	

2.2.1 Actionable benchmarks in transport sector

The Climate Action Tracker identified two short-term actionable benchmarks for the transport sector to limit warming to 1.5°C at a global level (Kuramochi et al., 2018):

- The last fossil car needs to be sold before 2035 to achieve car fleets consisting of 100% zero-emissions cars by 2050.
- A 1.5°C compatible vision for aviation and shipping needs to be developed and agreed upon.

Additionally, freight transport needs to decarbonise: Freight trucks need to be almost fully decarbonised by approximately 2050 (Climate Action Tracker, 2018b).

2.2.2 Recent policy developments

Since 2015, the Australian Government has been consulting on mandatory fuel emissions standards. It established a Ministerial Forum to coordinate Federal and State government approaches to addressing emissions from motor vehicles, including new measures for improving fuel quality standards, with next steps to encourage the uptake of low emissions vehicles (Australian Government, 2019e). The Forum intends to provide a draft implementation plan on potential measures for consideration by Government. Meanwhile Australia continues to have no efficiency or carbon emissions standards for passenger vehicles, which cause the largest share of emissions, only relying on information programmes such as the Green Vehicle Guide. The government has announced it will develop a strategy for electric vehicles but no details have been provided and no targets have been set.

Table 10 provides a comprehensive overview of the currently implemented and planned sectoral climate policies. It illustrates how Australia is one of the few countries that has not implemented fuel efficiency standards (Climate Analytics, 2019e), or any targets for the uptake of electric vehicles.

Table 10: Overview of implemented climate change policies in the transport sector in Australia

OVERVIEW OF EXISTING AND PLANNED CLIMATE CHANGE POLICIES FOR THE TRANSPORT SECTOR IN AUSTRALIA				
Changing Activity	**Energy efficiency**	**Renewables**	**Modal switch**	**Other**
Urban planning and infrastructure investment to minimise transport needs Investment in passenger rail: The national rail program funded AUD $10 bil. in passenger rail projects and $20 mil. In faster rail connections (Australian Government, 2017a, p. 34). Plus, AUD $500 mil. upgrade to regional rail in Victoria, and the CEFC funded $150 million in the south-west Sydney freight hub (Australian Government, 2017a).	**Minimum energy/emissions performance standards or support for energy efficient for light duty vehicles** (none)	**Biofuel or other RE target** (none)	**Support for modal share switch** (none)	**Low emission vehicle finance** The Clean Energy Finance Corporation (CEFC) finances low carbon emission vehicle upgrades for businesses. By 2017, the CEFC helped finance nearly 1000 vehicle upgrades (CEFC, n.d.). (CER, 2019b)(CER, 2016b, 2016a) (Climate Change Authority, 2019) (ATO, 2019)
	Minimum energy/emissions performance standards or support for energy efficient for heavy duty vehicles (none)	**Support schemes for biofuels** No overall support schemes but some research funding from ARENA (2020) with 3 projects with a total value of AUD$ 20.9 mil.	**E-mobility programme** **Clean Energy Finance Corporation (CEFC) and Australian Renewable Energy Agency (ARENA) financing** The CEFC has financed nearly $43m AUD in electric vehicle (EV) purchases (CEFC 2018). The CEFC and Macquarie Leasing established a $100 million AUD asset finance program, providing discounts on finance for electric and plug-in hybrid vehicles (CEFC, 2017). ARENA has supported the research and development for biofuel technology and an EV charging network for the east coast of Australia (Climate Change Authority, 2019).	**Emissions Reduction Fund (ERF)** The ERF (policy details are found in Table 1) has avoided 1.2 $MtCO_2e$ through the transport sector (CER, 2019b), by replacing vehicles, modifying vehicles, fuel switching, changing operational practices for land and sea vehicles or in aviation (CER, 2016b, 2016a). However The past 3 auctions (June 2018, December 2018, July 2019) saw no certificates issued relating to transport (CER 2018b, 2019a).
	Consumer education initiatives The Green Vehicle Guide is a government initiative to inform vehicle buyers on the environmental performance of light	**Sustainability standards for biomass use** (none)	**National Hydrogen Strategy** The National Hydrogen Strategy is 'technology neutral' and includes renewable energy to a degree but also allows for fossil fuel based	**Safeguard Mechanism** A small share of transport emissions is covered under the safeguard mechanism as large transport facilities have to

	vehicles (Australian Government, 2019d). New vehicles in Australia require a label displaying the fuel efficiency and carbon dioxide emissions on the windscreen when sold to inform buyers (Australian Government, 2019c).		hydrogen with CCS as "clean hydrogen". The government plans to support research and trials, including using hydrogen for transport with a focus on heavy long-range road transport, rail and shipping (COAG Energy Council, 2019a).	measure and manage their emissions (Climate Change Authority, 2019).
				Tax discounts The luxury car tax is imposed on expensive cars, but fuel-efficient vehicle owners have the benefit of a higher tax threshold (ATO, 2019).
				Road User Charge A tax applied to gasoline and diesel used by heavy vehicles on public roads (OECD, 2019).

No policies currently exist and a similar policy gap exists in all other countries

No policies currently exist however Australia could adopt policies from other countries

Existing and planned policies in Australia

There are an array of piecemeal policies within Australia with implications for the transport sector. Even though cars contribute a significant proportion of emissions for this sector, Australia does not have any roadworthy or emission testing requirements for vehicles in use. Old inefficient vehicles can be kept on the road for long timeframes.

Australia has fuel quality standards enforced by the Fuel Quality Standards Act 2000 and the Fuel Quality Standards Regulations 2001 (to be replaced by the Fuel Quality Standards Regulations 2019) (DEE, 2019h). These regulatory incentives set a minimum requirement to safeguard the consumer and the environment and aim to reduce vehicle emissions, however, these are not related to greenhouse gas emissions.

The Clean Energy Finance Corporation (CEFC) promotes vehicle efficiency. In 2017-2018, the CEFC provided AUD$100m for transport (CEFC 2018). Part of the CEFC transport funding provides finance to businesses wanting to upgrade their fleet to low carbon emissions vehicles, and nearly 1000 lower emissions vehicles had been financed by 2017 (CEFC, n.d.).

The Emissions Reduction Fund offers Australian Carbon Credit Units to encourage businesses and organisations in the transport sector to voluntarily reduce their emissions by replacing or modifying their vehicle fleet, fuel switching, or changing the operational practises in different areas of the transport sector (CER, 2016b, 2016a). The past 3 auctions (June 2018, December 2018, July 2019) saw no certificates issued relating to transport (CER, 2018b, 2019b).

The safeguard mechanism aims to ensure that emissions reductions from the ERF are not displaced by increases elsewhere. It applies to facilities with large emissions, including those in the transport sector. However, the safeguard mechanism only covers a small proportion of road transport emissions (Climate Change Authority, 2019).

The luxury car tax incentivises vehicle efficiency as it provides a higher tax threshold for efficient cars. The luxury car tax applies to vehicles valued above AUD$67,525, but fuel-efficient vehicles only pay the tax if they are valued over AUD$75,526 (ATO, 2019). However, the Australian government also provides a fuel tax credit scheme that subsidies the use of fossil fuel vehicles. The fuel tax credit scheme allows companies to claim tax credits on fuel used, including on fuel used by heavy vehicles and light vehicles travelling off public roads. The scheme budget has increased year on year to a 2019-20 budget of AUD$7.2 billion (Market Forces, 2019). The luxury car tax discount may be a token incentive to persuade some consumers to purchase fuel-efficient vehicles, however, overall government tax discounts support the fossil fuel industry, subsidising both fuel producers and users.

The Australian government has produced a few initiatives to educate the consumer when purchasing vehicles to increase awareness of vehicle efficiency and its benefits The Green Vehicle Guide is an information program to inform purchasers (individuals and businesses) on efficient vehicles. The government also rolled out fuel efficiency and carbon dioxide labels placed on the windscreen of new cars at the point of sale.

The Ministerial Forum on Vehicle Emissions (MFVE) was established to coordinate an all-of-government approach to addressing motor vehicle emissions. The MFVE have sought consultation on draft regulation impact statements on vehicle emissions and fuel efficiency. There has been no further action taken to date (Australian Government, 2019e).

The market share of electric vehicles in Australia is 0.6% of new vehicle sales, in comparison to 2.5% to 5% in developed countries (Electric Vehicle Council, 2020). The sales of electric vehicles tripled in 2019 despite the lack of government support (Electric Vehicle Council, 2020).

The uptake of electric vehicles in Australia has been hindered by lack of charging infrastructure, incentives and policies which discourages potential buyers. Over 2 million households have rooftop solar in Australia, which pairs well with at-home electric vehicle charging. 'Electric highways' have been set up in Western Australia with the "RAC Electric Highway", the "Queensland Electric Super Highway" and the Tesla Supercharge network in south-eastern Australia. It is now possible to circumnavigate Australia with an electric vehicle although "bush standard" (32 amp) charging may be slow in the more remote areas (AEVA, 2018). Access to fast charging and more charging locations will increase electric vehicle uptake.

The need to develop charging infrastructure and an increase in uptake of electric vehicles was recognised by the Clean Energy Finance Corporation (CEFC). Since the CEFC inception, it has provided nearly AUD$43 million to support the purchase of EVs (CEFC 2018). ARENA has provided research and development funding for an electric vehicle charging network on the east coast (Climate Change Authority, 2019). The CEFC and Macquarie Leasing brokered a deal to accelerate the uptake of electric vehicles through a AUD$100 million asset finance program. They offered a 0.7 percent discount on finance for EVs and plug-in hybrid vehicles (CEFC, 2017).

The Australian government has announced it will develop a national strategy for electric vehicles. The government expects this strategy to reduce emissions by up to 10 $MtCO_2e$ by 2030 (Australian Government, 2019b), however no details are provided, apart from the strategy intending to support electric vehicle recharging infrastructure, and no targets have been set.

The National Hydrogen Strategy promotes the creation of hydrogen hubs to develop supply chain infrastructure, and promote sector coupling, including transport, industrial use, exports and gas blending (COAG Energy Council, 2019a). The strategy is technology neutral, however, if the hydrogen used in transport fuel cells is derived from renewable energy, it will introduce a new carbon free source of transportation into the energy mix. Renewable hydrogen presents opportunities to replace emissions intensive freight transport for heavy long-range road transport, rail and shipping.

The Hydrogen Strategy 'initial steps' relating to transportation include agreeing a shared vision for cost competitive hydrogen for transport applications, building demand for hydrogen as a transport fuel, supporting refuelling station on major freight corridors, agreeing fuel infrastructure priorities, considering hydrogen use for government vehicle fleets, supporting building refuelling infrastructure with industry, and promoting open access to any government support refuel infrastructure (COAG Energy Council, 2019a). Preliminary work has started to establish prospective Australian use cases, 'next steps' include cost benefit analysis of pilot projects, integration of pilots with a roadmap with investment priorities, and incentivising private investment (Floyd, Hibbert, & Amico, 2019).

There are no emissions targets specifically related to Australia's rail network. Regarding Australia's national rail program, the 2017-2018 budget involved $10 billion AUD to invest in passenger rail projects, and another $20 million for faster rail connections between capital cities and regional centres (Australian Government, 2017a, p. 34). The government invested $500 million to upgrade regional rail in Victoria, and the CEFC invested $150 million in a south-west Sydney freight hub (Australian Government, 2017a). The hub is expected to reduce emissions by 0.1 $MtCO_2e$ per year switching freight from trucks to trains (Australian Government, 2017a).

Comparison of recent developments and projections to benchmarks

2.2.2.1 **Actionable indicator No.3:** Last fossil fuel car sold before 2035

There are no plans to phase out combustion engines in cars, and there are no policies or targets in place. Compared to other countries, the uptake of electric vehicles (EVs) is very slow in Australia. The current uptake rate is around 0.5% of new light vehicle sales, and projected to increase to 19% by 2030 (DEE, 2019a). Despite this slow progress, no federal policies are in place to incentivise use or support charging infrastructure.

Expert advisers such as the Climate Council (2018b) are asking for a national strategy for transport. Policy inaction and lack of support hold back the adoption of zero-emission vehicles. Particularly without an EV strategy, there is a need for policy to cover the main source of transport emissions, i.e light vehicles.

Freight transport

The National Hydrogen Strategy recently adopted covers freight transport but does not have any specific decarbonisation targets. The rigid and articulated trucks subsectors can transition to zero emissions if the hydrogen used for transportation fuel is derived from renewable sources, however, the Hydrogen Strategy includes fossil fuels.

1.1.1.1 **Actionable benchmark No.4:** Develop a 1.5°C compatible vision in aviation and shipping

Aviation

There is no domestic policy to tackle emissions in domestic aviation despite the upward trend in emissions projected for this sector. Emission from domestic aviation will increase from 9 $MtCO_2e$ in 2020 to 12 $MtCO_2e$ in 2030 (DEE, 2019a). The government has made commitments to reduce international aviation emissions. Australia was a founding member of the International Civil Aviation Organisation and is collaborating internationally to achieve a medium-term goal of keeping global net international aviation emissions at the same level from 2020, including a Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) (DFAT, 2019) which will ensure aircraft operators offset their international flight emissions from 2021 (CCA 2019a).

Maritime shipping

Similarly, there is no domestic maritime climate policy to deal with the subsectors' emissions. Projections for domestic shipping will remain at 2 $MtCO_2e$ in 2020 and 3$MTCO_2e$ 2030 (DEE, 2019a). The government has made commitments to reduce emissions for international shipping. As a member of the UN International Maritime Organisation (IMO), Australia has committed to reducing GHG emissions from international shipping to 50% below 2008 levels by 2050 (IMO Resolution MEPC 304 (72)) (DFAT, 2019).

2.2.3 Conclusion

There are scattered and ineffective policies and no comprehensive sector-level action. The transport sector currently constitutes the third largest source of emissions in Australia. Car transport accounts for the largest portion of these emissions. The emissions performance of Australia's car and truck fleet is among the worst in the world (Castro-Alvarez et al., 2018). The Ministerial Forum on Vehicle Emissions has been coordinating an approach since 2015 but without yet setting an emissions standard. The emissions standard is urgently needed to provide a Paris-compatible pathway for this sector. **Australia does not have any efficiency or carbon emissions standards for passenger vehicles, despite nearly 80% of new light-duty vehicles sold globally are subject to some kind of emissions or fuel economy standard**. The Climate Change Authority (2020) has recommended implementing a GHG standard for light vehicles, and a cost-benefit analysis for an emissions standard for heavy vehicles. **Australia is also one of the few major economies without any strategy for electric mobility.** The government recently announced it will develop a strategy (Australian Government, 2019b) but has not provided any details. The National Hydrogen Strategy could reduce emissions in freight transport, but the strategy does not include any specific decarbonisation targets and does not focus on hydrogen derived from renewable energy so it is unclear if emissions will decrease for this subsector.

2.3 Buildings sector

Direct combustion of fossil fuels in the buildings sector accounts for 3 per cent of Australia's total emissions (DEE, 2019a). The buildings sector includes both residential and commercial direct combustion emissions, mainly from gas consumption (DEE, 2019a). The direct combustion emissions from buildings is projected to marginally decrease by -4% from 2020 to 2030 (DEE, 2019a).The marginal decrease in emissions is attributed to energy efficiency improvements as a result of the Climate Solutions Package offsetting new buildings connecting to the gas network (DEE, 2019a).

The buildings sector accounts for 57% of Australia's electricity usage (IEA, 2018a) so energy efficiency in buildings and appliances is an essential part to decarbonise this sector. Residential and commercial buildings constructed after 2019 could cover 51% of all buildings by 2050 (ClimateWorks Australia, 2018a). Both new buildings and existing need to be energy efficient. Australia lacks a strategy to reach a 1.5 °C consistent benchmark in the buildings sector. Failure to ensure adequate levels of energy efficiency in buildings places further pressure on the electricity grid to decarbonise.

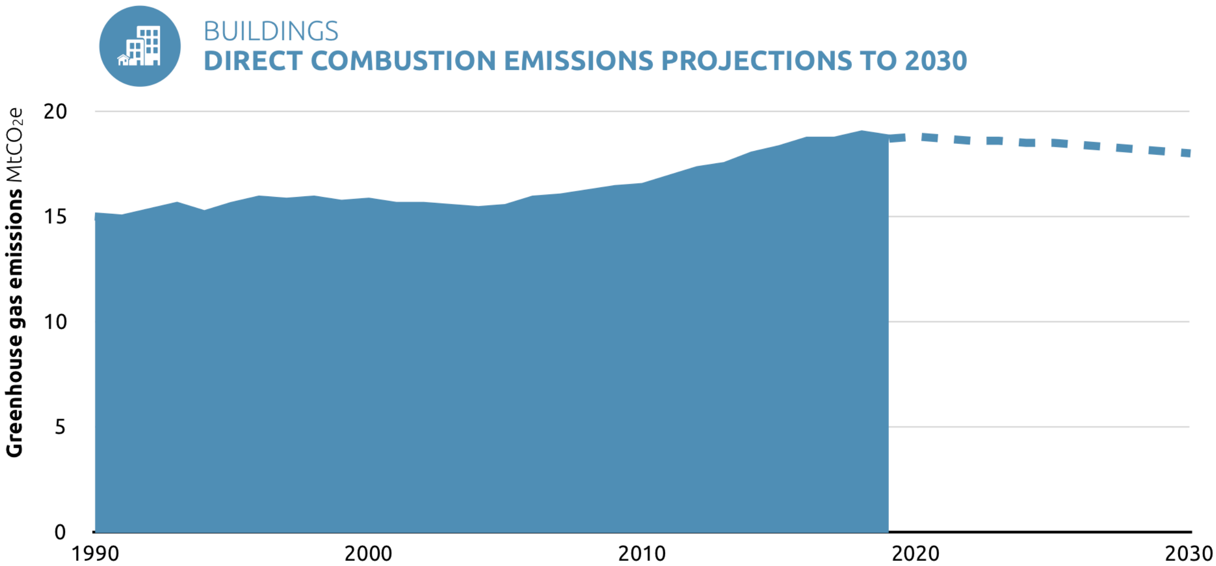


Figure 21 - Direct combustion from buildings emissions, (historical data from 1990 to 2019, projected data 2020 to 2030) Source: (DEE, 2019a)

Table 11 provides a comprehensive overview of implemented and planned sectoral climate policies. It illustrates how Australia has shown no action in establishing adequate policies in this sector to substantially improve energy efficiency or minimise sector emissions.

Table 11: Progress on the most important steps in the buildings sector to limit temperature increase to 1.5°C

Sector	1.5 °C-consistent benchmark	Projection(s) under current policies	Gap assessment (qualitative)	Policy rating
Buildings sector	*All new buildings fossil-free and near zero energy by 2020*	• *Emissions from the buildings sector are projected to marginally decrease from 18.8 $MtCO_2e$ in 2020 to 18 $MtCO_2e$ in 2030 DEE 2019a).* • • *The Climate Solution Package estimates new energy efficiency measures (which are focused on buildings) will reduce emissions by 63 $MtCO_2e$ by 2030 (Australian Government, 2019b).*	- There is no policy to ensure new builds will be fossil fuel-free or near zero energy by 2020 to meet this benchmark. +/- The National Construction Code has minimum building efficiency standards. These standards need to be improved (ClimateWorks Australia, 2018a; COAG Energy Council, 2018a, 2018b; Harrington et al., 2018). - The National Construction Code is not due to be updated until 2022 (ABCB, 2019b), after the benchmark deadline. + The Council of Australian Governments (COAG) is considering applying the Commercial Building Disclosure program to other buildings (DEE, 2019f), which would reduce building emissions. + The government has started a new Energy Efficient Communities Program to support energy efficiency in buildings + Some state governments have market mechanism schemes in place to increase energy efficiency (Climate Change Authority, 2019). - Residential building efficiency standards are behind other countries with similar climates (Energy Efficiency Council, 2019). - Building sector stakeholders find there is widespread under-compliance for energy efficiency in buildings (Government of South Australia, n.d.).	Getting Started
	Increase building renovation rates from <1% to 5% by 2020	• Australia has no building renovation projections. •	- There is no data on building renovation rates nor policy focussed on increasing building renovation rates. +/- The National Construction Code applies to major renovation work in existing buildings (NatHERS, 2019a) and the NCC needs to be improved however, the next NCC update 2022 is beyond the benchmark deadline (as detailed above).	No Action

2.3.1 Actionable benchmarks in the buildings sector

The Climate Action Tracker identified two short-term actionable benchmarks for the buildings sector to limit warming to 1.5°C at a global level (Kuramochi et al., 2018):

- All new buildings ought to be fossil-free and near-zero energy by 2020.
- The annual retrofit rates of existing building stock need to increase from less than 1% in 2015 to 5% by 2020.

The following gap analysis compares historical and projected developments in Australia's buildings sector to these global benchmarks without any further adjustment to allow for comparison between countries under analysis. Country specific circumstances will be addressed in the in-depth analysis on raising ambition in the following chapters. Please refer to Kuramochi et al. (Kuramochi et al., 2018) for a more detailed explanation of each indicator.

2.3.2 Recent policy developments

Table 12 provides a comprehensive overview of the implemented and planned sectoral climate policies.

Table 12: Overview of existing and planned climate change policies in the buildings sector in Australia.

<table>
<tr><th colspan="3">OVERVIEW OF EXISTING, PLANNED AND POTENTIAL CLIMATE CHANGE POLICIES FOR THE BUILDINGS SECTOR IN AUSTRALIA</th></tr>
<tr><th>Changing Activity</th><th>Energy efficiency</th><th>Renewables</th></tr>
<tr><td rowspan="2">Urban planning strategies
(none- going forward)
The 'Our Cities, Our Future' national urban policy published in 2011 long-term objectives end in 2020 (Australian Government, 2011b).</td><td>Building codes and standards and fiscal/financial incentives for low-emissions choices
▪ National Construction Code (NCC). The National Construction Code is implemented through state legislation and provides a minimum efficiency requirement for commercial and residential properties (Climate Change Authority, 2019). This code has been revised with a new version effective from 1 May 2019, including enhanced energy efficiency provisions for commercial buildings (ABCB, 2019a).
▪ Commercial Buildings Disclosure (CBD) Program. Under the CBD program, sellers and lessors must disclose the energy efficiency ratings of large commercial office spaces (Australian Government, n.d.).
▪ National Carbon Offset Standard. The Carbon Offset Standard is a government standard to support businesses to voluntarily measure, reduce and offset their greenhouse gas emissions (DEE, 2019d).
Energy Efficient Communities Program. The program offers AUD$50m in grants to improve energy efficiency technology and practises, available to businesses and community organisations (DEE, n.d.)</td><td>Support scheme for heating and cooling
(none)</td></tr>
<tr><td>Minimum energy performance and equipment standards for appliances
▪ Greenhouse and Energy Minimum Standards (GEMS) The Greenhouse and Energy Minimum Standards Act 2012 (Australian Government, 2012) sets minimum energy performance standards and energy rating labelling requirements for products such as air conditioning units, dishwashers, fridges, lighting, televisions, etc. This act is currently under review.</td><td>Support scheme for hot water and cooking
(none)
Sustainability standards for biomass use
(none)</td></tr>
<tr><td colspan="3">Fossil fuel subsidies
• No policy to reduce fossil fuel subsidies</td></tr>
</table>

No policies currently exist and a similar policy gap exists in all other countries	*No policies currently exist however Australia could adopt policies from other countries*	*Existing and planned policies in Australia*

Major building regulations and codes

There are no mandatory emissions standards in the Australian buildings sector, but emissions are marginally addressed through policy relating to energy efficiency. The Council of Australian Governments (COAG) developed a National Energy Productivity Plan (NEPP), which sets out a general framework with an aim to improve energy productivity by 40% over from 2015 to 2030 (Australian Government, 2015). This target requires Australia to double its energy productivity compared to 2015 business as usual levels (Australian Government, 2015). Although the NEPP is not solely focussed on the buildings sector, it outlines a number of measures related to the building sector. One measure was to develop a national approach to residential building energy ratings by 2016. The COAG Energy Council developed principles whereby state and territory governments develop their own schemes (COAG Energy Council, 2016).

New buildings in Australia have to comply with the National Construction Code (NCC). The NCC is overseen by the Australian Building Codes Board (ABCB) and defines Australia's building regulations, standards and performance requirements. Part of the National Construction Code's purpose is to provide commercial and residential properties with minimum energy efficiency requirements (Climate Change Authority, 2019). The code regulates the building, heating and cooling equipment, lighting and hot water. The Nationwide House Rating Scheme (NatHERS) is used to assess compliance. The NCC was revised in May 2019 with enhanced energy efficiency requirements for commercial buildings, but the code did not change for residential buildings (ABCB, 2019a).

Residential properties have flexible options in meeting requirements. Detached houses and row houses (categorised as class 1 buildings) can either comply with the 6 star rating of NatHERS, or meeting the "deemed to satisfy" NCC provisions, or develop their own performance solution demonstrating requirements are met through other means (NatHERS, 2019b). Apartments can have lower efficiency requirements than houses. Apartments can have 5 NatHERS stars, if there is an apartment average of 6 stars for the building (NatHERS, 2019b). State and territories may also have their own regulations (NatHERS, 2019b).

The National Construction Code minimum requirements (and the state and territory regulations in general[7]) are not deemed effective in providing adequate energy efficiency in buildings. Several assessments of the buildings sector are calling for further improvements to be made to the National Construction Code update in 2022 and policy certainty, including reports by the COAG Energy Council who have consulted sector stakeholders (ClimateWorks Australia, 2018a; COAG Energy Council, 2018a, 2018b; Harrington et al., 2018). The COAG Energy Council Report for Achieving Low Energy Homes (COAG Energy Council, 2018a) identifies market failures and barriers that are preventing change without government intervention. Barriers include a lack of information, such as payback periods; split incentives, when one party accrues costs for example of capital investment, but another receives the benefits such as lower bills; and capital constraints, such as the high upfront capital costs for financial savings over time (COAG Energy Council, 2018a).

The National Construction Code applies to new building work in existing buildings as "major renovations" but what is considered a "major renovation" differs by state and territory (NatHERS, 2019a). There are no specific policies or targets to increase renovation rates.

Buildings can meet voluntary but more ambitious measures. Buildings can be constructed beyond the NatHERS minimum requirement of 6 stars. However, a study analysing 187,000 NatHERS certificates from 2016 to 2018 found that 82% of Australian housing is designed to meet minimum requirements, and 98.5% are below the economic and environmental optimum (Moore, Berry, & Ambrose, 2019). The average NatHERS rating was 6.2 stars (Moore et al., 2019). Therefore, Australian's do not often opt for low emissions buildings.

The National Energy Efficient Building Project (NEEBP) was designed in 2012 to support better energy efficiency in new buildings and renovations (Government of South Australia, n.d.). The Government of South Australia leads the project, jointly funded through the COAG Energy Council (Government of South Australia, n.d.). The initial review of Australian buildings under the project found that under-compliance to NatHERS standards was widespread, particularly in residential properties (Government of South Australia, n.d.). The project has since conducted a number of trials to determine the best methods for compliance (Government of South Australia, n.d.).

The Commercial Buildings Disclosure (CBD) Program mandates sellers and lessors of large commercial office space to disclose energy efficiency ratings of their properties. The CBD program is currently under review to assess whether the program should be expanded to other high-energy buildings, for example, shopping centres, data centres, hotels and office tenancies (DEE, 2019f). The program is projected to reduce emissions by 3.6MtCO_2e from 2015 to 2019 (ACIL ALLEN, 2015).

[7] It is beyond the scope of this overview to discuss the wide array of regulations in place at the state level.

The Carbon Neutral Program is a measure to support businesses to voluntarily measure, reduce and offset greenhouse gas emissions. The government offers a National Carbon Offset Standard, and a framework to claim and be certified as carbon neutral for organisations, products/services, buildings, precincts and events (DEE, 2019d). In 2017, carbon-neutral certified businesses voluntarily offset over 205 $MtCO_2e$, which includes the voluntary retirement of over 0.11 $MtCO_2e$ of ACCUs (Climate Change Authority, 2019). Total emissions reductions are greater than these figures as organisations are required to reduce emissions before offsetting (Climate Change Authority, 2019). Only 6 buildings have been certified carbon neutral (DEE, 2019d). The buildings have implemented some energy efficiency measures and have onsite renewable energy, but they offset remaining emissions, through investing in carbon offset projects (DEE, 2019d).

The Energy Efficient Communities Program will be available from "early 2020". It will provide AUD$50m in grants for small businesses, businesses that consume over 0.05 petajoules of energy per year, and community organisations to encourage the implementation of energy efficiency practises and technology (DEE, n.d.). The Program aims to deliver 3 $MtCO_2e$ in abatements to 2030 (DEE, n.d.). The program intends to save energy through equipment upgrades such as installing solar PV and batteries, or solar hot water. It supports the investment in energy and emissions monitoring and management systems, and energy systems assessments (DEE, n.d.).

Appliances

The Greenhouse and Energy Minimum Standards (GEMS) Act 2012 (Australian Government, 2012) established a framework for product energy efficiency. Regulated products such as fridges and televisions have minimum energy performance standards and/or energy rating labels (Australian Government, 2019g). An intergovernmental agreement for GEMS was signed on behalf of Australian Capital Territory, New South Wales, Queensland, Tasmania, Victoria and Western Australia (Australian Government, 2016a). The Northern Territory is not a signatory, but New Zealand takes part in the scheme. The GEMS act may change as it is currently under review. The draft review suggests the act is effective but further benefits could be achieved through updating efficiency standards and expanding the coverage to other high energy products (Commonwealth of Australia, 2018). Reporting indicates that the standards reduced emissions by 11.8 $mtCO_2e$ per annum (Australian Government, 2017b).

2.3.3 Comparison of recent developments and projections to benchmarks

2.3.3.1 **Actionable indicator No.5:** All new buildings fossil free and near zero energy by 2020

Australia does not have a policy in place to ensure new buildings are fossil-free, or for buildings to be near zero energy by 2020. At present, current policy focuses on the energy efficiency of commercial buildings. The 2019 update to the NCC improved the energy efficiency of commercial buildings, without changes in efficiency requirements for residential buildings. Documents by the COAG Energy Council indicate that government and stakeholders have established a trajectory to low emissions buildings (COAG Energy Council, 2018b). But the trajectory entails major changes to the National Construction Code. The Climate Change Authority (Climate Change Authority, 2020) support this trajectory and accelerating energy efficiency improvements in the NCC. Plans for any further improvements to the very limited efficiency requirements detailed in the NCC already in place are not set to occur until the next NCC update in 2022. Therefore, it is unlikely the benchmark deadline of 2020 will be met.

Government projections show emissions from the buildings sector will marginally decline due to energy efficiency measures listed in the Climate Solutions Package released in February 2019 (DEE, 2019a). The Climate Solutions Package lists several energy efficiency policies including the

Energy Efficient Communities Program to be implemented in early 2020; the Energy Rating Labels to include gas and electric heating appliances, which is yet to be implemented; improving the voluntary National Australian Built Environment Rating System (NABERS); and consideration for widening the application of the Commercial Building Disclosure (CBD) Program (Australian Government, 2019b).

The COAG Energy Council is reviewing the CBD Program changes, for the expansion of the program to other high energy demand buildings (DEE, 2019f). Expanding the program would further reduce emissions, although, it would not apply to the residential sector. The program may encourage new builds to be more efficient as sellers and lessors must disclose their energy efficiency rating.

Research suggests that more ambitious improvements are possible than the NEPP target. A recent study by the Energy Efficiency Council (Energy Efficiency Council, 2019) recommends Australia should raise its 2030 energy productivity ambition and set sub-targets for specific sectors such as buildings (Energy Efficiency Council, 2019). The study found that effective energy management could cover half of Australia's abatements to meet its NDC, through adopting global schemes and standards on energy efficiency. Yet, Australia has been ranked the worst developed country for energy efficiency policy and performance (Castro-Alvarez et al., 2018; Energy Efficiency Council, 2019). The current inadequate energy efficiency policy results in higher emissions than necessary (Energy Efficiency Council, 2019). Emissions can be reduced through adopting well-established energy management policies, practises and technologies that have proved successful in other countries (Energy Efficiency Council, 2019). An 'energy efficiency first' approach needs to be taken, with a national energy efficiency scheme, which would include strong minimum standards covering appliances and buildings (Energy Efficiency Council, 2019). These policies would create additional benefits of lower bills, improving productivity of buildings, increase in jobs, economic growth and increased energy security (Energy Efficiency Council, 2019).

The Australian Sustainable Built Environment Council (ASBEC) found that cost-effective building and appliance upgrades would reduce buildings' energy consumption by more than 25% by 2030, resulting in household and energy bills by $20 billion AUD over 15 years (ASBEC, 2016b).

Actionable indicator No.6: Increase building renovation rates from <1 to 5% by 2020
There are no policies in place to increase building renovation rates, despite the fact that buildings are long-lived assets. The National Construction Code applies to major renovation work in existing buildings, but the current standards for residential buildings are behind compared to other countries with similar climates (Energy Efficiency Council, 2019).

2.3.4 Conclusion

Government policies relating to the buildings sector are inadequate. There are effectively no policies in place to increase renovation rates or substantially minimise the emissions of the buildings sector as evidenced in the government emissions projections. The new Energy Efficient Communities Program, the CBD Program and Energy Efficiency labels offer some form of energy efficiency improvements. The National Construction Code sets a minimum requirement for efficiency standards in new buildings and major renovations, but higher standards are required (ClimateWorks Australia, 2018a; COAG Energy Council, 2018a, 2018b; Harrington et al., 2018). Meeting the benchmark to have all new buildings fossil-free and near-zero energy by 2020 seems an impossibility as the next revision to the National Construction Code is beyond the benchmark deadline. The slow progress on policy development combined with the fact buildings are long-lived assets means that renovations of current buildings will need to be scaled up. Research suggests Australia could affordably scale-up its energy productivity targets following proven schemes and standards implemented in other countries (Energy Efficiency Council, 2019).

2.4 Industry sector

Australia's emissions from industry[8] (direct combustion, fugitives,[9] and industrial processes) account for 30% of total emissions (excl. LULUCF) (DEE, 2019a) making it the second largest emitting sector. The main cause is direct combustion accounting for 18% of total emissions (DEE, 2019a). Direct combustion is the burning of fossil fuels for heat, steam or pressure in either the manufacturing, energy or mining sectors. Fugitive emissions account for 10% of Australia's total emissions in 2019 (see Figure 1).

With a rapid increase in production of liquified natural gas (LNG) for export, LNG processing is one of the fastest-growing sources of emissions (see the recent rise in LNG represented in figure 8). Increasing gas extraction leads to more fugitive emissions, direct combustion emissions and electricity sector emissions (Climate Analytics, 2018a; DEE, 2019a). Industrial processes and product use (IPPU) accounts for 7% of Australia's total emissions (see Figure 1). Government projections indicate decreasing emissions in IPPU driven by a reduction in hydrofluorocarbons (HFCs) (DEE, 2019a).

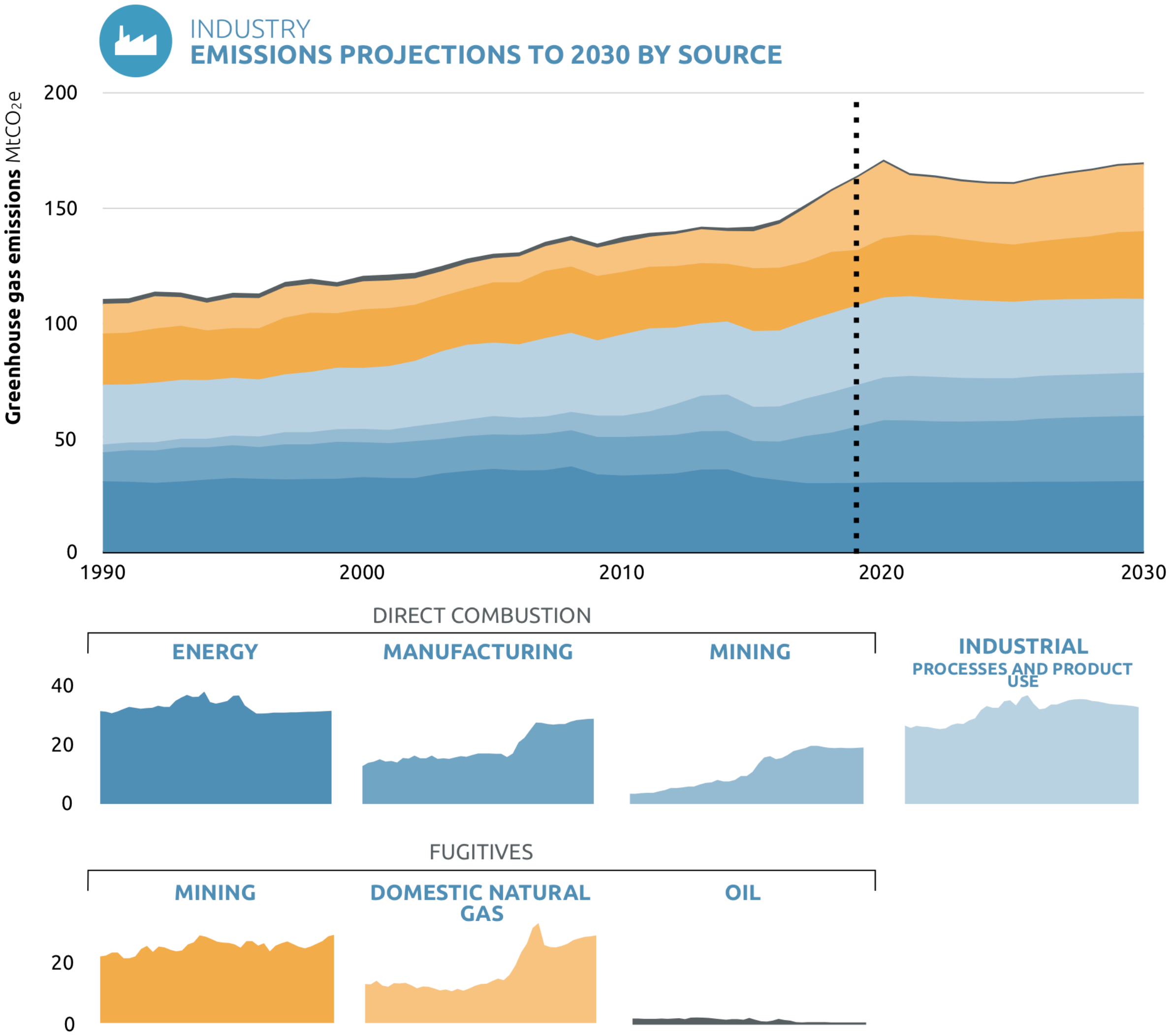


Figure 22 - Australia's industry sector emissions[10], (historical data from 1990 to 2019, projected data 2020 to 2030) Source: (DEE, 2019a)

8 The Industry Sector includes direct combustion emissions from manufacturing, energy, and mining (but not from buildings, military, nor from agriculture and fisheries), and fugitive emissions (coal, oil, and gas), as well as industrial processes and product use emissions.

9 Fugitive emissions in this section refers to emissions from the extraction, processing and delivery of fossil fuels..

10 This includes direct combustion emissions from manufacturing, energy, and mining (but not from buildings, military, nor from agriculture and fisheries), and fugitive emissions (coal, oil, and gas), as well as industrial processes and product use emissions.

Australia is one of the few countries in the world that is going backward in terms of energy efficiency in industry, while other countries are making progress, including China and India (Climate Analytics, 2018a).

Australia is ranked as one of the worst-performing major developed countries in the world for energy efficiency (Climate Analytics, 2018a).

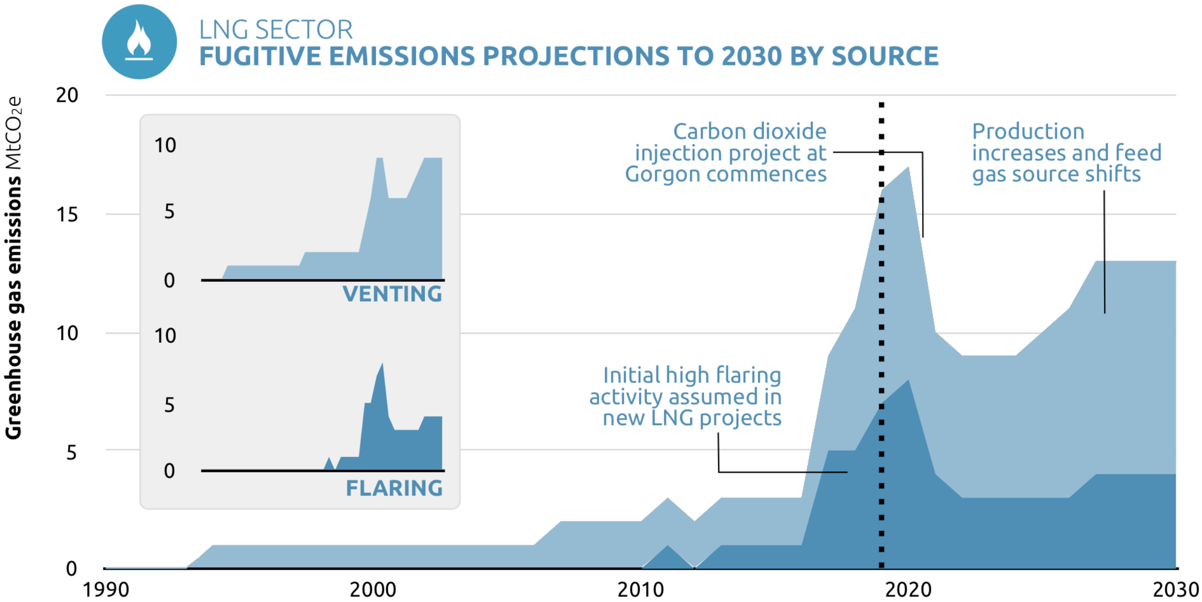


Figure 23 - Australia's LNG sub sector fugitive emissions, (historical data from 1990 to 2019, projected data 2020 to 2030) Source: (DEE, 2019a)

Table 13 provides a comprehensive overview of implemented and planned sectoral climate policies. It highlights the carbon intensity of the industry sector and how policies are not focused on efficiency nor lowering emissions.

Table 13: Progress on the most important steps in the industry sector to limit temperature increase to 1.5°C

Sector	1.5 °C-consistent benchmark	Projection(s) under current policies	Gap assessment (qualitative)	Policy rating

Industry sector	*All new installations in emissions-intensive sectors are low-carbon after 2020, maximise material efficiency*	• **Industrial processes and product use:** Industrial processes and product use emissions are projected to be 35 $MtCO_2e$ in 2020, and 32 $MtCO_2e$ in 2030, with a -8% reduction in emissions, primarily a result of a decrease in HFCs (DEE, 2019a).
		
		• **Direct Combustion:** (energy, mining and manufacturing only). Emissions from direct combustion are projected to be 76$MtCO_2e$ in 2020 and 78$MtCO_2e$ in 2030, a 3% rise in emissions (DEE, 2019a). Mining and manufacturing subsector emissions remain relatively stable with small projected increases from 2020 to 2030. The energy subsector has similar projections, but with LNG production driving a 5% increase from 2025 to 2030 according to government projections(DEE, 2019a).
		
		• **Fugitives:** Overall, fugitive emissions are projected to decline from 2020 to 2030 by 1%. The largest share of fugitive emissions are from oil and gas, a sub sector expected to reduce LNG emissions from reduced flaring activity, and new LNG facility emissions are expected to be offset by CCS technology at the Gorgon LNG facility (DEE, 2019a).
			- Low carbon is not a priority in the industry sector. Current policies such as the safeguard mechanism do not ensure new installations are low carbon or to maximise material efficiency. Current policies have proven to be ineffective as emissions are projected to increase.
			- Australia's long-term plan to decarbonise was abolished with the "carbon tax".
			-/+ Government figures have not shown a reduction in emissions in the past year (2018 to 2019) in IPPU, direct combustion, nor fugitives, but emissions in these subsectors are projected to decline (DEE, 2019a).
			+ Emissions reductions are projected for IPPU, with a marginal decrease in emissions, attributed to the phasedown of hydrofluorocarbons (HFC).
			+/- Government projections indicate fugitive emissions will overall decrease from 2020 to 2030 (DEE, 2019a). However, these projections rely on the Gorgon CCS project to sequester new LNG plant emissions. This project has experienced repeated delays.
			- The Emissions Reduction Fund (ERF) has very few industry projects in its portfolio.
			- The ERF and Safeguard Mechanism have been heavily criticised for low levels of emissions abatement (ABC News, 2019; Reputex, 2019a; Sydney Morning Herald., 2019d).
			- The Safeguard Mechanism baselines are adjusted, and even retrospectively backdated (Morton, 2019b), creating little incentives for industry to decarbonise. Emissions from these large facilities continue to increase by 12% (Reputex, 2019a; RepuTex, 2020; Sydney Morning Herald., 2019d) and therefore the ERF abatements are not safeguarded as large levels of emissions continue without an effective safeguard.
			+/- Despite these issues, the Climate Solutions Fund intends to top up the ERF funding.
			- The federal government takes an increasingly technology neutral approach to industry policy:
			  - The government appointed a Covid-Commission comprised - to a large extent - of gas industry stakeholders. The commissions recommends a gas-led economic recovery (Parkinson, 2020).
			  - The government appointed an expert panel (without public disclosure) to review the ERF. Again the panel was comprised of fossil fuel stakeholders (Morton, 2020).
			  - The government has accepted most recommendations of the panel including adding CCS to the remit of the CEFC, ARENA and to the ERF/CSF. In addition, the government will add an incentive scheme to the safeguard mechanism to reward large emitters that manage to reduce emissions despite the ineffectiveness of the ERF (Morton, 2020).
			  - In May 2020, the government released Technology Investment Roadmap discussion paper for public comment. The paper includes gas, CCS and does not rule out coal and nuclear (Australian Government, 2020d).
			  - The Government released a National Hydrogen Strategy. As a technology neutral strategy, it is at risk of supporting the fossil fuel industry and associated emissions.The NEPP has not been effective in creating efficiency and none of the policies with a high impact proven in other countries have been implemented (Climate Analytics, 2018a).
			- LNG emissions have soured and Australia plans to export 80 Mt of LNG in 2020 and 87 Mt by 2030 (DEE, 2019a), with destination emissions not accounted for in the national accounts.
				

2.4.1 Actionable benchmarks in industry sector

The Climate Action Tracker identified one short-term actionable benchmark for the industry sector to limit warming to 1.5°C at a global level (Kuramochi et al., 2018):

- All new installations in emissions-intensive sectors need to be low carbon after 2020 such as low-carbon steelmaking technologies, including carbon capture and storage (CCS) and material efficiency, needs to be maximized.

New installations need to be the most energy-efficient with the least emission-intensive production methods (Climate Action Tracker, 2018a). Material efficiency can be improved through design, reuse, and recycling and end-use changes (Climate Action Tracker, 2018a). Reduction in demand is required through behavioural shifts (Climate Action Tracker, 2018a). Each action will need to be specifically applied to subsectors of industry for contextual change.

The following gap analysis compares historical and projected developments in Australia's industry sector to this global benchmark without any further adjustment to allow for comparison between countries under analysis. Country specific circumstances will be addressed in the in-depth analysis of raising ambition in chapter 4.

Table 14: Overview of existing and planned climate change policies in the industry sector in Australia

OVERVIEW OF EXISTING, PLANNED AND POTENTIAL CLIMATE CHANGE POLICIES FOR THE INDUSTRY SECTOR IN AUSTRALIA				
Changing Activity	**Energy efficiency**	**Renewables**	**CCS or fuel switch**	**Non-energy**
Strategy for material efficiency (none)	**Support for energy efficiency in industrial production** ▪ **National Energy Productivity Plan (NEPP)** National Energy Productivity Plan (NEPP) has a target to improve energy productivity by 40% between 2015 and 2030 (Australian Government 2019) **but lacks specific policies** (Climate Analytics, 2018a).	**Support schemes for renewables** ▪ (only for electricity generation, see electricity sector text)	**CCS support scheme** ▪ Low Emissions Technologies for Fossil Fuels (LETFF) programs (See Table 8). ▪ The government has indicated CCS will be included in the ERF (Morton, 2020).	**Landfill methane reduction** (See waste sector for details)
	Energy reporting and audits ▪ No reporting required for energy efficiency.	**Sustainability standards for biomass use** (none)	**The National Hydrogen Strategy** (COAG Energy Council, 2019a)Although the strategy is technology neutral supporting both renewable energy and fossil fuel produced hydrogen, there will be some support for renewable energy derived hydrogen.	**Incentives to reduce CH4 from oil and gas production** (none) The Safeguard Mechanism is ineffective at reducing or even levelling GHG emissions (discussion below).

	Minimum energy performance and equipment standards Exist but less ambitious than comparable economies (Climate Analytics 2018a).			**Incentives to reduce N2O from industrial processes** Covered by the Emissions Reduction Fund **Incentives to reduce fluorinated gases (HFCs)** Australia committed to a HFC phase-down of 85% by 2036 under the Montreal Protocol (Australian Government 2019). Australia aims to phase-down at an expediated rate, compared to the agreed pace under
Overarching carbon pricing scheme or emissions limit ▪ **There is no effective carbon pricing scheme or emissions limit for the industry sector.** ▪ **While the Emissions Reduction Fund (ERF) generates** Australian Carbon Credit Units (ACCUs) for organisations that voluntarily register their projects to store or avoid emissions, this does not qualify as an overarching carbon pricing scheme. It is funded through the federal budget, leading to no price incentive for emitters. ▪ Under the **Safeguard mechanism** emissions from large greenhouse gas emitters are regulated to keep their emissions below a baseline. This is supposed to ensure that emissions stored or avoided by the ERF are not offset elsewhere, however, the mechanism allows for an increase in emissions,				
Energy and other taxes ▪ The main energy related taxes are the Excise Duty on gasoline, diesel, heating oil, kerosene, fuel oil, and other liquid petroleum based products, LNG/CNG, bio-gasoline and biodiesel (although the fuel tax credit scheme allows for this tax to be claimed back for eligible businesses) (OECD, 2019)				
Financial Support Schemes for Sustainable Development (none)				
No fossil fuel subsidies Australia subsidies fossil fuels through the fuel tax credit scheme and accelerated depreciation for oil and gas assets (UNEP, 2019)				

	No policies currently exist and a similar policy gap exists in all other countries
	No policies currently exist however Australia could adopt policies from other countries
	Existing and planned policies in Australia

2.4.2 Recent policy developments

There is no effective policy to reduce greenhouse gas emissions from burning fossil fuels in the industry sector. The so-called centrepiece of Australia's climate policy, the Emission Reduction Fund (ERF), has barely any industrial sector projects in its portfolio. Organisations and individuals can register their projects to reduce their emissions. Based on specified activities of the fund, one Australian Carbon Credit Unit (ACCU) is issued per tonne of GHG stored or avoided. Auctions are held by the Clean Energy Regular. Businesses bid at auctions and the Clean Energy Regulator chooses the lowest cost abatement (DEE, 2019k). If successful, the business enters a contract and is paid at the auction bid price for the ACCUs delivered (DEE, 2019k).

The ERF was designated a budget of AUD$2.55 billion for the government purchase of ACCUs (CER, 2019b). By the ninth auction on July 2019, the ERF has delivered 44.8 $MtCO_2e$ with 147.3 $MtCO_2e$ remaining (CER, 2019b). The ERF was designed to cover different sectors. Instead, it is dominated by projects in the land-use sector: only 5.2 $MtCO_2e$ of a total of 192 $MtCO_2e$ of abatement contracted through the ERF so far are from projects related to energy efficiency, and 2.9 $MtCO_2e$ for industrial fugitive emissions as of the ninth auction in 2019 (CER, 2019b).

The Climate Solutions Package was announced in February 2019, and was set to add a further AUD$2 billion in funding over a ten year period for the continuation of the ERF. By April 2019, the budget revealed the AUD$2 billion would be spread over 15 years rather than ten (Karp, 2019). The budget was effectively cut from AUD$200m to AUD$133m per year. The package was projected to contribute 103 $MtCO_2e$ emissions reductions by 2030 (Australian Government, 2019b).

However, the abatements of the ERF are highly contested (ABC News, 2019; Reputex, 2019a). By the ninth auction, 14.8 $MtCO_2e$ emissions abatements contracted had been terminated or lapsed (CER, 2019b) as businesses did not deliver the agreed ACCUs. An ABC News (ABC News, 2019) analysis of the Clean Energy Regulator datasets shows that the ERF has flatlined since 2017. The ERF datasets indicate the ERF has only avoided a mere 4 $MtCO_2e$ of emissions over four auction rounds, which is a 97% drop compared to the reported first two years of the ERF, despite the 123 contracts worth AUD$372m (ABC News, 2019).

A recent government announcement indicates carbon capture and storage projects will qualify under the emissions reduction fund (Morton, 2020). A move that has been highly criticised as it adds to the mounting taxpayers dollars that have been wasted on failed CCS technology (Mazengard, 2020).

The safeguard mechanism was designed so that emissions abated under the ERF are not offset by significant increases in emissions beyond business-as-usual levels elsewhere in the economy. The largest greenhouse gas emitters are legislatively obliged to measure, report and manage their GHG emission, and keep emissions below a set baseline.

The safeguard mechanism under the Direct Action Plan was established in 2016 and applies to large industrial (and gas, manufacturing, transport, construction, and waste) emissions sources emitting over 0.1 $MtCO_2e$ per year (CER, 2019h). The safeguard mechanism came into effect 1 July 2016 and subsequently amended in March 2019 with changes to the baselines (as of 1 July 2018) to "accommodate economic growth and natural resource variability" (CER, 2019h). In the reporting year 2017-2018 the safeguard mechanism covered 211 facilities, with combined covered emissions of 138.4 $MtCO_2e$ (CER, 2019g) or 24% of 2018 emissions (excl. LULUCF).

The safeguard mechanism baselines are generously defined and adjusted allowing for emissions to increase.
As of March 2019, 30% of facilities had adjusted their baseline (Reputex, 2019a; Sydney Morning Herald., 2019d). As baselines are adjusted, there are fewer incentives to drive efficiency.

A study by Reputex found high-emitting industrial facilities covered by the safeguard mechanism, have seen a 12% rise in emissions (Reputex, 2019a; Sydney Morning Herald., 2019d). The emissions are projected to increase a further 19% to 2030 (Reputex, 2019a; Sydney Morning Herald., 2019d). This substantial rise in emissions could potentially cancel out taxpayer-funded emissions reductions under the ERF (Climate Analytics, 2018a; Reputex, 2019a; Sydney Morning Herald., 2019d).

The Reputex assessment finds that the $2 billion AUD in funding will abate between 25 and 100 $MtCO_2e$ by 2030 (Sydney Morning Herald., 2019d). If the maximum reductions occur and industry increase emissions at the projected rate to 2030 under the safeguard mechanism, the ERF will have abated a total of 13 $MtCO_2e$ net reductions of emissions (Sydney Morning Herald., 2019d). This is far from the government claims of the ERF and Climate Solutions Fund abating 300 $MtCO_2e$ by 2030 (Sydney Morning Herald., 2019d). By 2030, the safeguard mechanism could remove all the emissions reductions of the ERF despite the purpose of the safeguard mechanism to ensure that emissions are not increased elsewhere.

As an example, a coal mine company in Queensland, Anglo American, doubled its emissions from 1.3 $MtCO_2e$ to 2.3 $MtCO_2e$ over a two year period under the safeguard mechanism (Morton, 2019b). To offset such an increase in emissions would cost $13.7m AUD (Morton, 2019b). In the financial year 2016/17 the company exceeded its baseline emissions limit, but the Clean Energy Regulator retrospectively changed the limit from 1.3 $MtCO_2e$ to 1.36 $MtCO_2e$, rather than enforce the company to buy carbon credits to offset the extra emissions (Morton, 2019b). In 2017/18 the company was granted a higher baseline (Morton, 2019b). Without a hard cap on emissions limits the mechanism is not an effective safeguard.

The government appointed a panel to assess climate policy without a public disclosure (Morton, 2020). The panel's recommendations have led to government announcements for an incentive scheme allowing large emitters to earn revenue for emitting less than under the safeguard mechanism baselines (Morton, 2020). Without reducing the baselines, large emitters will be paid while the policy remains ineffective in emissions reductions (Morton, 2020).

The National Hydrogen Strategy was released in November 2019 by the Council of Australian Governments' (COAG) Hydrogen Working Group (COAG Energy Council, 2019a). Renewable based (or 'green') hydrogen allows for large share of renewables to be integrated into industry, especially where direct electrification is not feasible. Green hydrogen can be utilised to refine minerals, manufacture steel or produce chemicals, processes that are currently emissions intensive.

The National Hydrogen Strategy takes a "technology-neutral" approach. Hydrogen can also be used to prop up the fossil fuel industry if the hydrogen is derived from fossil fuels, or labelled 'clean' using CCS technology as is the case with the current strategy.

The government announced existing funds of 370 million AUD from the CEFC and ARENA will be designated towards the strategy, with just 70 million AUD explicitly designated for projects generating (renewable energy derived) hydrogen from water with electrolysers (Seccombe, 2019).

As a comparison, **the Hydrogen Energy Supply Chain coal to hydrogen project has a budget of 500 million AUD, of which the federal and Victorian government are funding AUD $50 million each (Seccombe, 2019).**

South Australia and Western Australia have renewable hydrogen strategies and the Queensland government has released a Hydrogen strategy focusing on green hydrogen and export opportunities (Government of South Australia, 2017; Queensland Government, 2019; WA Dept. of Primary Industries and Regional Development, 2019).

2.4.2.1 Energy Efficiency

The National Energy Productivity Plan (NEPP) aims to improve energy productivity (that is economic output per unit of energy used) by 40% between 2015 and 2030. It was designed to achieve low-cost GHG reductions and energy efficiency (Australian Government, 2019b). Commitment to the Government's NEPP is lacking four years after its publication. Australia has not implemented any of the policies that have proven key to increasing efficiency and reducing emissions in the industry sector, such as high-efficiency standards and regulation, encouragement for energy management and energy auditing. The NEPP has made a marginal impact ensuring there are energy standards for products (air conditioners, swimming pool pumps, white goods) and new builds and renovations. The NEPP also created higher energy standards for equipment with the Equipment Energy Efficiency (E3) Program for both energy efficiency standards and energy labelling and equipment and appliances.

2.4.2.2 Incentives to reduce fluorinated gases

The Australian government is phasing down hydrofluorocarbons (HFC) (see Table 11). HFCs are greenhouse gases used in refrigeration, air conditioning, and fire protection systems. The most common HFC is HFC134a, and it is "1430 times more potent than carbon dioxide" (Australian Government, 2017a). Legislation started on 1 January 2018, reducing HFC imports every two years until an 85% reduction (from 2011-13 levels) is achieved by 2036 (Australian Government, 2017a). The Australian Climate Solution's Package claims 35 $MtCO_2e$ will be reduced due to an information program to inform air conditioning and refrigeration equipment owners of the benefits of regular maintenance (Australian Government, 2019b).

2.4.3 Comparison of recent developments and projections to benchmark

2.4.3.1 **Actionable indicator No.7:** All new installations in emissions-intensive sectors are low-carbon after 2020, maximise material efficiency

Australia is far from meeting the benchmarks within the industry sector. There is no policy to ensure new installations in industry are low carbon nor maximise material efficiency.

Industrial processes and product use emissions are projected to fall 8% from 2020 to 2030 (DEE, 2019a). The main driver of this decline is the phase-down of HFCs, as HFC represents the largest (35%) source of emissions in IPPU in 2020 (DEE, 2019a). The metal industry accounts for 31% of IPPU emissions, and is projected to contribute 11 $MtCO_2e$ per year (DEE, 2019a). The chemical industry represents 16% of IPPU emissions in 2020, increasing by around 1 $MtCO_2e$ per year to 2030 (DEE, 2019a). The mineral industry represents 16% of emissions, and emits 5-6 $MtCO_2e$ per year to 2030 (DEE, 2019a).

Direct combustion emissions (from energy, mining and manufacturing only) are set to rise 3% between 2020 to 2030, from 76 $MtCO_2e$ to 78 $MtCO_2e$ (DEE, 2019a). Increases in energy related direct combustion emissions are spurred by the ramp up of the LNG industry, with a 5% increases in emissions from 2025 to 2030 (DEE, 2019a). Mining and manufacturing subsector emissions remain relatively stable with slight increases in emissions from 2020 to 2030 (DEE, 2019a).

Government projections indicate fugitive emissions will decline overall from 2020 to 2030 despite the fact emissions in this subsector have been increasing since 2014 (DEE, 2019a). Coal fugitives are projected to increase 43% between 2020 and 2030 as a result of increase production of coking coal from underground mines for export (DEE, 2019a).

New coal mines are expected to be opened in Queensland, increasing coal production from 2024 (DEE, 2019a). Open cut mine emissions are projected to remain stable from 2020 to 2030, with closure of old mines offsetting new mines (DEE, 2019a).

Oil and gas fugitives are projected to represent 57% of fugitive emissions in 2020, these emissions are projected to decline 13% from 34 $MtCO_2e$ in 2020 to 30 $MtCO_2e$ in 2030 (DEE, 2019a). Domestic natural gas fugitives are projected to remain stable at around 16 $MtCO_2e$ per year from 2020 to 2030 (DEE, 2019a). Oil fugitives remain at around 1 $MtCO_2e$ for the same period (DEE, 2019a).

There will be 10 LNG facilities in operation by 2020, with projections indicating increased emissions in the short term from flaring. The Darwin facility will close for maintenance in 2023, and reduce emissions before returning to capacity mid 2020s (DEE, 2019a). The Pluto facility begins operations in 2025 and the West Shelf moves its feed gas to other basins with higher CO_2 concentrations. New LNG emissions are expected to be offset by the Gorgon LNG facility's CCS technology (DEE, 2019a). Government projections assume the facility can abate 3.4 $MtCO_2e$ per year (DEE, 2019a).

The Gorgon CCS project in Western Australia was planned to commence in 2016, but only began in August 2019 (Morton, 2019a). The CCS project should abate 3.4 $MtCO_2e$ when fully "operational", although Western Australia's Environmental Protection Agency has the view that Chevron's requirements to meet this target should not rely on all stages to be constructed as Chevron can avoid commitments by adding future processing trains to their plans (DEE, 2019a; EPA, 2019). There is currently no date for Chevron to meet full operational capacity and or abate its targeted emissions per year, so the government LNG emissions projections may not ring true.

A report by the Australia Institute found the Gorgon project represented half of Australia's emissions increases in 2018 (Swann, 2018). The project would have cost AUD$55m per year in offsets, however, the project received AUD$60 in subsidies and a safeguard mechanism limit that assumes there is not CCS in operation (Swann, 2018). It is unclear how on the one hand, the government assumes there is no CCS in operation for the safeguard mechanism, and does not penalise the project for high emissions. On the other hand, the government accounts for the project's emissions to be captured and stored in their emissions projections.

A report by the CSIRO (2019b) comparing coal and natural gas electricity production finds emissions reductions when switching to gas, as it avoids the GHG emissions associated with liquefaction, shipping and regasification overseas. Australia's LNG emissions projections do not demonstrate the overall impact of LNG to the global emissions budget. Australia contributes 1.2-1.4% of the total global budget, but when factoring Australia's fossil fuel export emissions, its share increases to 3.6% (Hare, Roming, Hutfilter, Schaeffer, & Beer, 2018).

Coal related fugitive emissions are projected to increase from 26 $MtCO_2e$ in 2020 to 43 $MtCO_2e$ in 2030 (DEE, 2019a).

The government continues support to the mining industry. A bill was passed in April 2019 the Export Finance and Insurance Corporation Amendment (Support for Infrastructure Financing) Bill 2019 (Parliament of Australia, 2019). The bill increases the funding and powers of Efic (the Export Finance agency). The agency has more power and capital to invest in new overseas infrastructure projects, to increase the fossil fuel exports of Australia.

The government also supports coal production, impacted fugitive emissions. Coal production is projected to increase from 634 Mt in 2020 to 659 Mt in 2030. Government support for coal can be seen in the deal made between the federal government and the New South Wales government to secure coal supply to Mount Piper coal power plant to at least 2042 (RenewEconomy, 2020b).

The safeguard mechanism has not been designed to reduce emissions, rather limit emissions. But approving flexible safeguard mechanism baselines has achieved the opposite letting companies increase their baseline emissions. Declining baselines would be much more effective policy update (Climate Change Authority, 2020).

A cost-effective way to reduce emissions is by pricing carbon effectively. The OECD carbon pricing gap is a tool to demonstrate the difference between the price of carbon and what polluters pay. Australia's 2015 carbon pricing gap was above the global average at 78% (Climate Analytics, 2018c; OECD, 2018).

In terms of energy efficiency, the National Energy Productivity Plan has not made an impact four years after its development. On the 2018 International Energy Efficiency Scorecard assessing energy efficiency policy and performance of the industrial sector, Australia scored poorly with 6 out of a 25 point scale, with only Saudi Arabia, UAE and South Africa with a worse rating, and 21 other countries with better scores (Castro-Alvarez et al., 2018).

Australia has not implemented the policies that have a high impact on increasing energy efficiency within the plan (Climate Analytics, 2018a). Relative to the impact the industry sector has on Australia's emissions, the government has only made a small effort to reduce emissions. A recent Energy Efficiency Council (Energy Efficiency Council, 2019) report highlights how government support for energy efficiency in manufacturing in Australia is severely lacking compared to government support offered in other countries.

2.4.4 Conclusion

Australia lacks an effective policy to reduce greenhouse gas emissions in the industry sector. Industry has not been convinced by the incentives to lower emissions through the ERF, and the ERF only has a few industry projects in its portfolio. The Climate Solutions Package intends to boost the ERF with top-up funding, despite the ERF and safeguard mechanism receiving widespread criticism which estimates only small levels of emissions will be abated (ABC News, 2019; Reputex, 2019a; Sydney Morning Herald., 2019d) and **the safeguard mechanism effectively allowing for an increase in emissions of large facilities instead of creating an incentive to reduce them.**

The government is supporting industry despite the related emissions, for example, through safeguard mechanism adjustments, and not penalizing late and low levels of contracted carbon capture and storage.

There is no strategy in Australia to achieve decarbonisation in the industry sector. Implementing energy efficiency policies across all industry sectors are key steps in reducing emissions and saving money. **Australia has not implemented policies that have a high impact on increasing energy efficiency**.

Many heating processes in industry can be replaced to use electricity which can be produced 100% from renewable energy sources, mainly wind and solar. In other processes such as high-temperature heating or ammonia production, fossil fuel gas can be replaced by hydrogen or other fuels based on 100% renewable energy power.

Australia's abundance of solar and wind energy can prompt international trade in renewables through hydrogen-rich chemicals and fuels (IEA, 2018a).

Decarbonising Australia's industry sector needs to be achieved through increased energy efficiency as well as emissions efficiency (fuel switching and process changes/innovation), material efficiency, demand reductions, and full decarbonisation. The industry sector is varied and challenges differ significantly, but technologies are available across the industry sector. Electrification and green, renewable, hydrogen technologies with zero-emissions power are the key.

2.5 Agriculture and forestry

While the forest sector is currently a net sink, and regrowth of Australia's previously harvested forests outweigh the forests that are currently harvested (DEE, 2019a) the rate of deforestation levels are huge. Australia was listed as the world's worst developed country in broadscale deforestation levels, particularly the deforestation hotspot of Eastern Australia, primarily due to the demand for livestock (WWF, 2018b). It is estimated that three to eight million hectares of forest could be lost by 2030 in Eastern Australia (Slezak, 2018; WWF, 2018c). Commercial agriculture plays are large part in deforestation, and in itself remains a source of emissions.

It is unclear how the government projections in Figure 9 take into account the alarming increase in deforestation rates observed and projected in particular in Queensland, where about 395,000 hectares of native vegetation was cleared in 2015-16, 33% more than the previous year (Queensland Government, 2017).

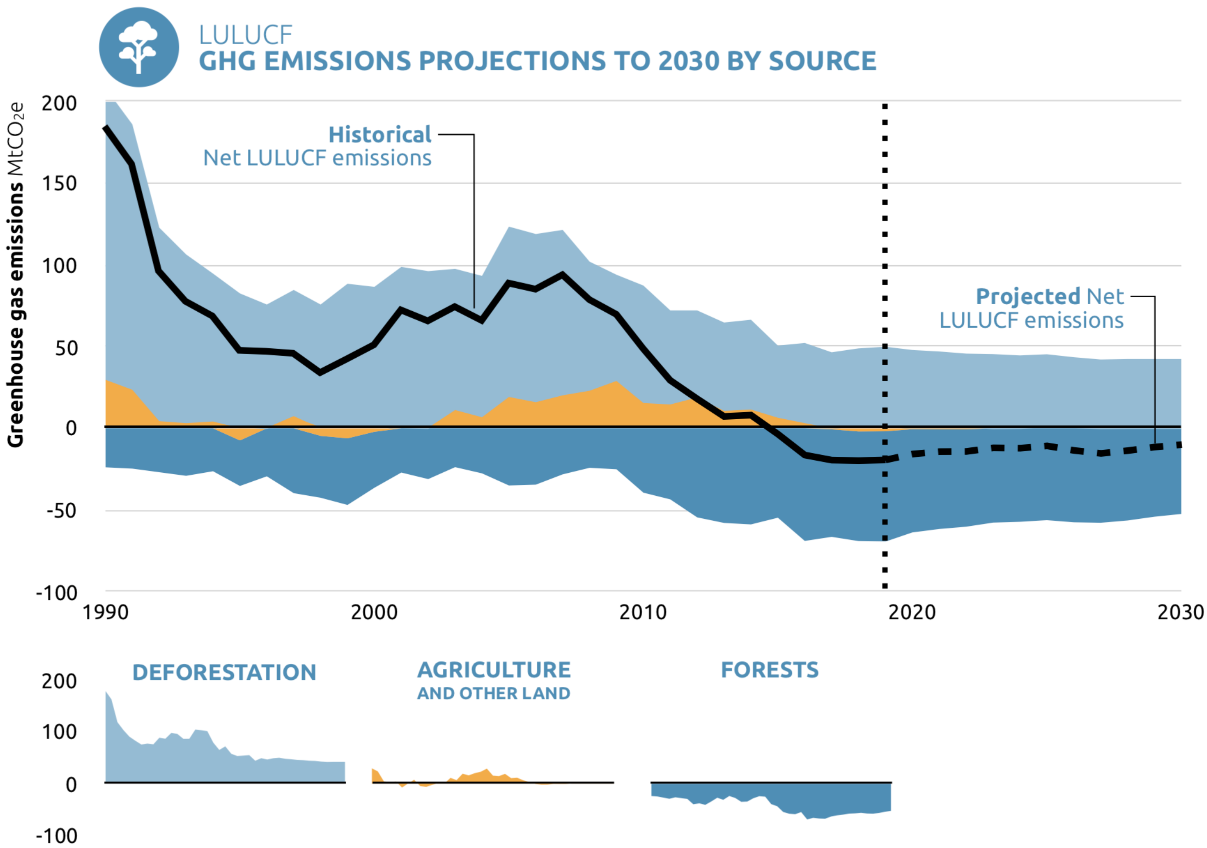


Figure 24 - Land use, land-use change and forestry emissions, (historical data from 1990 to 2019, projected data 2020 to 2030) Source: : (DEE, 2019a).

Agriculture accounted for 12 per cent of Australia's total emissions in 2019 (excl. LULUCF, see Figure 1) and emissions are set to increase 11% from 2020 to 2030 (DEE, 2019a). Emissions in the agriculture sector are derived from enteric fermentation (digestive processes of some animals), liming and urea application, manure management, rice cultivation, agricultural soils and field burning (DEE, 2019a). Operating equipment, fuel and electricity in this sector are not considered under agriculture sector but are covered in the other relevant sectors such as electricity.

Most of the emissions from this sector are in the form of methane and nitrous oxide. The largest contributor to agriculture emissions is beef, followed by sheep and dairy cattle (see Figure 10).

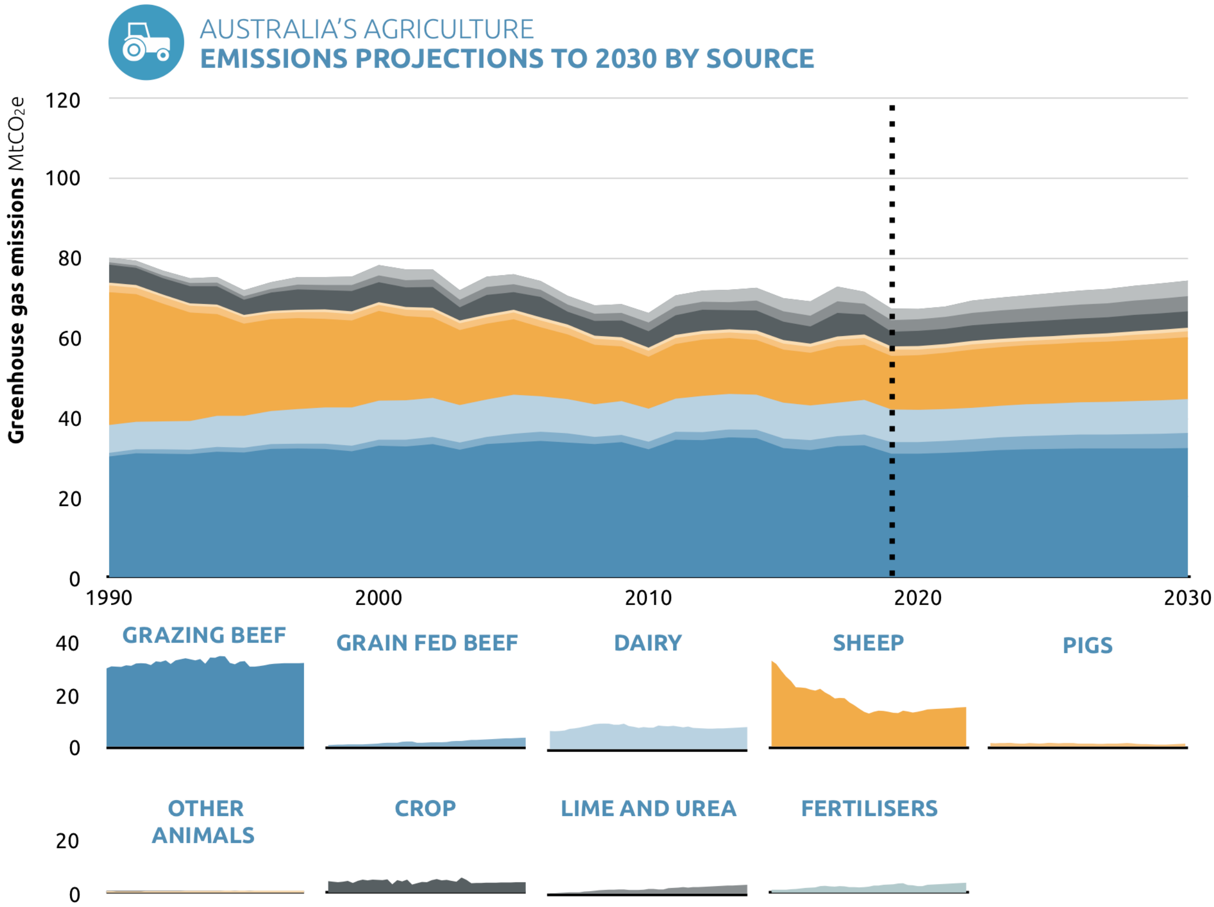


Figure 25 - Agriculture emissions (historical data from 1990 to 2019, projected data 2020 to 2030) Source: (DEE, 2019a).

Table 15 summarises Australia's progress on the most important steps to decarbonise the LULUCF and commercial agriculture sectors to limit temperature to 1.5°C.

Table 15: Australia's progress on the most important steps in the LULUCF and commercial agriculture sectors to limit temperature increase to 1.5°C

Sector	1.5 °C-consistent benchmark	Projection(s) under current policies	Gap assessment (qualitative)	Policy rating
LULUCF	Reduce emissions from forestry and other land use to 95% below 2010 by 2030, stop net deforestation by 2025	• *According to government data, the LULUCF sector has been a net sink since 2015* (DEE, 2019a). • *The carbon sink is projected to decrease from -16 $MtCO_2e$ in 2020 to -10 $MtCO_2e$ in 2030 representing a 37% change, and remaining a net sink* (DEE, 2019a).	- Australia's deforestation levels are high by world standards, as Australia is the only developed country deforestation hotspot in the world (Slezak, 2018; WWF, 2018c). -/+ National government projections suggest that Australia could be compatible with this benchmark, but there is a discrepancy between national and state-level data. LULUCF emissions are projected to remain a net sink to 2030 (DEE, 2019a). - There are high rates of deforestation in Queensland. and it is unclear how the national government projections take these figures into account. - The government has been criticised for adjusted historical emissions accounts in line with their political narrative (The Guardian, 2019). - Recent and unprecedented bushfires will have a negative impact on this sector, as the scale and intensity of fires impacts the rate of forest regrowth and carbon sequestration (Sydney Morning Herald, 2020).	
Commercial Agriculture	Keep emissions in 2020 at or below current levels, establish and disseminate regional best practice, ramp up research	• *Government projections indicate agriculture emissions will decrease from 67.4 $MtCO_2e$ in 2019 to 67.3 $MtCO_2e$ in 2020, rising to over 74 $MtCO_2e$ in 2030* (DEE, 2019a). *From 2020 to 2030 there is an 11% increase in emissions, but emissions in this sector are highly dependent on climate variations* (DEE, 2019a).	- Projections indicate the agriculture sector will meet part of this benchmark. Emissions will increase on a yearly basis from 2020. - The Department of Agriculture and Water Resources created the Carbon Farming Futures Program that ramped up research and best practise from 2012 to 2017. The program ended in 2017 with no replacement policy. + The Australia government is part of international research initiatives. + Australia participates in the Global Research Alliance on Agricultural Greenhouse Gas (n.d.). The latest update of Australia's projects for the Global Methane Initiative (2019) is from 2013. Australia has not ramped up methane research.	

2.5.1 Actionable benchmarks in agriculture and forestry

The Climate Action Tracker identified two short-term actionable benchmarks for the agriculture and forestry sector to limit warming to 1.5°C at a global level (Kuramochi et al., 2018):

- Emissions from forestry and other land use needs to be reduced to 95% below 2010 by 2030 and stop net deforestation, to be achieved by 2025.

- Emissions from commercial agriculture in 2020 need to be kept at or below current levels with the simultaneous establishment and dissemination of regional best practice and a ramp-up of research.

In addition, the Climate Action Tracker has identified important steps towards reducing emissions in the agriculture sector both on the demand and on the supply side: Reducing food waste, shifting to healthy diets, and implementing best farming practices, such as efficient fertiliser have a substantial mitigation potential and large benefits for public health (Climate Action Tracker, 2018e, 2018b).

The following gap analysis compares historical and projected developments in Australia's LULUCF and commercial agriculture sectors to these global benchmarks without any further adjustment to allow for comparison between countries under analysis. Country specific circumstances will be addressed in the in-depth analysis on raising ambition in the following chapters. Please refer to the publication for more detailed explanation on each indicator.

2.5.2 Recent policy developments

Australia has a few climate policies in the agriculture and forestry sectors, which have been implemented to a variable degree. However, there is no specific policy to reduce emissions from agriculture.

Table 13 provides a comprehensive overview of the currently implemented and planned sectoral climate policies with the potential to affect GHG emissions directly.

Table 16: Overview of existing and planned climate change policies in the agriculture and forestry sector in Australia

OVERVIEW OF EXISTING and PLANNED CLIMATE CHANGE POLICIES FOR THE AGRICULTURE AND FORESTRY SECTORS IN AUSTRALIA				
Changing Activity	Energy efficiency	Renewables	Nuclear or CCS or fuel switch	Non-energy
Standards and support for sustainable agricultural practices and use of agricultural products ▪ **National Food Waste Strategy.** The strategy includes a voluntary commitment program for businesses (such as farms) to reduce waste (DEE, 2017b), which would lower the associated emissions.				
Incentives to reduce emissions from agriculture ▪ **Emissions Reduction Fund.** Farmers can register their carbon farming projects to reduce their emissions. The Emissions Reduction Fund ACCUs can be earnt from reducing livestock emissions or increasing carbon storage in soil (CCA 2019a).				
Incentives to reduce deforestation or support for afforestation/reforestation ▪ **Emissions Reduction Fund** Forest growers can register their commercial plantation forestry projects to store or avoid GHG emissions, for example, through establishing new plantation forests or extending short-rotation plantations to longer rotations (DEE, 2017c). ▪ **Land management and conservation laws** The Environment Protection and Biodiversity Conservation Act 1999 protects some areas of land from proposed development (Climate Change Authority, 2019). State governments also have legislation to protect environmentally significant areas, and planning and development legislation. ▪ **National Land Care Program and National Forest Industries Plan** The Australian government will invest AUD$1 billion in a national land care program (Climate Change Authority, 2019). Sustainable forest industries and carbon storage are planned through the National Forest Industries Plan (Australian Government, 2018b). The plan sets forth a pathway to a billion more plantation trees to create jobs and growth.				

No policies currently exist and a similar policy gap exists in all other countries | *No policies currently exist however Australia could adopt policies from other countries* | *Existing and planned policies in Australia*

2.5.3 Forestry

The primary policy in place for carbon abatement and carbon sinks is the Emission Reduction Fund for this sector. Most carbon abatements from the Emissions Reduction Fund are from vegetation projects. Over the Funds total contracted abatements, over 65% of abatements are vegetation projects (125.7 $MtCO_2e$) and 7% from savannah burning projects (13.6 $MtCO_2e$) with 27.5 $MtCO_2e$ and 3$MtCO_2e$ delivered respectively, so far (CER, 2019b). The latest July 2019 auction only contracted 3 projects in total, and these were all vegetation projects (CER, 2019b).

The Emissions Reduction Fund was reviewed in 2017 by an independent Emissions Reduction Assurance Committee which found the scheme was on track delivering low cost reductions and abatements (DEE, 2017a, 2019l). Yet, the ERF has many transparency and legitimacy issues. Forestry carbon sinks are at risk of reversal through fires, the administration suffers from complexity, auctions prices are low, there are barriers to participation, and there are issues of additionality where projects would have occurred without the ERF (Baxter, 2017; CCA, 2017a; Reputex, 2018).

Australia has land management and conservation laws in place, offering a degree of protection to the environment. The Environment Protection and Biodiversity Conservation Act 1999 protects some areas from proposed development. State governments also have similar legislation in place to protect "environmentally significant" areas, and planning and development legislation (Climate Change Authority, 2019). State governments are signatories to the 1992/5 National Forest Policy Statement, to ensure sustainable management of forests (Commonwealth of Australia, 1995). Regional Forest Agreements are part of the NFPS strategy, and represent 20 year plans for sustainable management.

The Australian government will invest AUD$1 billion in a national land care program (Climate Change Authority, 2019). Sustainable forest industries and carbon storage are planned through the National Forest Industries Plan which outlines a pathway for a billion plantation trees to encourage jobs and growth (Australian Government, 2018b).

2.5.4 Agriculture

The farming subsector can benefit from the Emissions Reduction Fund. Farmers can register their carbon farming projects to reduce their emissions by reducing livestock emissions or increasing carbon storage in soil (CCA 2019a). The ERF has so far contracted 18.1 $MtCO_2e$ of emissions reductions from agriculture, representing 9% of the ERF portfolio, with only 1$MtCO_2e$ delivered so far (CER, 2019b). However, farmers are not exploiting the full potential of the ERF. In 2017-2018 only 1% of ACCUs came from agriculture, and none in the July 2019 auction (CER, 2018b, 2019b).

The Carbon Farming Futures program ran from 2012 to 2017, and invested AUD$139 million in 200 projects and 530 farm trials (Department of Agriculture and Water Resources, 2017). It promoted research and best practise techniques to reduce emissions. The program ended in 2017 and has not been replaced with further policy. The program did educate farmers on how to use the Emission Reduction Fund, although as farming only constitutes 1% of ACCUs in 2017-18, the education tools may not have been effective. The Carbon Farming Initiative was integrated into ERF.

The National Food Waste Strategy intends to half food waste by 2030. The strategy began in 2018 and outlines a plan, a monitoring and evaluation framework, a voluntary commitment program for businesses and short term projects to reduce waste with an initial investment of AUD$1 million (DEE, 2017b). This Strategy applies to farm businesses, but it is discussed in the Waste Sector section below.

2.5.5 Comparison of recent developments and projections to benchmarks

2.5.5.1 **Actionable indicator No.8:** Reduce emissions from forestry and other land use to 95% below 2010 by 2030, stop net deforestation by the 2020s

National government projections suggest that Australia could be compatible with this benchmark, but there is a discrepancy between national and state level data. Deforestation levels have remained a net sink since 2015 (DEE, 2019a). In 2010, the LULUCF sector emissions amounted to 49 $MtCO_2e$ and in 2030 they are projected to be a net sink of -10 $MtCO_2e$ (DEE, 2019a). This is beyond 95% below 2010 emission levels by 2030 benchmark.

According to the Australian Bureau of Agricultural and Resource Economics, Australia's forests have experienced a net increase for the past ten years from 2008 to 2018 (ABARES, 2018). The increase in forest area is attributed to the effects of regrowth of land cleared for agriculture, forest expansion, environmental plantings, and changes to commercial plantations (ABARES, 2018). (Emissions and carbon sink projections of land clearing, hardwood plantations and native forests are outlined in Table 12).

Yet, there is an alarming increase in deforestation rates observed and projected in particular in Queensland, as 395,000 hectares of woody vegetation were cleared in 2015-16, 33% more than the previous year (Queensland Government, 2017) and it is unclear how the federal government projections take these figures into account.

The National Greenhouse Gas Inventory for 2015-16 estimates emissions at 1.7 $MtCO_2e$, down from 13% from the previous year (Australian Government, 2016b). The discrepancy between state and national figures is unexplained, and questions the accuracy of Australia's reporting under international obligations.

Australia has been characterized as the only developed country deforestation hotspot in the world, with estimates that three to eight million hectares of forest could be lost by 2030 in Eastern Australia (Slezak, 2018; WWF, 2018c).

Estimate indicate the recent and unprecedented bushfires in Australia (in 2019 and 2020) released two thirds of the national carbon emissions, at around 350 $MtCO_2e$ by early January 2020 (Sydney Morning Herald, 2020). The scale of the fires have led experts to believe the forests may not be able to reabsorb the carbon for possibly 100 years (Sydney Morning Herald, 2020).

The Australian Government made revisions to historical emissions data in the 2019 projections, and now claim emissions are lower than when the Coalition were elected which does not reflect the data released in the 2018 projections (Australian Government, 2018a; DEE, 2019a; The Guardian, 2019). Large revision were made in the emissions related to soil in grazing land.

There are no national level commitments to ensure net deforestation levels remain a net sink. Consideration needs to be made to ensure that the efforts made are not reversed through bushfires. To meet this benchmark Australia needs to ratchet-up climate policy in the sector.

2.5.5.2 **Actionable indicator No.9:** Keep emissions in 2020 at or below current levels, establish and disseminate regional best practice, ramp up research

Australia will meet only a portion of this benchmark. The latest emissions data from 2019 indicates that emissions will slightly decline to 2020, from 67.4 $MtCO_2e$ to 67.3 $MtCO_2e$, but emissions in this sector are highly dependent on climate variability (DEE, 2019a).

The only policy to disseminate regional best practise and ramp up research came to an end and has not been replaced. The Department of Agriculture and Water Resources created the Carbon Farming Futures Program from 2012 to 2017. Without this program, and given the small contribution farming plays in the ERF, Australia's commercial agriculture sector remains to have no action in its ability to meet this benchmark. The Climate Change Authority (Climate Change Authority, 2020) has also noted the need for a ramp up of research in this sector, and recommends the allocation of additional funds for low emissions agricultural research and carbon farming, in addition to investment and incentives to support "climate-smart" and low emissions agriculture and environmental services.

The Australia government is part of international research initiatives such as the Global Research Alliance on Agricultural Greenhouse Gas and the Global Methane Initiative. Australia has attended recent research meetings related to the Global Research Alliance on Agricultural Greenhouse Gas (Global Research Alliance, n.d.). The latest update of Australia's projects for the Global Methane Initiative is from 2013 (Global Methane Initiative, 2019). Australia has not ramped up research in this area.

Conclusion

Australia has an infamous track record on forest clearing. While the forestry sector is currently Australia's best performing sector in emissions, the national and state data on deforestation demonstrate very different accounts of the sectors progress, or lack of progress. Queensland data demonstrates large tracts of land are being cleared. Australia is the only developed country deforestation hotspot in the world, with estimates that 3-6 million hectares of forest could be lost by 2030 in Eastern Australia, while more than 7.7 million hectares have been cleared since 2000. The historical data for this sector has been adjusted, and largely varies from the previous year, raising questions of reliability.

There is no effective policy in place to reduce emission in the agriculture sector, as the Carbon Farming Futures Programme ended in 2017 and the Emissions Reduction Fund has hardly any projects focusing on reducing emissions in this sector.

2.6 Waste

The waste sector is responsible for 2 percent of Australia's emissions (DEE, 2019a). The emissions are mainly derived from methane gas generated from decaying organic material in landfill. The waste sector includes the waste from domestic, commercial and industrial sources. Figure 11 shows current trends and projections for the waste sector. Table 14 gives an overview of implemented policies.

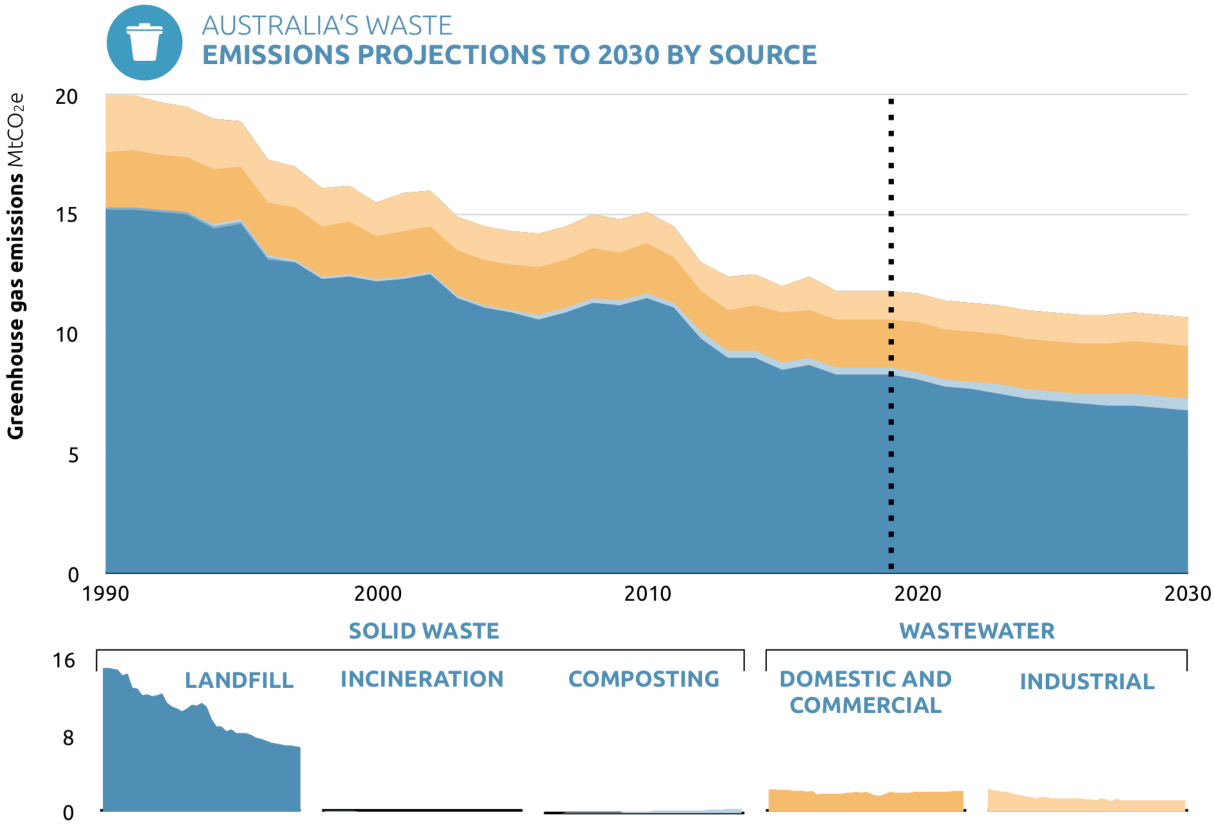


Figure 26 - Waste sector emissions, (historical data from 1990 to 2019, projected data 2020 to 2030) Source: (DEE, 2019a).

The ERF portfolio has 106 landfill and waste projects, and has issued Australian Carbon Credit Units equivalent to 20.2 $MtCO_2e$ (CER, 2019e). The safeguard mechanism limits emissions from waste deposited at large landfills since July 2016, but it does not cover legacy emissions from waste deposited before this date (CER, 2019c). In 2017-2018, 23% of ACCUs were from waste, in the last auction there were no waste projects added to the ERF portfolio (CER, 2018b, 2019d). The ERF has received criticism relating to the issue of additionality. A study found that the ERF incentivizes existing actors to continue existing projects, but the abatements used are counted as new abatements, despite the fact they would have occurred without the ERF (Baxter & Gilligan, 2018). This "progress" should not be applied to calculations towards Australia's contribution to abatements (Baxter & Gilligan, 2018).

Australia developed a National Waste Policy in 2018. The policy is not specifically aimed at reducing emissions, but reducing waste, shifting from a 'take, make use and dispose' to a circular economy (Australian Government, 2018c). Strategy 12 plans to reduce organic waste. As organic waste is the source of the waste sectors landfill emissions, this strategy should impact the emissions of this sector. The strategy involved avoiding organic matter waste generation, and diverting the organic material away from landfill to other uses such as soil. Although the strategy does not provide further details on the 'appropriate infrastructure' necessary. Waste policy is often dealt with at the local level.

Table 14: Overview of implemented climate change policies in the waste sector in Australia

<table>
<tr><th colspan="5">OVERVIEW OF IMPLEMENTED CLIMATE CHANGE POLICIES FOR THE WASTE SECTOR IN THE AUSTRALIA</th></tr>
<tr><th>Changing Activity</th><th>Energy efficiency</th><th>Renewables</th><th>Nuclear or CCS or fuel switch</th><th>Non-energy</th></tr>
<tr><td></td><td></td><td colspan="3">Emissions Reduction Fund
The EMF portfolio has 106 waste and landfill projects (CER, 2019e), and the related safeguard mechanism covers some large landfill emissions since July 2016.

National Waste Policy
The National Waste Policy plans for a more circular economy to reduce waste, and briefly outlines a strategy to reduce organic waste, which is the source of most of the sectors emissions (Australian Government, 2018c).

National Food Waste Strategy
National and state government have committed to a AUD $1.37 million investment to reduce food waste by 50% by 2030 (DEE, 2017b).

CEFC and ARENA
Both the CEFC and ARENA have funded waste related projects. In 2017-2018, the CEFC provided AUD$127m (total project value $148m) for waste related projects (CEFC 2018). The CEFC has funded biomass energy-from-waste (CEFC 2018), and ARENA has funded waste-to-energy projects from agricultural bi-products (CCA 2019a).</td></tr>
<tr><td colspan="5">Emissions reduction goals
none</td></tr>
</table>

No policies currently exist and a similar policy gap exists in all other countries

No policies currently exist however Australia could adopt policies from other countries

Existing and planned policies in Australia

The National Food Waste Strategy plans to reduce food waste by 50% by 2030 (DEE, 2017b). The target is in line with Sustainable Development Goal 12.3 to halve per capita food waste at the retail and consumer levels and reduce food losses along the production and supply chains, including post-harvest losses (DEE, 2017b). Australia's food waste costs the economy AUD$20 billion each year (DEE, 2017b). The first steps in the strategy was to support an independent organisation to develop an implementation plan for the strategy, a voluntary commitment by business and industry to reduce food waste, and a national food waste baseline to monitor and track progress towards reducing food waste.

Government projections indicate waste sector emissions will decrease by 8% from 2020 to 2030, from 12 $MtCO_2e$ to 11 $MtCO_2e$, respectively (DEE, 2019a). The decrease in emissions is attributed to lower landfill levels and increases in methane capture, taking into account the National Food Waste Strategy and state and territory level waste targets (DEE, 2019a).

The National Food Waste Strategy (DEE, 2017b) plans to reduce food waste by 50% by 2030, covering a portion of the meeting the benchmark to divert all organic waste from landfill. The CEFC and ARENA can also support Australia's effort in meeting the benchmark (projects are outlined in Table 14) by scaling up their funding towards waste-to-energy plants.

2.6.1 Conclusion

Australia needs to scale up its national waste policy with more ambitious targets to tackle emissions, focusing on organic material waste. The policy needs to be more specific on targets and implementation. Unspecified state and national policies do not provide a pathway to emissions reductions in this sector. First efforts need to focus on waste reduction, which can generate savings to the economy, particularly regarding food waste. Businesses and households can reduce their spending through less waste. This creates a smaller task in redirecting organic waste from landfill. There are a number of options to redirect organic material from compost to converting waste to energy.

Regional and local government plans need to follow the national waste policy pathway, tackling waste at the source. The Climate Change Authority (Climate Change Authority, 2020) also recommend national, state and territory governments work together to reduce landfill emissions and harmonise regulations, recognising the benefits of a circular economy. Currently, the additionality issues of the ERF distort the figures of Australia's progress in abatement, and push Australia further away from meeting this benchmark.

3 Selection of focus areas for analysis on scaling up climate action

The report specifically prioritises energy related emissions for in-depth analysis of scaling up climate action in Australia, whilst also providing a broad coverage of all the other sectors: building, transport, industry, electricity supply, fossil fuels sector, and non-energy emissions from agriculture and waste.

This section explains the reasoning for looking further into these energy related emissions areas, considering Australian national context and country-specific circumstances. This report differs to previous Scaling Up Climate Action reports as it has a broader coverage of sectors, instead of subsectors. In particular, it provides granular coverage of all energy related emissions. The report also derives an aggregate 1.5ºC consistent GHG emissions pathway to draw a conclusion for the need to scale up Australia's overall emissions target.

Relevant literature in the field and most recent emission scenarios clearly indicate that all sectors need to maximise their efforts for 1.5°C Paris Agreement compatibility (Kuramochi et al., 2018). The selection of focus areas for scaling up climate action is based on the following criteria combined with expert judgement by the authors.

i. **GHG emissions:** The relevance of the (sub-)sector in terms of historical and projected future GHG emissions
ii. **Existing gap**: The existing gap between currently existing and planned policies and 1.5°C compatible benchmark(s)
iii. **Potential for scaling up climate action:** The potential for enhancing climate action given local and global sectoral development (e.g. decreasing prices for RE technologies, pending investment in infrastructure)
iv. **Priority in the national discourse:** Priority of the respective (sub-)sector in the national discourse or window of opportunity to enhance climate action due to recent social, political, or economic developments
v. **Overlaps with other sectors:** The (sub-)sector's overlap with other sectors relevant for long-term decarbonisation (e.g. CO_2-neutral electricity sector in parallel to electrification trends in the transport or buildings sector)
vi. **Co-benefits potential and sustainable development goals:** Potential to realise co-benefits of scaling up climate action in a given country context (e.g. local job development through ambitious renewables deployment or reduction in urban air pollution due modal shifts away from combustion engines), especially linking to the country's sustainable development goals

The following sections provide explanation for each sector selection, also considered the technical feasibility of the research for the sectors, for example data availability might be a limiting factor.

3.1 Electricity

The focus on the Australian electricity sector is justified by the significant share of emissions coming from the sector and the critical role it can play to decarbonise other end-use sectors.

- **GHG emissions:** The power sector is the single largest contributor to greenhouse gas emissions, and contributes approximately one third of Australia's total emissions.
- **Potential for increasing ambition:** Coal power stations are increasingly unreliable, with almost 100 breakdowns between December 2017 and June 2018 in Australia. Ageing coal stations are increasingly expensive to operate, risk black-outs and high prices. Renewables with storage are the cheapest form of 'reliable' energy supply, surpassing also gas. They provide reliable generation and can ramp up even if the sun is not shining, while providing clean, reliable supply at least cost.

- **Overlaps with other sectors**: decarbonisation of building sector, transport sector, industry sector (electrification and/or green hydrogen)

Co-benefits potential: increasing the share of renewables in the power sector and phasing out coal will lead to significant benefits by reducing air pollution. The health impacts of coal-fired power generation are estimated to cost Australia AUD$2.6 billion annually. The use of coal is contributing to 4000 premature deaths each year, mostly by exacerbating existing chronic cardiac and respiratory illnesses (Climate Analytics, 2019d).

3.2 Industry

(see section 2) In Australia, greenhouse gas emissions from the industrial sector make up 28% of total emissions. They are mainly caused by "direct combustion", in other words burning fossil fuels for heat, steam or pressure in either the manufacturing, energy or mining sectors. With a rapid increase in production of liquified natural gas (LNG) for export, LNG processing is one of the fastest-growing sources of emissions. Increasing gas extraction is also leading to more fugitive emissions.

Australia's industry emissions are continuing to increase, mostly from increasing extraction and production of liquified natural gas (LNG) for export. Emissions from manufacturing and mining are not projected to decrease, nor are fugitive emissions released during coal mining or gas extraction and processing. Australia has minimal policies in place to reduce these emissions. Implementing energy efficiency policies across all industry sectors are key steps in reducing emissions and saving money.

- **GHG emissions:** In Australia, greenhouse gas emissions from the industrial sector make up 28% of total emissions. They are mainly caused by "direct combustion", in other words burning fossil fuels for heat, steam or pressure in either the manufacturing, energy or mining sectors. With a rapid increase in production of liquified natural gas (LNG) for export, LNG processing is one of the fastest-growing sources of emissions. Increasing gas extraction is also leading to more fugitive emissions. Emissions from industrial processes and product use are projected to decrease slightly between 2020 and 2030 due to a recently-legislated phase-down of industrial fluorinated gases (HFCs), which will reduce the permitted amount of bulk HFC gas imports into Australia from 2018.
- **Existing gap:** Meeting Australia's climate commitments through the Paris Agreement will require steep reductions in emissions across the entire economy. A paradigm shift towards zero emissions and decarbonisation of key industry sectors is critical.
- **Potential for increasing ambition:** Many studies have shown that Australia can decarbonise its industry sector and transition away from fossil fuels by 2050. The IEA has pointed out the vast opportunities in Australia based on the "extreme abundance of solar and wind resources" to spur international trade in renewables-based, hydrogen-rich chemicals and fuels.
- **Overlaps with other sectors**: Decarbonisation of industry relies on direct and indirect electrification, and therefore on decarbonisation of electricity generation. Electrification can also support integration of variable renewable energy (sector coupling).
- **Co-benefits potential:** Options for zero carbon primary steel production are the combination of renewable energy with an electrolysis reduction process route and the production of primary steel through direct reduction of iron ore with renewables-based hydrogen. Australia with its huge potential for wind and solar energy can become a world leader in zero emissions steel production.

3.3 Transport

The transport sector is the third largest source of emissions in the Australian economy, and emissions are growing fast.

- **GHG emissions:** In 2017 transport represented 18% of total emissions and has increased by 57% since 1990. By 2030, transport emissions are projected to be 82% higher than 1990.
- **Existing gap:** Australia's transport emissions are continuing to rise due to high polluting cars, more cars on the road, low share of trips taken by public transportation and increased demand for freight driving truck emissions. However, meeting Australia's climate commitments through the Paris Agreement will require steep reductions in emissions across the entire economy. A paradigm shift towards zero emission vehicles is a key ingredient to achieving this.
- **Potential for increasing ambition:** Australia has very little in the way of national transport policies.
- **Overlaps with other sectors**: Decarbonisation of transport relies on electrification, and therefore on decarbonisation of electricity generation. Electrification can also support integration of variable renewable energy (sector copuling).
- **Co-benefits potential:** After coal-fired power stations, motor vehicle emissions are the second largest source of air pollutants (oxides of nitrogen and carbon monoxide) nationally. The OECD has estimated that the economic cost of Australian motor vehicle emissions was about $5.8 billion in 2010. Moving to zero emissions would also avoid oil imports. Instead, Australia can use its abundant wind and solar energy resources. Congestion in Australia costs the economy more than $16 billion a year - a figure that is expected to increase. Adopting public transport policies could tackle congestion and hence decrease lost time, air pollution and vehicle costs.

In addition, we analyse the building sector as an end use sector with large potential for electrification, and for catching up with best practice policies in other countries.

4 Scenario analysis of scaling up climate action in Australia

This section presents scenario analysis supporting scaling up climate action in Australia. We quantify emission reductions achieved through enhanced climate action, and identify sectoral transformations required to be consistent with the temperature limit goals of the Paris Agreement. This scenario analysis allows identification of the gaps between Australia's sectoral emission trajectories under the reference scenario and sectoral transformations required for alignment with the Paris Agreement's temperature goal. Additionally, we investigate the sectoral transformations demonstrated by international frontrunners as well as existing scenarios developed in the specific national context.

This analysis uses the same approach as other studies of the Scaling up Series, such as the study on scaling up climate action for the European Union (Climate Action Tracker, 2018c) when analysing key end use sectors identified in Section 3 (Industry, transport, and buildings) based on the selection of three different scenario categories as elaborated below, but goes further by covering all energy sectors and subsectors.

Ambitious sectoral transitions in demand sectors imply higher electricity demand either through direct electrification (e.g. use of electric vehicles, replacing gas heating with heat pumps, replacing gas with renewable electricity for LNG processing and other industry processes) or indirect through Power to Gas (PtG) or Power to Liquid (PtL) technologies, for instance use of hydrogen produced via renewable electrolysis for industry processes or fuel cells for heavy freight transport or production of alternative fuels on this basis for example for aviation.

A key strategy for decarbonising the whole energy system including all demand sectors is the fast decarbonisation of the power sector, considering increased electricity demand and sector coupling. In order to develop our pathways for the electricity sector, we take into account the electricity demand from various end-use sectors for different scenarios. This is passed through an optimization model for the electricity sector that provides the least cost solutions for the energy system while satisfying the emissions budget constraints.

Detailed sector specific analysis includes the following scenario categories:

1 **NATIONAL** SCENARIOS

2 **BEST IN CLASS** SCENARIOS

3 **1.5°C PARIS AGREEMENT COMPATIBLE** SCENARIOS

1.5°C Paris Agreement compatible scenarios

The category of '1.5°C Paris Agreement compatible scenarios' comprises sectoral indicator values, which are in line with a 1.5°C compatible sectoral emissions trajectory. The analysis in this scenario category enhances the general understanding about required sectoral transformations in the Australian context to be in line with the Paris Agreement's temperature goal.

Applying best-in-class level(s)

The scenario category 'applying sectoral best-in-class level(s)' identifies indicator values from international and regional frontrunner(s) on national climate action in the respective (sub-) sector. The absolute indicator level(s) or growth rate(s) are applied to the developments in the respective sector. The analysis in this scenario category reveals the sectoral implications if sectoral transitions achieved by international frontrunners are replicated at an Australian scale.

National scenarios

The scenario category 'National scenarios' comprises sectoral indicator levels obtained from analyses conducted particularly by Australian research institutions and universities. Such analyses mainly include long-term, modelling studies for the whole Australia's energy sector or at sectoral level. The analysis in this scenario category aims to illustrate the sectoral decarbonisation pathways proposed by national studies that consider the Australian-specific circumstances.

4.1 Buildings sector

The Paris Agreement compatible sectoral trajectories almost fully decarbonise Australia's buildings sector by 2050. Energy savings achieved through deep retrofit of existing buildings in parallel to construction of zero-emissions new buildings, energy efficiency improvement of lighting and appliances as well as strong electrification (e.g. heat pumps) or other technological shifts to renewable energy in space/water heating [11] can fully decarbonise the Australian buildings sector by mid-century. Space cooling relies on electricity as the main source already under the Reference Scenario. This relies critically on decarbonising the electricity supply sector (see Section 0).

Table 17 gives an overview of the scenario analysis results for scaling up climate action in the buildings sector of Australia. Differentiation between residential and commercial buildings is relevant for the national scenario category, based on the underlying literature.

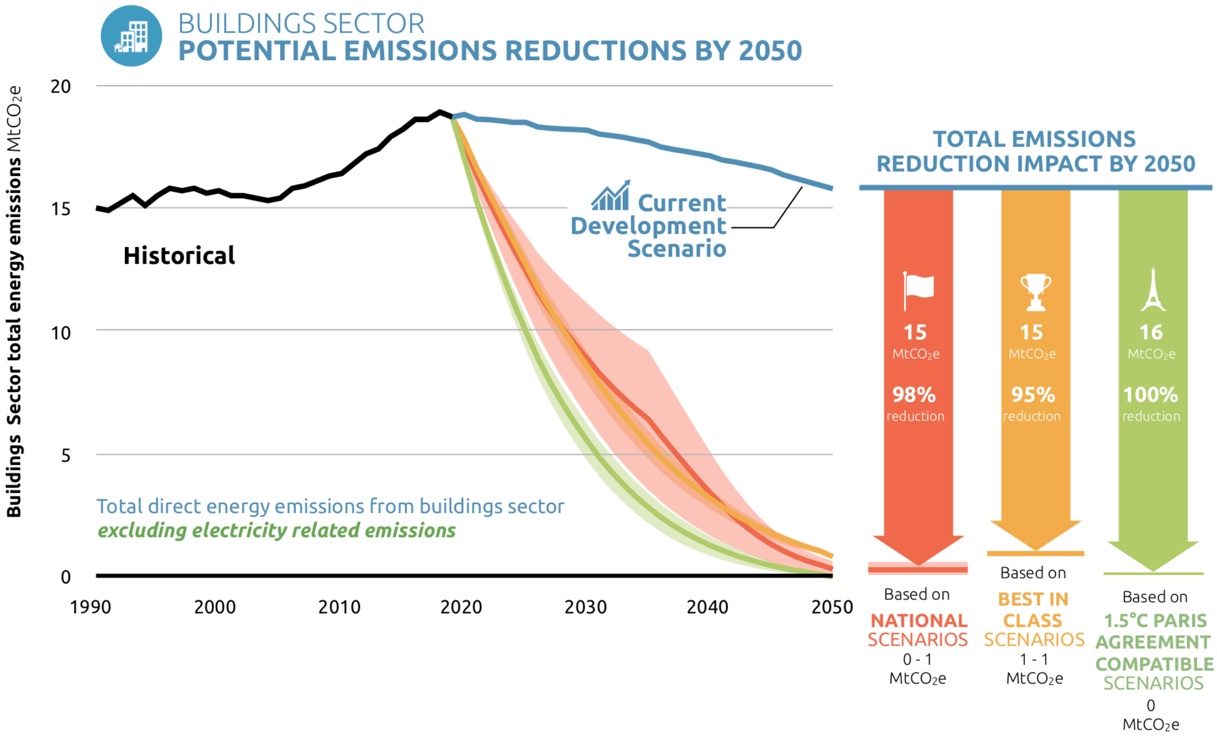


Figure 27 Overview of sectoral emission pathways under Reference scenario projections and different levels of accelerated climate action in Australia's buildings sector excluding electricity-related emissions. All sectoral projections towards 2050 done in the CAT PROSPECTS Australia scenario evaluation tool.visualizes the emissions trajectories across various scenarios resulted from quantification with the PROSPECTS Australia scenario evaluation tool.

[11] The PROSPECTS Australia scenario evaluation tool, applied for the quantification here, explicitly considers the electrification of water/space heating as a means of decarbonisation. However, this can also be achieved via direct shift to renewable energy, e.g. solar thermal.

Table 17: Outcome overview of scaling up climate action analysis in the Australia's buildings sector. Differences between indicator values for residential and commercial buildings are highlighted in italics and only relate to the national scenarios.

Indicator	Indicator values for scenario categories		
	National scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Residential Buildings			
Renovation rate	• **4%** per year renovation rate from 2020-2050 • Rate under current policies from 2016-2020	• **1.5-2.1%** per year renovation rate from 2021-2050 • Rate under current policies from 2016-2020	• **5%** per year renovation rate from 2020-2050 • Rate under current policies from 2016-2020
	Based on deep decarbonisation scenario for the Australian residential building sector as investigated by ClimateWorks Australia (2014) and data from IEA Buildings model	*Based on best-in-class practice identified in Kriegler et al.* (Kriegler et al., 2018)	*Based on benchmark for OECD region specified in Kuramochi et al.* (Kuramochi et al., 2018)
Relative improvement of energy efficiency in renovated/new buildings	**59-80%** improvement compared to 2015	**45-80%** improvement compared to 2015	**75-100%** improvement compared to 2015
	Based on deep decarbonisation scenario for the Australian residential building sector as investigated by ClimateWorks Australia (2014)	*Based on best-in-class benchmarks for retrofits and new buildings identified in Kriegler et al.* (Kriegler et al., 2018), *Fekete et al. (2015) and Erhorn and Erhorn-Kluttig, (2015)*	*Based on benchmarks for retrofits and new buildings identified in Kuramochi et al.* (Kuramochi et al., 2018)
Energy intensity improvement of cooking/ lighting/ appliances (electricity + direct energy)	Average efficiency improvement of **2%** per year applied from 2016-2050	Average efficiency improvement of **1.5-1.8%** per year applied from 2016-2050	Average efficiency improvement of **2%** per year applied from 2016-2050
	Based on deep decarbonisation scenario for the Australian residential building sector as investigated by ClimateWorks Australia (2014)	*Based on best-in-class practice identified in Fekete et al. (2015) and Kriegler et al. (2018)*	*Based on benchmarks identified in Kriegler et al.* (Kriegler et al., 2018)
Decarbonisation of water heating/space heating	**95-100%** electrification rate in water/space heating by **2050**	Not specified benchmark. Electrification rate under National Scenario is applied	**100%** electrification rate in water/space heating by **2050**
	Based on deep decarbonisation scenario for the Australian residential building sector as investigated by ClimateWorks Australia (2014) and based on the plans assuming "going gas free" (electrification, replacing gas appliances with high-efficiency electric alternatives) (BZE 2013)	*N/A*	*Based on plans to remove natural-gas based heat boilers in the buildings sector and replacing those with zero emissions electric/hybrid heat pumps or other renewable energy-based heating,*
Electrification of cooking/appliances	**100%** electrification rate in cooking/appliances by **2050**	Not specified benchmark. Electrification rate under Reference Scenario is applied	**100%** electrification rate in cooking/appliances by **2050**
	. *Based on deep decarbonisation scenario for the Australian residential building sector as investigated by ClimateWorks Australia (2014) and based on the plans assuming "going gas free" (electrification, replacing gas appliances with high-efficiency electric alternatives) (BZE 2013)*	*N/A*	*Based on the plans assuming "going gas free" (electrification, replacing gas appliances with high-efficiency electric alternatives) (BZE 2013)*

Commercial buildings			
Renovation rate	• ***3%*** *per year renovation rate from 2020-2050* • Rate under current policies from 2016-2020	• **1.5-2.1%** per year renovation rate from 2019-2050 • Rate under current policies from 2016-2018	• **5%** per year renovation rate from 2020-2050 • Rate under current policies from 2016-2020
	Based on deep decarbonisation scenario for the Australian residential building sector as investigated by ClimateWorks Australia (2014) and data from IEA Buildings model	*Based on best-in-class practice identified in Kriegler et al.* (Kriegler et al., 2018)	*Based on benchmark for OECD region specified in Kuramochi et al.* (Kuramochi et al., 2018)
Relative improvement of energy efficiency in renovated/new buildings	***50-80%*** *improvement compared to 2015*	**96%** improvement compared to 2015	**75-100%** improvement compared to 2015
	Based on deep decarbonisation scenario for the Australian commercial building sector as investigated by ClimateWorks Australia (2014)	*Based on Erhorn-Kluttig, (2015); Kurnitski et al. (2014) applying the case of Denmark with most ambitious definition of nZEB*	*Based on benchmarks for retrofits and new buildings identified in Kuramochi et al.* (Kuramochi et al., 2018)
Energy intensity improvement of cooking/ lighting/ appliances (electricity + direct energy)	*Average efficiency improvement of* ***1-2%*** *per year applied from 2016-2050*	Average efficiency improvement of **1.5-1.8%** per year applied from 2016-2050	Average efficiency improvement of **2%** per year applied from 2016-2050
	Based on deep decarbonisation scenario for the Australian commercial building sector as investigated by ClimateWorks Australia (2014)	*Based on best-in-class practice identified in Fekete et al. (2015) and Kriegler et al. (2018)*	*Based on benchmarks identified in Kriegler et al.* (Kriegler et al., 2018)
Decarbonisation of water heating/space heating	**95-100%** electrification rate in water/space heating by **2050**	Not specified benchmark. Electrification rate under National Scenario is applied	**100%** electrification rate in water/space heating by **2050**
	Based on deep decarbonisation scenario for the Australian commercial building sector as investigated by ClimateWorks Australia (2014) and based on the plans assuming "going gas free" (electrification, replacing gas appliances with high-efficiency electric alternatives) (BZE 2013)	*[-]*	*Based on plans to remove natural-gas based heat boilers in the buildings sector and replacing those with zero emissions electric/hybrid heat pumps or other renewable energy-based heating, as introduced by some EU MS* (Climate Action Tracker, 2018c)
Electrification of cooking/appliances	100% Electrification rate by 2050 already achieved in the Reference Scenario	100% Electrification rate by 2050 already achieved in the Reference Scenario	100% Electrification rate by 2050 already achieved in the Reference Scenario
	Based on PROSPECTS AUS tool developed by Climate Action Tracker (2018). Main reference is IEA Buildings Model.	*Based on PROSPECTS Australia scenario evaluation tool developed by Climate Action Tracker (2018). Main reference is IEA Buildings Model.*	*Based on PROSPECTS Australia scenario evaluation tool developed by Climate Action Tracker (2018). Main reference is IEA Buildings Model.*

Required policy measures for sectoral transformation	Remaining challenges threatening implementation
⇨ Commit to cohesive national zero carbon ready building code. Major changes to the National Building Code should not wait until 2022: Introduce residential standards and incremental increases in non-residential standards; Introduce energy efficiency targets, ensuring clear timelines and targets for industry certainty; ⇨ Increase awareness and information about energy efficiency benefits for homebuyers and commercial buyers. ⇨ Ensure compliance to energy efficiency standards in the construction of buildings though national audits. ⇨ Ensure transparency with national energy efficiency disclosure schemes to inform renters or buyers on the building's energy efficiency. ⇨ Ban fossil fuels for heating from 2030 onwards. ⇨ Knowledge and skills program for the building industry. ⇨ Affordable repayment scheme for energy efficient refurbishments.	⇨ Lack of information and awareness of energy efficiency benefits for property buyers. ⇨ Lack of compliance from the building industry. ⇨ Lack of knowledge and skill related to energy efficiency in the building industry. ⇨ Perceived high up-front costs of investment. ⇨ Issue of split incentives where the investor who increases energy efficiency, does not reap the benefits of lower bills (renter benefit).

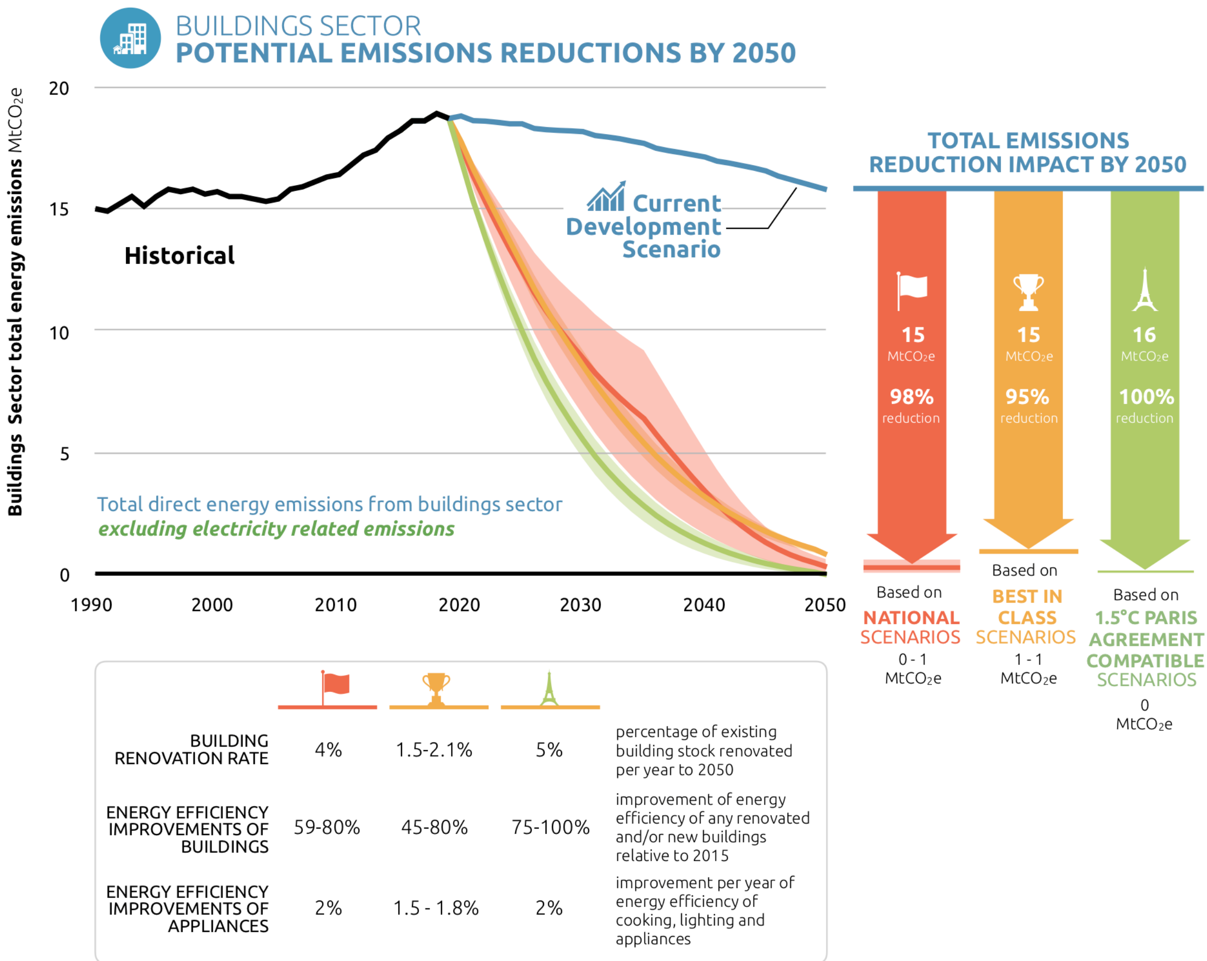


Figure 27 Overview of sectoral emission pathways under Reference scenario projections and different levels of accelerated climate action in Australia's buildings sector excluding electricity-related emissions. All sectoral projections towards 2050 done in the CAT PROSPECTS Australia scenario evaluation tool.

4.1.1 Context for scaling up climate action in the buildings sector

There is a significant potential for emissions reduction in the buildings sector

- Australian houses are uncomfortable. They are cold in winter and hot in summer, and expensive to keep warm and cool. Regulating the temperature draws a large demand from the electricity grid. Currently, the building sector accounts for 57% of Australia's electricity usage (IEA, 2018a) and only 19% of electricity is sourced from renewable energy (DEE 2019). There is huge potential to both increase energy efficiency to reduce energy consumption and replace fossil fuels such as gas with renewable energy (e.g. heat pumps). Improving the energy efficiency of buildings will have a large impact on the electricity reliability, while improving electricity affordability for Australian households and businesses.
- The fact that buildings are long lived assets, increases the emissions reductions potential. Buildings constructed after 2019 could cover 51% of all buildings by 2050 (ClimateWorks Australia, 2018a). Buildings can last beyond 50 years depending on their durability. New builds need high levels of efficiency standards, and old buildings need to be retrofitted to improve energy efficiency.
- There are only a handful of zero emissions buildings in Australia (Josh's House, 2019), there are also buildings that meet the government's Carbon Neutral Certification. Buildings under this program both reduce their emissions but also offset remaining emission (DEE, 2019d).

Significant benefits beyond climate mitigation

- Energy efficiency can reduce fuel poverty for low income earners, due to energy savings and creating affordable heating and cooling (ASBEC, 2016a; Beyond Zero Emissions & Melbourne Energy Institute, 2013; International Energy Agency (IEA), 2014). This is a big issue for low income households who struggle to afford the high electricity costs.
- Effective management of buildings with renewable energy can further reduce electricity bills and benefit the electricity grid, by using onsite renewables and storage in peak periods. These distributed energy sources can be optimised to reduce the peak demand on the grid. This both can provide better grid management and reduce the capital costs for further generation as there is less demand.
- Energy efficient buildings provide the household and commercial rentals with a competitive advantage in the marketplace. Green office buildings outperform other office buildings across a range of indicators, and a green label home adds an average of 9% to house sales (ASBEC, 2016a).
- There are multiple health and well-being impacts of energy efficiency in buildings including reduced respiratory disease symptoms, and fewer deaths in extreme climates (ASBEC, 2016a; International Energy Agency (IEA), 2014). Energy efficiency improvements can reduce temperature changes, noise, drafts, mould and mildew from the building, ensuring a better physical and mental state for occupants.
- Energy efficient buildings have been found to improve health and productivity for commercial buildings occupants (ASBEC, 2016a; Beyond Zero Emissions & Melbourne Energy Institute, 2013) The buildings have improved air quality and ventilation improving productivity up to 11%, and exposure to daylight can reduce sick leave, both of which result in significant positive financial implications for businesses (ASBEC, 2016a).
- Building and retrofitting energy efficient buildings, and renewable energy and battery storage in buildings have been linked to economic growth and job creation in Australia (ASBEC, 2016a; Beyond Zero Emissions & Melbourne Energy Institute, 2013). Job creation includes both in the construction industry, the renewable energy industry and

the broader economy. Australia's energy productivity can be improved, where investment in energy efficiency results in a greater economic return in Australia. Research by ClimateWorks' (ClimateWorks Australia, 2015) demonstrates Australia could nearly double energy productivity of the economy by 2030. Energy efficiency plays a large role in energy productivity, for example through the installation of efficient boilers to energy management and optimisation in buildings.

Important barriers still exist:

- The current policy framework lacks a cohesive governance framework for energy efficiency, which creates an inability to resolve policy barriers, inconsistencies between jurisdictions and a lack of stakeholder engagement to improve energy performance (ASBEC, 2016a). The periodic updates to the National Construction Code have so far only permitted unambitious and conservative changes.
- There is a lack of information and awareness of energy efficiency benefits (Donaldson, 2017) for property buyers and tenants. It is not clear to buyers and renters how efficient a home is before they buy or rent. There is no incentive for builders to make buildings more efficient, but rather build at the cheapest price. Schemes can be used to rate the efficiency of homes, so that buyers and renters can factor efficiency into their purchase or rental decisions. There is no national energy efficiency disclosure scheme, although schemes have proven successful in other countries (Energy Efficiency Council, 2019).
- Evidence suggests there are many areas for improvement to ensure compliance with energy efficiency in the construction of buildings, and often builders opt for poor quality and cheaper products are as substitutes to energy efficient and compliant options (Donaldson, 2017).
- The building industry suffers from a lack of knowledge and skill related to energy efficiency, such as basic issues of sealing, insulation and installation (Donaldson, 2017).
- Energy efficiency requirements need credibility and compliance, possible through a national audit system (Donaldson, 2017).
- Another barrier is the upfront costs. Energy efficiency refurbishments can both be an expense for up-front capital and in terms of vacancy costs. The time taken to refurbish a building delays income from the property for both residential and office rentals. In addition, small businesses and low-income households may not be able to afford renovations or efficient appliances. The large initial upfront costs can be combatted with affordable repayment schemes depending on the scale of the renovation work, which will affect payback times and the motivation for owners to undertake renovations.
- Issue of split incentives arise when the investor who increases energy efficiency, does not reap the benefits of lower bills (renter benefit). 31% of Australian's are renting (Australian Bureau of Statistics, 2016). There is no incentive for investors to pay the capital investment of energy efficiency is they are not planning to live in the property. Homeowner households have a much higher rate of insulation, window treatments and solar electricity or hot water systems compared to renters (Australian Bureau of Statistics., 2012). Other countries have introduced minimum standards for rental properties which could similarly be applied to Australian rentals (Energy Efficiency Council, 2019).

4.1.2 Scenario analysis for scaling up climate action in the buildings sector

4.1.2.1 Identification of indicator levels

Table 18 provides an overview of indicator levels identified for scenario modelling in the residential and commercial buildings sector. The upper part of the table presents the relevant benchmarks as specified in the literature. The lower part shows how those benchmark levels have been adapted into selected indicator levels for providing input to the PROSPECTS Australia scenario evaluation tool.

Table 18: Overview of different benchmarks specified in the literature and translation into indicator levels for analysis of scaling up climate action in the residential and commercial buildings sector with PROSPECTS Australia scenario evaluation tool

	National scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Residential Buildings			
Renovation rate	• **4%** per year renovation rate from **2020** onward	• **1.5-2.1%** renovation rate from end of **2020** onward	• **5%** renovation rate from **2020** onward
	Based on the deep decarbonisation scenario for the Australian residential building stock as investigated by ClimateWorks Australia (2014) and IEA buildings model	*Based on best-in-class practice identified in Kriegler et al.* (Kriegler et al., 2018)	*Based on benchmark for OECD region specified in Kuramochi et al.* (Kuramochi et al., 2018)
New buildings stock	• **59%-80%** average improvement in the energy performance of new/retrofitted buildings by 2050	• **20 kWh/m²/year** of new buildings stock from **end of 2020** onward	• **Near net zero energy** new buildings stock from **2020** onward
	Based on the deep decarbonisation scenario for the Australian residential building stock as investigated by ClimateWorks Australia (2014)	*Based on Erhorn-Kluttig, (2015); Kurnitski et al. (2014) applying the case of Denmark with most ambitious definition of nZEB*	*Based on benchmarks for new buildings identified in* (Kuramochi et al., 2018)
Appliances	• Average efficiency improvement of **2%** per year (<u>all appliances</u>)	• Average efficiency improvement of **1.5-1.8%** per year (<u>all appliances</u>)	• Average efficiency improvement of **2%** per year (<u>all appliances</u>)
	Based on the deep decarbonisation scenario for the Australian residential building stock as investigated by ClimateWorks Australia (2014	*Based on best-in-class practice identified in Fekete et al.* (Fekete et al., 2015) *and Kriegler et al. (2018)*	*Based on benchmarks identified in Kriegler et al.* (Kriegler et al., 2018)
Decarbonising water/space heating	• **95-100%** electrification of water/space heating by **2050** *Based on the deep decarbonisation scenario for the Australian residential building stock as investigated by ClimateWorks Australia (2014) and based on the plans assuming "going gas free" (electrification, replacing gas appliances with high-efficiency electric alternatives) (BZE 2013)*	Not specified benchmark. Electrification rate under National Scenario is applied	• **100%** electrification of water/space heating by **2050** *Based on plans to remove natural gas based heat boilers in the buildings sector and replacing those with zero emissions electric/hybrid heat pumps, or other renewable energy technologies*
Electrification of Cooking/appliances	• **100%** electrification of cooking/appliances by **2050** *Based on deep decarbonisation scenario for the Australian residential building sector as investigated by ClimateWorks Australia (2014) and based on the plans assuming "going gas free" (electrification, replacing gas appliances with high-efficiency electric alternatives) (BZE 2013)*	Not specified benchmark. Electrification rate under Reference Scenario is applied	• **100%** electrification of cooking/appliances by **2050** *Based on the plans assuming "going gas free" (electrification, replacing gas appliances with high-efficiency electric alternatives) (BZE 2013)*
Commercial buildings			
Renovation rate	• **3%** per year renovation rates from **2020** onward	• **1.5-2.1%** renovation rate from end of **2018** onward	• **5%** renovation rate from **2020** onward

	Based on the deep decarbonisation scenario for the Australian residential building stock as investigated by ClimateWorks Australia (2014)	*Based on best-in-class practice identified in* (Kriegler et al., 2018)	*Based on benchmark for OECD region specified in Kuramochi et al.* (Kuramochi et al., 2018)
New buildings stock	• **50-80%** average improvement in the energy performance of new/retrofitted buildings by 2050	• **25 kWh/m2/year** of new buildings stock from **end of 2018** onward	• **Near net zero energy** new buildings stock from **2020** onward
	Based on the deep decarbonisation scenario for the Australian commercial building stock as investigated by ClimateWorks Australia (2014)	*Based on Erhorn-Kluttig, (2015); Kurnitski et al. (2014) applying the case of Denmark with most ambitious definition of nZEB*	*Based on benchmarks for new buildings identified in Kuramochi et al.* (Kuramochi et al., 2018)
Appliances	• Average efficiency improvement of **1-2%** per year (<u>all appliances</u>)	• Average efficiency improvement of **1.5-1.8%** per year (<u>all appliances</u>)	• Average efficiency improvement of **2%** per year (<u>all appliances</u>)
	Based on the deep decarbonisation scenario for the Australian commercial building stock as investigated by ClimateWorks Australia (2014	*Based on best-in-class practice identified in Fekete et al.* (Fekete et al., 2015) *and Kriegler et al. (2018)*	*Based on benchmarks identified in Kriegler et al.* (Kriegler et al., 2018)
Decarbonising water/space heating	• **95-100%** electrification of water/space heating by **2050** *Based on the deep decarbonisation scenario for the Australian residential building stock as investigated by ClimateWorks Australia (2014) and based on the plans assuming "going gas free" (electrification, replacing gas appliances with high-efficiency electric alternatives) (BZE 2013)*	Not specified benchmark. Electrification rate under National Scenario is applied	• **100%** electrification of water/space heating by **2050** *Based on plans to remove natural gas based heat boilers in the buildings sector and replacing those with zero emissions electric/hybrid heat pumps, or other renewable energy technologies*
Electrification of Cooking/appliances	100% Electrification rate by 2050 already achieved in the Reference Scenario	100% Electrification rate by 2050 already achieved in the Reference Scenario	100% Electrification rate by 2050 already achieved in the Reference Scenario
	Based on PROSPECTS Australia scenario evaluation tool developed by Climate Action Tracker (2018). Main reference is IEA Buildings Model.	*Based on PROSPECTS Australia scenario evaluation tool developed by Climate Action Tracker (2018). Main reference is IEA Buildings Model.*	*Based on PROSPECTS Australia scenario evaluation tool developed by Climate Action Tracker (2018). Main reference is IEA Buildings Model.*

Indicator levels for scenario analysis in the PROSPECTS Australia scenario evaluation tool

Residential Buildings

		National scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Renovation rate	High ambition	• **4% per year** renovation rate from **2020** onward • Rate of current policies before 2020	• **2.1%** per year renovation rate from **end of 2020** onward • Rate of current policies until 2021	• **5%** per year renovation rate from **2020** onward • Rate under current policies before 2020
	Low ambition		• **1.5%** per year renovation rate from **end of 2020** onward • Rate of current policies until 2021	
Relative improvement of energy efficiency in renovated/ new buildings	High ambition	**80%** as derived from high ambition end of efficiency improvements of renovated buildings based on the eight-star new build	**80%** as derived from benchmark for new buildings stock of **20 kWh/m2/year** compared to average historical energy intensity per m^2 in 2015	**100%** as derived from benchmark for new buildings stock of **near net zero energy: 0 kWh/m^2/year**
	Low ambition	**59%** as derived from low ambition end of efficiency improvements of renovated buildings based on the six-star new build	**45%** as derived from benchmark for renovated buildings stock	**75%** as derived from lower range of benchmark for renovated buildings stock

Energy intensity improvement of cooking/ lighting/ appliances (electricity + direct energy)	High ambition	Average efficiency improvement of **2%** per year (all appliances)	Average efficiency improvement of **1.8%** per year (all appliances)	Average efficiency improvement of **2%** per year (all appliances)
	Low ambition		Average efficiency improvement of **1.5%** per year (all appliances)	
Decarbonisation of water heating/space heating	High ambition	**100%** electrification rate in water/space heating by 2050	Not specified benchmark. Electrification rate under National Scenario is applied	**100%** electrification rate in water/space heating by 2050
	Low ambition	**95%** electrification rate in water/space heating by 2050		
Electrification rate in cooking/lighting/appliances	High ambition	**100%** electrification rate in cooking/lighting/appliances by 2050	Not specified benchmark. Electrification rate under Reference Scenario is applied	**100%** electrification rate in cooking/lighting/appliances by 2050
	Low ambition			
Commercial buildings				
Renovation rate	High ambition	• **3% per year** renovation rate **from 2020** onward • Rate of current policies before 2020	• **2.1%** per year renovation rate from **end of 2018** onward • Rate of current policies until 2018	• **5%** per year renovation rate from **2020** onward • Rate under current policies before 2020
	Low ambition		• **1.5%** per year renovation rate from **end of 2018** onward • Rate of current policies until 2018	
Relative improvement of energy efficiency in renovated/ new buildings	High ambition	**80%** efficiency improvements of renovated commercial buildings	**96%** as derived from benchmark for new buildings stock of **25 kWh/m2/year** compared to average historical energy intensity per m^2 in 2016	**100%** as derived from benchmark for new buildings stock of near net zero energy **0 kWh/m²/year**
	Low ambition	**50%** efficiency improvements of renovated commercial buildings		**75%** as derived from lower range of benchmark for renovated buildings stock
Energy intensity improvement of cooking/ lighting/ appliances (electricity + direct energy)	High ambition	Average efficiency improvement of **2%** per year (all appliances)	Average efficiency improvement of **1.8%** per year <u>(all appliances)</u>	Average efficiency improvement of **2%** per year (all appliances)
	Low ambition	Average efficiency improvement of **1%** per year (all appliances)	Average efficiency improvement of **1.5%** per year <u>(all appliances)</u>	
Decarbonisation of water heating/space heating	High ambition	**100%** electrification rate in water/space heating by 2050		

	Low ambition	**95%** electrification rate in water/space heating by 2050	Not specified benchmark. Electrification rate under National Scenario is applied	**100%** electrification rate in water/space heating by 2050
Electrification rate in cooking/lighting/appliances	High ambition	**100%** electrification rate in cooking/lighting/appliances by 2050 already reflected in the Reference Scenario	**100%** electrification rate in cooking/lighting/appliances by 2050 already reflected in the Reference Scenario	**100%** electrification rate in cooking/lighting/appliances by 2050 already reflected in the Reference Scenario
	Low ambition			

1.5°C Paris Agreement compatible scenarios

A review of relevant literature and studies identifies the following Paris Agreement compatible benchmarks for the three selected indicators in the residential and commercial buildings sector:

- All new buildings need to be fossil free and near net-zero energy by 2020. This is an average value proposed for OECD regions based on 1.5°C compatible benchmarks as identified in (Kuramochi et al., 2018).
- For the retrofit of existing buildings stock, the renovation rate needs to increase to 5% by 2020 (average for OECD regions) based on (Kuramochi et al., 2018).
- For the energy efficiency improvements of lighting and appliances, an average efficiency improvement of 2.0% p.a. is assumed as implied by the "net zero" policy package proposed by (Kriegler et al., 2018), which adds policies pushing for zero emission technologies particularly in energy end-use sectors in line with the Paris Agreement's goal to reach net zero CO_2 emissions in the second half of the century.
- For decarbonisation of water heating/space heating, it is assumed that a 100% electrification rate will be achieved in the Australian buildings by 2050. Replacing fossil fuel-based heating with renewable energy such as solar thermal heating would achieve equivalent results. This has been mainly inspired by the assessment conducted in (Climate Action Tracker, 2016) concluding that the buildings sector needs to completely phase out emissions by mid-century, in line with a 1.5°C pathway. Some EU MS are introducing a ban for fossil fuels for heating, e.g. Denmark, Netherlands (Ref. EU Scaling up report).
- For decarbonisation of cooking, it is assumed that a 100% electrification rate will be achieved in the Australian residential buildings by 2050. This has been mainly inspired by the assessment conducted in (Climate Action Tracker, 2016) concluding that the buildings sector needs to completely phase out emissions by mid-century, in line with a 1.5°C pathway.

Based on the Paris Agreement compatible benchmarks as specified above, the following indicator levels have been identified for the quantification of emissions trajectories in residential and commercial buildings sectors applying the PROSPECTS Australia scenario evaluation tool:

- **Renovation rate:** 5% per year renovation rate from 2020 onwards with a renovation rate under currently implemented policies of 1% used before 2020.
- **Relative improvement of energy efficiency in renovated/new buildings:** Range of 75% (deep retrofit of existing buildings) to 100% (near-zero emission new buildings).
- **Relative improvement of total energy intensity of cooking/lighting/appliances (electricity + direct energy):** Average efficiency improvement of 2% per year for all appliances from 2016 onwards until 2050.
- **Decarbonisation of space heating/water heating:** 100% electrification of space heating/water to be achieved by 2050. We applied an s-curve trajectory, where the electrification level rises from today (residential: 21.3%; commercial: 38.4%) towards the target/saturation level.
- **Electrification of cooking/appliances:** 100% electrification of cooking/lighting/appliances to be achieved by 2050. We applied an s-curve trajectory, where the electrification level rises from today (residential: 89%) towards the target/saturation level. Full electrification of cooking/lighting/appliances in the commercial sector already achieved under the Reference Scenario.

Applying best-in-class levels

Applying best-in-class levels are implemented here according to international frontrunners in increasing energy efficiency of new buildings stock and renovation of existing buildings. This allows to identify the implications of a successful implementation of mitigation measures at the level of international frontrunners for the Australia's buildings sector. A review of relevant literature identifies the following best-in-class benchmarks in the buildings sector:

- For the new buildings stock, the European Union's Energy Performance of Buildings Directive (EPBD) requires that all newly constructed buildings in EU Member States will have to consume 'nearly net-zero' energy by the end of 2020 and the energy will have to be 'to a very large extent' from renewable sources (Climate Action Tracker, 2016b; Fekete et al., 2015; BPIE, 2011). The EPBD is the main policy driver affecting energy use in buildings at European level and can be considered as international best practice policy. Member States shall include their national definition of nZEB into national legislation and inform the EC on the details in their national plans for increasing the number of nZEB . Among the Member States, Denmark has the most ambitious definition of nZEB with proposed (primary) energy consumption level of 20 $kWh/m^2/a$ specified for new residential buildings and 25 $kWh/m^2/a$ for new non-residential buildings (Erhorn-Kluttig 2015; Kurnitski et al. 2014). We apply this as the best-in-class energy performance level of the new residential buildings stock. This would translate into 80% energy efficiency improvement by taking 94 $kWh/m^2/a$ as the average level for current energy consumption of the Australia's residential buildings stock (DEE, 2018). This would translate into 96% energy efficiency improvement compared to the average level for current energy consumption of the Australia's commercial buildings stock (DEE, 2018).

- For the retrofit of existing residential buildings stock, a renovation rate of 1.5%-2.1% with efficiency improvement of 45% from end of 2020 onwards is applied as best-in-class level, which is comprised of the following components:
    - Renovation rate: 1.5% p.a.-2.1% p.a. renovation rate according to the good practice' policy scenario developed by the recent study conducted in (Kriegler et al., 2018).
    - Relative improvement of energy efficiency in renovated/new residential buildings: Subsidies and loans in Germany offered by the government-owned banking group *Kreditanstalt fuer Wiederaufbau* (KfW) provide economic incentives for new buildings as well as energy efficient renovations of existing buildings that meet requirements of the quality label ''Effizienzhaus" (efficient building). The maximum subsidy (correspondent to the highest standard) are granted to the buildings which are at least 45% more efficient than the reference house in the respective category.
    - Target year: The target year of the renovation rate specified above is end of 2020 for residential buildings and end of 2018 for non-residential buildings for developed countries as informed by the European Union's Energy Performance of Buildings Directive (EPBD) for new buildings stock.
- For energy efficiency improvement of appliances and lighting, an average efficiency improvement of 1.5% p.a. is considered across all appliances for the lower bound of best-in-class levels according to the good practice' policy scenario developed by (Kriegler et al., 2018). An upper bound of efficiency improvement of 1.8% p.a. across all appliances is considered as international best practice according to the study conducted in (Fekete et al., 2015). This is based on average improvement of appliances' efficiencies between 2001 and 2012 for EU member states with successful efficiency policies implemented before 2005: UK, Sweden, Netherlands, France, Slovakia, Finland, Czech Republic, Latvia according to the MURE database.

The identified best-in-class benchmarks, elaborated above, were translated into the following indicator levels to provide input for the PROSPECTS Australia scenario evaluation tool:

Residential Buildings

- **Renovation rate**: A range of 1.5%-2.1% per year renovation rate from end of 2020 onwards with a renovation rate under currently implemented policies of 1% used before 2020.
- **Relative improvement of energy efficiency in renovated/new buildings**: A range of 45% (deep retrofit of existing buildings) to 80% efficiency improvement based on the European Union's Energy Performance of Buildings Directive (EPBD)
- **Relative improvement of total energy intensity of cooking/lighting/appliances (electricity + direct energy)**: A range of average efficiency improvement of 1.5%-1.8% per year for all appliances

Commercial Buildings

- **Renovation rate**: A range of 1.5%-2.1% per year renovation rate from 2019 onwards with a renovation rate under currently implemented policies of 1% used before 2020.
- **Relative improvement of energy efficiency in renovated/new buildings**: 96% efficiency improvement based on the European Union's Energy Performance of Buildings Directive (EPBD)
- **Relative improvement of total energy intensity of cooking/lighting/appliances (electricity + direct energy)**: A range of average efficiency improvement of 1.5%-1.8% per year for all appliances according to the international best practice as identified in the study conducted by (Fekete et al., 2015) and the 'good practice' policy scenario developed by (Kriegler et al., 2018), respectively.

National scenarios

Indicator values for the 'National Scenarios' have been inspired based on recently published modelling studies by the Australian research institutions and universities. A review of relevant literature identifies the following Australian specific scenarios in the buildings sector[12]:

- The Australian deep decarbonization scenario as investigated by (ClimateWorks Australia, Australian National University (ANU), Commonwealth Scientific and Industrial Research Organisation (CSIRO), & CoPS., 2014), uses a combination of bottom-up sectoral models brought together in a national economic model to explore how Australia can transition to a low carbon economy.
    - **Relative improvement of energy efficiency in renovated/new buildings:** The Building Code of Australia (BCA), which is produced and maintained by the Australian Building Code Board on behalf of the Australian government as well as state and territory governments, contains technical provisions for the design and construction of buildings (ABCB, 2018). New residential buildings are designed to a minimum standard of at least six stars in most states through the building code of Australia. The House Energy Rating (6 Star Rating) method involves modelling the proposed building using thermal modelling software. The final result is a star rating, which correlates to the amount of energy required to heat and cool the building to a comfortable temperature year-round. The higher the star rating, the less energy is required by the building. Based on analysis of the performance of buildings in the most populated climate zones in Australia, the new residential buildings are 59% more efficient than the existing building stock performing equivalent to a two-star rating on average (ClimateWorks Australia, Australian National University (ANU), et al., 2014). Increasing the minimum performance standards for new residential buildings could further reduce the energy consumption. For instance, achieving eight-star rated new buildings could reduce energy demand for heating and cooling by more than 80% compared to the current building stock on a weighted average basis (ClimateWorks Australia, Australian National University (ANU), et al., 2014). Additionally, in the modelled pathway, the energy use per square meter reduces by about 50% in commercial buildings (ClimateWorks Australia, Australian National University (ANU), et al., 2014).
    - **Relative improvement of total energy intensity of cooking/lighting/appliances (electricity + direct energy):** An improvement rate of 2% p.a. has been assumed by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) for residential appliances. Although this level of improvement is lower than the technical potential, it remains at the high level of annual maximum achievable savings observed in studies over longer time periods. Energy savings from commercial appliances have been assumed between 1% and 2% p.a. in (ClimateWorks Australia, Australian National

[12] A recently published update of the Deep Decarbonisation scenarios (ClimateWorks Australia, 2020a) was not yet available at the time of this analysis.

University (ANU), et al., 2014). As with residential appliances and equipment this would not capture the full technical potential achievable with continuous learning and innovation. However, the assumed rate would reflect the challenges associated with implementing these energy savings across such a diverse range of end uses.

- **Decarbonisation of space heating/water heating:** In order to achieve substantial emissions reduction required for deep decarbonisation and concerning the high share of space heating in total energy use of residential sector (34%), it is particularly crucial that heating is provided by a decarbonised energy source such as decarbonised electricity. Alternative would be application of bioenergy or renewable hydrogen; however, this is not taken into account according to the limited availability of sustainable biomass and its major role in particular transport modes (e.g. HDVs, shipping, aviation) as well as industry sectors where fewer decarbonisation options exist. Electric heat pump and solar thermal systems are among the most efficient systems available, drastically reducing the energy use compared to traditional systems. Electricity is already used for a high proportion of energy use in most commercial buildings. An electrification rate of 95% assumed in the modeled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) is driven by electrification of heat starting prior to 2030 (e.g. use of heat pumps) while 100% electrification is achieved in grid-connected areas.
- **Decarbonisation of cooking/appliances:** 100% electrification of appliances is assumed to be achieved after 2030 in grid-connected areas in the modelled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014).

- The Zero Carbon Australia Project (ZCA) is an initiative of Beyond Zero Emissions as the not-for-profit research and education organization that works to design and implement a zero emissions economy for Australia and the University of Melbourne's Energy Research Institute. The Project is developing a roadmap for the transition to a decarbonized Australian economy over ten years. The ZCA Buildings Plan (BZE 2013) as one of the six plans under the ZCA focuses on measures to improve energy efficiency and electrify current natural gas services in the Australian buildings sector, aiming at reaching zero emissions for all existing buildings within 10 years. Based on the scenarios developed by (BZE 2013) in cooperation with relevant industry, the following indicators can be derived:
  - **Relative improvement of energy efficiency in renovated/new buildings:** Significant improvement of thermal performance of the building envelope can be achieved through well insulation of various building's components. This could lead up to 73-79% improvement in the energy performance of new/retrofitted buildings compared to a reference, of a not (or poorly) insulated residential building (BZE 2013).
  - **Decarbonisation of water/space heating and cooking/appliances (the plan also assumes "going gas free" (electrification, replacing gas appliances with high-efficiency electric alternatives)**

Derived from the scenarios for the Australian buildings sector by sources as described above, the following indicator levels have been identified for the quantification of emissions trajectories with the PROSPECTS Australia scenario evaluation tool:

Residential buildings

- **Renovation rate:** 4% per year renovation rate from 2020 onwards with a renovation rate under currently implemented policies of 1% used before 2020. The modelling conducted in (ClimateWorks Australia, Australian National University (ANU), et al., 2014) has assumed that approximately two percent of existing buildings are demolished each year, which assumes an average building lifespan of 50 years. There is poor availability of data on the average rates of building demolition or the relative ages of buildings making up the residential building stock, however, where this overestimate the turnover of buildings, this rate of replacement could be achieved through deep retrofits of buildings. Combining this with the development of residential floor space based on the IEA building model, we assumed a 4% p.a. renovation rate for the Australian residential buildings stock.

- **Relative improvement of energy efficiency in renovated/new buildings:** Range of 59% to 80% improvement of energy efficiency in renovated/new residential buildings compared to the existing building stock is taken into account according to the assumptions made in Australian deep decarbonisation scenario as investigated in (ClimateWorks Australia, Australian National University (ANU), et al., 2014).
- **Relative improvement of total energy intensity of cooking/lighting/appliances (electricity + direct energy):** An average efficiency improvement of 2% per year for all appliances is assumed based on the assumption made for residential appliances in Australian deep decarbonisation scenario as investigated in (ClimateWorks Australia, Australian National University (ANU), et al., 2014).
- **Decarbonisation of space heating/water heating:** 95% to 100% electrification of space/water heating to be achieved by 2050 based on the assumptions made for the residential buildings in the Australian deep decarbonisation scenario (ClimateWorks Australia 2014) as well as based on full decarbonisation of water/space heating ("going gas free") as envisaged by (BZE 2013). We applied an s-curve trajectory, where the electrification level rises from today (21.2%) towards the target/saturation level.
- **Decarbonisation of cooking/appliances:** 100% electrification of cooking/appliances to be achieved by 2050 based on the assumptions made for the residential buildings in the Australian deep decarbonisation scenario (ClimateWorks Australia 2014) as well as based on the plans assuming "going gas free" (electrification, replacing gas appliances with high-efficiency electric alternatives) according to (BZE 2013).

Commercial buildings

- **Renovation rate:** 3% per year renovation rate from 2020 onwards with a renovation rate under currently implemented policies of 1% used before 2020. The modelling conducted in (ClimateWorks Australia, Australian National University (ANU), et al., 2014) has assumed that approximately two percent of existing buildings are demolished each year, which assumes an average building lifespan of 50 years. Combining this with the development of commercial floor space based on the IEA building model, we assumed a 3% p.a. renovation rate for the Australian commercial buildings stock.
- **Relative improvement of energy efficiency in renovated/new buildings:** A lower bound of 50% improvement of energy performance of new commercial buildings based on the modelled pathway by (ClimateWorks Australia 2014), which assumes halving of energy intensity per square meter of commercial buildings by 2050. We also consider an upper bound of 80% improvement of energy performance of new commercial buildings similar to the upper ambition level assumed for the residential buildings
- **Relative improvement of total energy intensity of cooking/lighting/appliances (electricity + direct energy):** upper bound of average efficiency improvement of 2% per year and a lower bound of 1% per year average efficiency improvement for all appliances is assumed based on the ranges applied for commercial appliances under the Australian deep decarbonisation scenario by (ClimateWorks Australia, Australian National University (ANU), et al., 2014).
- **Decarbonisation of space heating/water heating:** 95% to 100% electrification of space/water heating to be achieved by 2050 based on the assumptions made for the commercial buildings in the Australian deep decarbonisation scenario (ClimateWorks Australia 2014) as well as based on full decarbonisation of water/space heating ("going gas free") as envisaged by (BZE 2013). We applied an s-curve trajectory, where the electrification level rises from today (38.4%) towards the target/saturation level.

4.1.2.2 Quantification of emission levels with PROSPECTS Australia

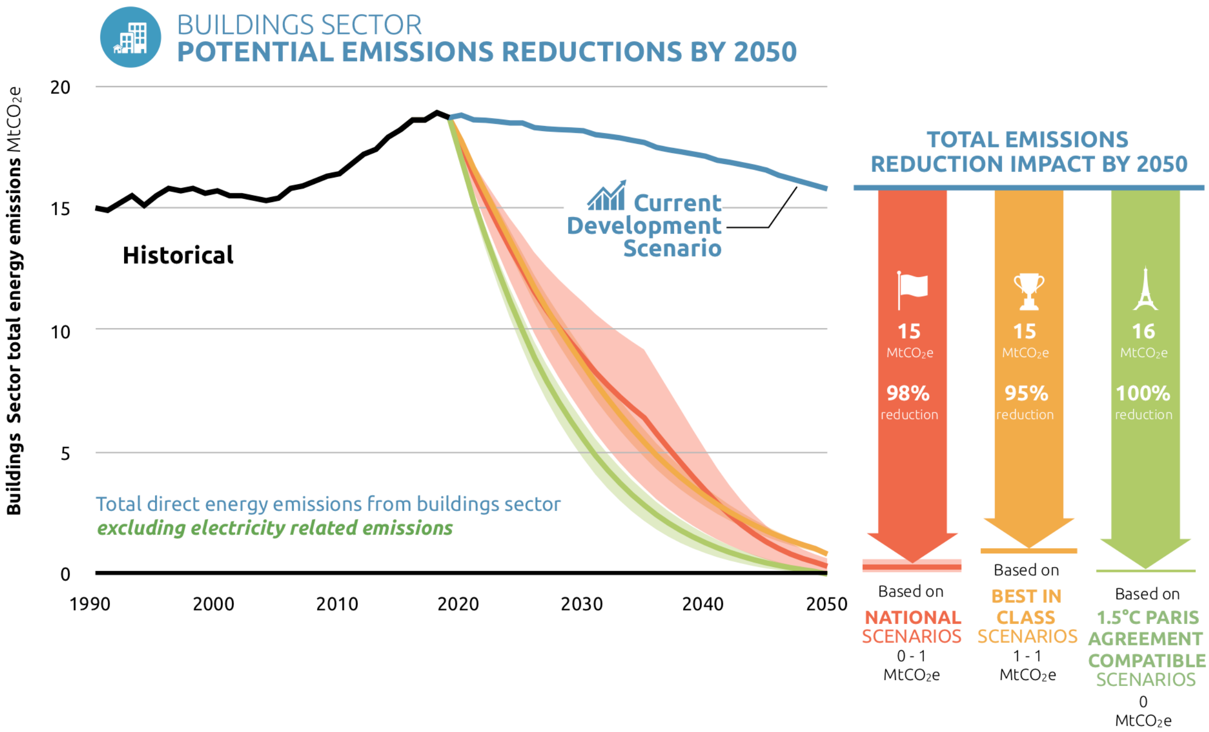


Figure 28 Overview of sectoral emission pathways under Reference scenario projections and different levels of accelerated climate action in Australia's buildings sector excluding electricity-related emissions;. All sectoral projections towards 2050 done in the CAT PROSPECTS Australia scenario evaluation tool.

Figure 28 illustrates the emissions trajectories from the Australia's buildings sector until mid-century including both direct energy emissions. This reveals how by applying mitigation measures on the demand side such as deep renovations and energy efficiency improvements/energy savings as well as electrification of the heating and cooking in buildings sector combined with a simultaneous decarbonisation of the electricity sector, significant reduction of emissions can be achieved by mid-century. Reductions in the reference scenario without electricity are consistent with the government projections until 2030, showing relatively small reduction from 2015 level by 2030.

In the reference scenario, the building sector emissions rise from 15.4 $MtCO_2e$/a in 2005 to 18.2 $MtCO_2e$/a in 2015. The emissions from building sector reaches to 18.2 $MtCO_2e$/a in 2030 and declines to 15.8 $MtCO_2e$/a in 2050 due to energy efficiency measures and building renovation. In 2050, the building sector emissions would still be 2.5% above 2005 levels in the reference scenario.[13] Enhancing climate action and strengthening mitigation measures in the buildings sector imply further emissions reductions far beyond the reference scenario projections:

- The '**1.5°C Paris Agreement compatible'** pathways substantially reduce emissions and lead to the complete decarbonisation of the Australia's buildings sector by mid-century. This is mainly driven by the deep renovations, strong efficiency improvements in

13 The DEE projections covering the emissions of direct combustion of fuels (excl. electricity-related emissions) for residential, commercial as well as construction sectors show emissions slightly reducing from 18.2 Mt in 2015 to about 18 MtCO2e/a in 2030 (Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019b). For comparison, the Reference Scenario results in emissions from Australia's buildings sector including residential and commercial (excluding electricity-related emissions) of about 18 MtCO2e/a in 2030, nearly equal to the 2015 level.

renovated and new buildings, energy intensity improvement of buildings' appliances as well as strong decarbonisation of heating and cooking.

- The '**Applying best-in-class levels'** pathways lead to the near complete decarbonisation of the Australia's buildings sector by 2050. The high ambition case is only slightly above the '1.5°C Paris Agreement compatible' pathway from 2030 onwards. The low ambition case foresees higher emissions in the medium-term with 81% emissions reduction relative to 2005 by 2030 compared to 84% reduction implied by the high ambition case. In the long-term, both the low ambition and high ambition scenario overlap, leading to near full decarbonisation of the Australia's building sector by mid-century.
- The '**National scenarios' pathway** reveals a broad range across the upper and lower ambition end through the transitory period. Both scenarios imply a substantial reduction of the emissions, leading to a near full decarbonisation of Australia's buildings sector by mid-century.

4.2 Transport sector

In this scenario analysis, we cover both passenger and freight transport sector. The Paris Agreement compatible sectoral trajectories almost fully decarbonise the Australian passenger and freight transport sector on land by 2050. Substantial modal shifts in passenger and freight transport as well as introducing zero-emission vehicles mobility in parallel to tightening of CO_2 fuel economy standards of new personal cars can fully decarbonise the Australian passenger and freight transport sector by mid-century if the electricity supply sector is decarbonised in line with the Paris Agreement temperature goal.
Table 19 provides an overview of scenario analysis in the Australian passenger and freight transport sector, presents the value ranges for selected indicators which considered relevant for the scenario modelling in the passenger and freight transport sector. displays the resulting emissions trajectories for all scenarios after quantification with PROSPECTS Australia scenario evaluation tool.

Table 19: Outcome overview of the scaling up climate action analysis in the Australia's passenger and freight transport sector

Indicator		Indicator values for scenario categories		
	Reference Scenario Projections (REF)	**National scenarios**	**Applying best-in-class level(s)**	**1.5°C compatible scenarios**
		Passenger Transport on Land		
Share of electric vehicle in total passenger vehicle fleet: Personal Vehicle	• **0.34%** by **2030** • **1.01%** by **2040** • **3.94%** by **2050**	**Higher ambition:** • **28%** by **2030** • **73% by 2040** • **100%** by **2050** **Lower Ambition:** • **28%** by **2030** • **65% by 2040** • **80%** by **2050**	• **28%** by **2030** • **68%** by **2040** • **96%** by **2050**	• **38%** by **2030** • **95%** by **2040** • **100%** by **2050**
	Based on PROSPECTS AUS tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model 2017.	*Based on the "Advanced Intervention" Scenario from (ARENA, 2018) for the High ambition case and Deep Decarbonisation Scenario by (ClimateWorks Australia, 2014) for the low ambition case.*	*Based on the analysis by (PwC 2018) assuming Australia achieves a battery electric vehicle (BEV) growth rate similar to that of the world leader Norway. The scenario is referred to as AU 50@30.*	*Based on benchmarks identified in Kuramochi et al.* (Kuramochi et al., 2018)

Share of electric vehicle in total passenger vehicle fleet: Buses	• **0.90%** by **2030** • **2.95%** by **2040** • **4.81%** by **2050**	• **29%** by **2030** • **50%** by **2040** • **50%** by **2050**	• **67%** by **2030** • **100%** by **2040** • **100%** by **2050**	• **67%** by **2030** • **100%** by **2040** • **100%** by **2050**
	Based on PROSPECTS tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model 2017.	*Based on Deep Decarbonisation Scenario by (ClimateWorks Australia, 2014)*	*Based on YaleEnvironment 360, 2018. (Based on California as best in Class)*	*No specifically defined benchmark for Paris Agreement compatibility for share of e-buses. Accordingly, the levels from 'Applying best-in-class level(s)' scenarios are used.*
Share of public transport (bus, train) in total passenger transport activity excl. aviation	• **11.8%** by **2030** • **11.52%** by **2040** • **11.51%** by **2050**	• **18%** by **2030** • **22%** by **2040** • **28%** by **2050**	Higher ambition: • **19.2%** by **2030** • **25.7%** by **2040** • **33.5%** by **2050** Lower Ambition: • **17.3%** by **2030** • **21.9%** by **2040** • **27.4%** by **2050**	• **19.2%** by **2030** • **25.7%** by **2040** • **33.5%** by **2050**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main references are ETP 2017 and BITRE 2017.	*Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014)*	*Based on European Commission, 2018. (Czeck Republick and Austraia)*	*No specifically defined benchmark for Paris Agreement compatibility for share in public transport. Accordingly, modal shifts defined in the most ambitious end of 'Applying best-in-class level(s)' scenarios are used.*
Emission intensity improvement rate for non-electrified passenger transport	• **1.7%** per year average for personal vehicles for **2016-2050** • **1.0%** per year average for busses for **2016-2050**	• **2.2%** per year average for passenger cars for **2016-2050** • **1.5%** per year average for buses for **2016-2050**	• **2.6%** per year average personal vehicle for **2016-2050** • **2.9%** per year average for buses for **2016-2050**	• **2.6%** per year average for personal vehicles for **2016-2050** • **2.9%** per year average for buses for **2016-2050**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model 2017.	*Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014)*	*Based on (European Commission, 2019)*	*No specifically defined benchmark for Paris Agreement compatibility for fuel economy standards. Accordingly, emission standards defined in 'Applying best-in-class level(s)' scenarios are used.*

Freight Transport				
Share of zero-emission trucks in total truck fleet	• **0.11%** by **2030** • **0.44% by 2040** • **1.4%** by **2050**	• **29%** by **2030** • **50% by 2040** • **50%** by **2050**	• **4%** by **2030** • **49% by 2040** • **94%** by **2050**	**Higher Ambition:** • **15%** by **2030** • **82%** by **2040** • **100%** by **2050** **Lower Ambition:** • **3%** by **2030** • **64% by 2040** • **100%** by **2050**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model 2017	*Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014).*	*Based on the analysis by the* (Climate Action Tracker, 2018d).	*Based on analysis by the Climate Action Tracker* (Climate Action Tracker, 2018d).
Share of zero-emission freight trains	▪ **1%** electrification rate of freight railways (same as 2015 level) for **2016-2050.**	Same as 'Reference Scenario'	**Higher Ambition:** • **10%** by **2030** • **95%** by **2040** • **100%** by **2050** **Lower Ambition:** • **3%** by **2030** • **51%** by **2040** • **90%** by **2050**	• **10%** by **2030** • **95%** by **2040** • **100%** by **2050**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main reference is BITRE 2014.	*Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main reference is BITRE 2014.*	*Based on (IEA 2019) and Global Railway Review (2017) and Statista (2019).*	*No specifically defined benchmark for Paris Agreement compatibility of electrification rate of freight railways. Accordingly, share of zero emission freight trains as defined in the most ambitious end of 'Applying best-in-class level(s)'are used.*
Share of train transport in total freight transport	• **63.01%** by **2030** • **61.23%** by **2040** • **60.34%** by **2050**	Same as 'Reference Scenario	• **74%** by **2030** • **77%** by **2040** • **80%** by **2050**	• **74%** by **2030** • **77%** by **2040** • **80%** by **2050**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main references are ETP 2017 and BITRE 2017.	*Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main references are ETP 2017 and BITRE 2017.*	*Based on (European Commission, 2011)*	*No specifically defined benchmark for Paris Agreement compatibility of modal shift. Accordingly, modal shift as defined in the most ambitious end of 'Applying best-in-class level(s)'are used.*
Emission intensity improvement rate for non-electrified freight trucks	• **1.4%** per year average for non-electrified truck transport over **2016-2050**	• **2.2%** per year average for non-electrified truck transport over **2016-2050**	• **2.9%** per year average for non-electrified transport activity by trucks over **2016-2050**	• **2.9%** per year average for non-electrified transport activity by trucks for **2016-2050**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main references are ETP 2017 and IEA Mobility Model 2017	*Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014)*	*Based on (European Commission, 2019)*	*No specifically defined benchmark for Paris Agreement compatibility for emission intensity improvement rate for non-electrified freight trucks. Accordingly, the levels from 'National Scenario' is applied.*

Domestic aviation				
Fuel mix: share of zero-carbon fuels	• **100% jet fuels** from **today** to **2050**	**Higher Ambition:** Share of biofuels and renewable-based synthetic fuels increases from 0% today to: • **20%** by **2030** • **34%** by **2040** • **100%** by **2050** **Lower Ambition:** Share of biofuels increases from 0% today to: • **9%** by **2030** • **50%** by **2040**	Same as 'Reference Scenario'	Share of zero carbon fuels increases starting from 0% today: • **43%** by **2030** • **71%** by **2040** • **100%** by **2050**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Author's assumption.	*Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014) for low ambition and 'Advanced Renewable' Scenario by* (Sven Teske et al., 2016a) *for the high ambition case*	*Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Author's assumption.*	*Based on benchmarks identified in Climate Action Tracker (2018).*
Emission intensity improvement	• **1%** per year average emission intensity improvement rate over **2016-2050**	• **1%** per year average emission intensity improvement rate over **2016-2050**	Same as 'Reference Scenario	• **1%** per year average emission intensity improvement rate over **2016-2050**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model 2017	*Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014)*	*Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model and BITRE 2017.*	*No specifically defined benchmark for Paris Agreement compatible scenario Accordingly, same indicator levels as in 'National Scenario' is used.*

Required policy measures for sectoral transformation	Remaining challenges threatening implementation
⇨ Introduce a ban on sales of combustion cars by 2035 and a target for trucks to send a clear signal to vehicle manufacturers ⇨ Develop a national strategy for electric vehicles including investment in charging infrastructure and ambitious targets as well as incentives, following best practice examples such as Norway. ⇨ Set ambitious greenhouse gas emission standards (at least as ambitious as the EU) both for passenger and heavy transport. ⇨ Concerted initiatives with industry to decarbonise domestic aviation and domestic maritime shipping. ⇨ Invest in research and development on opportunities to transition freight transport from road to rail.	⇨ Heavy reliance on combustion car transport compared to alternative transport methods. ⇨ Higher upfront costs of electric vehicles compared to combustion vehicles as well as lack of infrastructure needs incentives and policy intervention. ⇨ Impact on low income earners needs to be considered, in particular where there is heavy dependence on cars due to lack of public transport or other incentives for modal shift. ⇨ Urban design to incentives modal shift needs strategies at state and local level with support from federal level. ⇨ Australians have large vehicle lifestyle preferences.

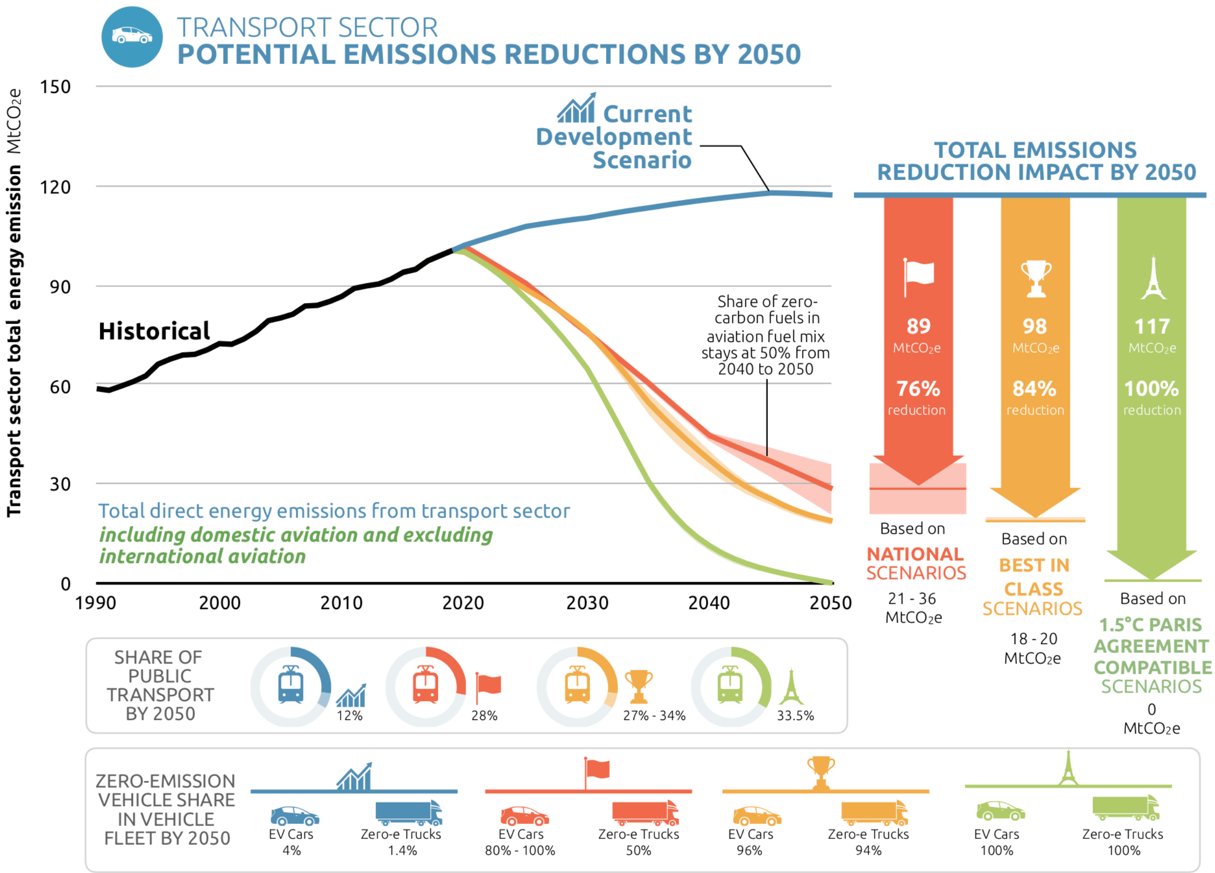


Figure 29 Overview of sectoral emission pathways under Reference scenario projections and different levels of accelerated climate action in Australia's passenger and freight transport sector excluding electricity related emissions.

4.2.1 Context for scaling up climate action in the transport sector

Transport sector playing an important role in the economy

- The Australian economy is reliant on transport. In 2015-16, transport activity contributed 7.4% ($122.3b) of GDP, and the total transport Gross Added Value (a measure of the value of industry production) equated to $125.3b, and it is a sector that employs 1 million people or 8.6% of the population (ABS, 2018). Transport affects both the productivity and costs of all industries in Australia (ABS, 2018).
- Australia's transformation away from internal combustion vehicles to electric vehicles needs to follow global trends. There was a 56% increase in EV sales from 2016 to 2017 global, and Australia saw an increase of 67% in the same year (ClimateWorks Australia, 2018b). More models and therefore more consumer choice was available in 2017 (ClimateWorks Australia, 2018b). However, Australia starts from a very low level, compared to other countries (Climate Analytics, 2019e). Businesses are the largest buyer of EVs in Australia accounting for 63% of sales in 2017 (excluding Tesla vehicles), and private buyers accounted for 34%, and governments only 3% (ClimateWorks Australia, 2018b)

Significant co-benefits of decarbonising the transport sector

- Road transport is responsible for air pollutants such as carbon monoxide, nitrogen oxides, particulate matter, volatile organic compounds and benzene. Australian vehicles pollute more than other comparable countries, for example, the emissions intensity of Australian vehicles is 45% higher than EU countries (NTC, 2018). Australian cars pollute more per kilometre in comparison to comparable countries, due to vehicle size, lack of vehicle emission standards or incentives, lower fuel prices, and decisions based on purchasers preference (NTC, 2018). Decarbonising the transport sector will reduce the health issues and the urban air quality issues related to these pollutants.

- Noise pollution is considered a public health issue (NTC, 2018; WHO, 2011). Those exposed to noise pollution can experience psychosocial and physiological effects, increased risk of cardiovascular disease, cognitive impairment and tinnitus (ringing in the ears) (WHO, 2011). Decarbonising the transport sector will reduce the noise pollution associated with internal combustion vehicles.
- Decreasing road transport improves attractiveness and liveability of urban areas. It creates less traffic congestion and related stress (Coleman, 2016), and a safer environment for walking and cycling.

Infrastructure an important issue

- Alternative methods of transport to internal combustion vehicles includes public transport, cycling and walking. All these options require investment in infrastructure to accommodate these modes of transport. A 'high shift' approach to transport infrastructure development can reduce public and private spending and transport emissions (Replogle & Fulton, 2014). Well-designed urban centres can be affordable option for cutting emissions and clean transport options (Replogle & Fulton, 2014).
- A study examining the top 25 cities with high EV sales, (of which account for almost half of global EV sales), found a positive correlation between charging infrastructure and EVs (ICCT, 2018). Charging infrastructure is a main driver of EV market growth (ICCT, 2018).

4.2.2 Scenario analysis for scaling up climate action in the transport sector

4.2.2.1 Identification of indicator levels

Table 20 provides an overview of indicator levels identified for the three different scenario categories in the Australia's passenger and freight transport sector. The upper part presents the respective benchmarks specified in relevant literature. The lower part shows how these benchmarks were translated into indicator levels to provide input for the PROSPECTS Australia scenario evaluation tool.

Table 20: Overview of different benchmarks specified in the literature and translation into indicator levels for analysis of scaling up climate action in the passenger and freight transport sector with PROSPECTS Australia scenario evaluation tool

Indicator		National scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Passenger Transport on land				
Electric vehicle shares in total stock	**Personal Vehicles**	Penetration rate of electric cars (in total car stock) of 28% by 2030, 73% by 2040 and 100% by 2050 for the High ambition scenario, and Penetration rate of electric cars (in total car stock) of 28% by 2030, 65% by 2040 and 80% by 2050 for Low ambition scenario	The scenario analysis by PwC assuming Australia achieves a battery electric vehicle (BEV) growth rate similar to that of the world leader Norway. The scenario is referred to as AU 50@30 and assumes that by 2030, 57% of new car sales will be BEV.	Zero-emissions vehicles constitute 100% of newly-sold vehicles worldwide by 2035, leading to a 100% zero emissions car stock by 2050 (Kuramochi et al., 2018)
		Based on the "Advanced Intervention" Scenario from (ARENA, 2018) for the High ambition case and Deep Decarbonisation Scenario by (ClimateWorks Australia, 2014) for the low ambition case	*Based on (PwC 2018)*	*Based on benchmarks identified in Kuramochi et al.* (Kuramochi et al., 2018)

	Buses	Penetration rate of electric buses (in total bus stock) of 29% by 2030 and 50% by 2040 *Based on Deep Decarbonisation Scenario by (ClimateWorks Australia, 2014)*	International frontrunners' share of electrified bus transportation: • California: full transition to 100% electric bus fleet by 2040 with last non-electric bus purchased latest by 2029 *Based on (YaleEnvironment 360, 2018)*	*No specifically defined benchmark for Paris Agreement compatibility for share of e-buses. Accordingly, the levels from 'Applying best-in-class level(s)' scenarios are used.*
				[-]
Modal shift		Fast rail shifts 15% of passenger travel away from aviation[14]. *Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014)*	EU frontrunners' share of public transport in total passenger transportation on land: • **33.5%** share of public transport in total passenger transport on land (Czech Republic 2016) • **27.4%** share of public transport in total passenger transport on land (Austria 2016) *Based on (European Commission, 2018)*	*No specifically defined benchmark for Paris Agreement compatibility for share in public transport. Accordingly, modal shifts defined in the most ambitious end of 'Applying best-in-class level(s)' scenarios are used.* *[-]*
Emission intensity improvement		Energy intensity of non-electric passenger car fleet decreases until 2050 by: 75%: Cars; 50%: Buses *Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014)*	EU targets for fuel economy of new passenger cars as one of the strictest standards in the world[15]: • **95** gCO_2/vkm by **2020/2021** • **15% reduction rel. to 2020** corresponding to **81** gCO_2/vkm by **2025**[4] • **37.5% reduction rel. to 2020** corresponding to **59** gCO_2/vkm by **2030**[16] EU targets for fuel economy of new heavy-duty vehicles as one of the strictest standards in the world applied for buses: • **In 2025, 15% lower than 2019** • **In 2030, at least 30% lower than in 2019** [17] *Based on (European Commission, 2019)*	*No specifically defined benchmark for Paris Agreement compatibility for fuel economy standards. Accordingly, emission standards defined in 'Applying best-in-class level(s)' scenarios are used* *[-]*

14 The benchmark for the modal shift based on the national scenario as specified by (ClimateWorks Australia, 2014) mainly specifies the 15% of passenger travel shifting away from aviation towards fast rail. No Further measures concerning other modal shifts is specified by the source.

15 The EU emission standards apply to the average for the fleet of all new vehicles. Translation of those targets to the indicator level (intensity improvement rate for non-electrified personal vehicles) for the purpose of quantification with PROSPECTS Australia scenario evaluation tool has been performed by taking the new vehicle stock and the split between EVs and ICEs into account for each scenario category and applying a stock turn over model.

16 On December 17, 2018, representatives of the European Commission, the European Parliament, and the European Council agreed on a compromise for the European Union (EU) regulation setting binding carbon dioxide (CO_2) emission targets for new passenger cars and light-commercial vehicles for 2025 and 2030. The agreed-upon targets aim to reduce the average CO_2 emissions from new cars by 15% in 2025 and by 37.5% in 2030, both relative to a 2021 baseline (European Commission, 2019a)(European Commission, 2019a)(European Commission, 2019a)(European Commission, 2019a)(European Commission, 2019a)(European Commission, 2019a)(European Commission, 2019a) (European Commission 2019; ICCT 2019).

17 On 17 May 2018, the European Commission presented a legislative proposal setting the first ever CO_2 emission standards for heavy-duty vehicles in the EU (European Commission 2019).

Freight Transport on land			
Share of zero-emission trucks in total truck fleet	Penetration rate of electric trucks (in total truck stock) of 29% by 2030 and saturation at 50% by 2040	30% electric trucks in new truck sales by 2030	Zero-emissions trucks constitute 100% of newly sold trucks worldwide by around 2035-2040, leading to an almost 100% zero-emissions truck stock by 2050
	Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014)	*Based on the analysis by the* (Climate Action Tracker, 2018d)	*Based on analysis by the Climate Action Tracker* (Climate Action Tracker, 2018d)
Share of zero emission freight trains	*No specifically defined benchmark for 'National Scenarios'*	90-100% share of zero-emission freight trains by 2050 mainly inspired by 90-100% electrification of freight railways already achieved by international frontrunners: Switzerland (100%) and Japan (90%) *Based on (IEA 2019) and Global Railway Review (2017) and Statista (2019)*	*No specifically defined benchmark for Paris Agreement compatibility of electrification rate of freight railways. Accordingly, electrification rate of freight railways as defined in the most ambitious end of 'Applying best-in-class level(s)'are used.* *[-]*
Modal shift: Share of train transport in total freight transport	Limited road to rail mode shifting due to logistical constraints assumed under the Deep decarbonization scenario by *(ClimateWorks Australia, 2014);* therefore, we assume same indicator level as in 'Reference Scenario' *Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model and BITRE 2017*	30% of Australian road freight could swap to rail by 2030 and more than 50% by 2050 inspired by the EU target *Based on (European Commission, 2011)*	*No specifically defined benchmark for Paris Agreement compatibility of modal shift. Accordingly, modal shift as defined in the most ambitious end of 'Applying best-in-class level(s)'are used.* *[-]*
Emission intensity improvement	Energy intensity of trucks decreases by 75% until 2050	EU targets for fuel economy of new HDVs as one of the strictest standards in the world[3]: • **15%** reduction rel. to 2019 by **2025**[18] • At least **30%** reduction rel. to 2019 by **2030**[5]	*No specifically defined benchmark for Paris Agreement compatibility for fuel economy standards. Accordingly, emission standards defined in 'National' scenarios are used.*
	Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014)	*Based on (European Commission, 2019)*	*[-]*
Domestic aviation			
Fuel mix: Share of zero carbon fuels	Low ambition: up to 50% adoption of biofuels in aviation transport by 2040 High ambition: 100% share of zero carbon fuels by 2050	*No specifically defined benchmark for 'Applying best-in-class level(s). Accordingly, same indicator levels as in 'Reference Scenario' is used.*	*Zero-carbon fuels constitute 100% of aviation fuel mix in line with full decarbonisation of mobility sector including all modes of transport as a crucial step for the transition to a low-carbon economy in line with the Paris Agreement*

[18] On 17 May 2018, the European Commission presented a legislative proposal setting the first ever CO_2 emission standards for heavy-duty vehicles in the EU. In 2025, the average CO_2 emissions of new heavy-duty vehicles will have to be 15% lower, compared to 2019. This target is mandatory and can be achieved using technologies that are already available on the market. In 2030, emissions have to be at least 30% lower (https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en).

	Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014) for low ambition and 'Advanced Renewable' Scenario by (Sven Teske et al., 2016a) *for the high ambition case*	*Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model and BITRE 2017.*	*Based on benchmarks identified in Climate Action Tracker (2018b)*
Emission intensity improvement	Energy intensity of air transport decreases by 1% p.a. corresponding to a total decrease of 33% until 2050.	*No specifically defined benchmark for 'Applying best-in-class level(s). Accordingly, same indicator levels as in 'Reference Scenario' is used.*	*No specifically defined benchmark for Paris Agreement compatible scenario Accordingly, same indicator levels as in 'National Scenario' is used.*
	Based on Deep decarbonisation scenario by (ClimateWorks Australia, 2014)	*Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main reference is IEA Mobility Model and BITRE 2017.*	*[-]*

Indicator levels for scenario analysis in the PROSPECTS Australia scenario evaluation tool

Indicator		National scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Passenger transport on land				
Share of electric vehicle in total passenger vehicle fleet: Personal Vehicle	High ambition	• **28%** by **2030** • **73% by 2040** • **100%** by **2050**	Starting from today's share increasing to **57%** share of EVs in new vehicle sales by **2030** and linearly rising to **100%** of new car sales by **2042.** Share of EVs in total car fleet: • **28%** by **2030** • **68%** by **2040** • **96%** by **2050**	S-curve uptake of EV share with **100% EV market share** for newly sold vehicles **from 2035 onwards.** Share of EVs in total car fleet: • **38%** by **2030** • **95%** by **2040** • **100%** by **2050**
	Low ambition	• **28%** by **2030** • **65% by 2040** • **80%** by **2050**		
Share of electric vehicle in total passenger vehicle fleet: Buses	High ambition / Low ambition	• **29%** by **2030** • **50% by 2040** • **50%** by **2050**	Starting from today's share increasing to **100%** share of EVs in new vehicle sales by **2030** Shares of e-buses in total bus fleet: • **67%** by **2030** • **100%** by **2040** • **100%** by **2050**	Starting from today's share increasing to **100%** share of e-buses in new vehicle sales by **2030** Shares of e-buses in total bus fleet: • **67%** by **2030** • **100%** by **2040** • **100%** by **2050**
Share of public transport (bus, train) in total passenger transport activity	High ambition	Share of public transport in total passenger road and rail transport activity: • **18%** by **2030** • **22%** by **2040** • **28%** by **2050**	Share of public transport in total passenger road and rail transport activity: • **19.2%** by **2030** • **25.7%** by **2040** • **33.5%** by **2050**	Share of public transport in total passenger road and rail transport activity: • **19.2%** by **2030** • **25.7%** by **2040** • **33.5%** by **2050**
	Low ambition		Share of public transport in total passenger road and rail transport activity: • **17.3%** by **2030** • **21.9%** by **2040** • **27.4%** by **2050**	
Emission intensity improvement rate for non-electrified passenger transport	High ambition / Low ambition	• **2.2%** per year average emission intensity improvement rate for passenger cars • **1.5%** per year average emission intensity improvement rate for buses	• **2.6%** per year average emission intensity improvement rate of non-electrified personal vehicle transport activity for **2016-2050 (But note also indicator for share of electric vehicles: 100% EV share from 2042 onwards for newly sold vehicles)** • **2.9%** per year average emission intensity improvement rate of non-electrified buses for **2016-2050**	• **2.6%** per year average emission intensity improvement rate of non-electrified personal vehicle transport activity for **2016-2050 (But note also indicator for share of electric vehicles: 100% EV share from 2035 onwards for newly sold vehicles)** • **2.9%** per year average emission intensity improvement rate of non-electrified buses for **2016-2050**

Freight transport				
Share of zero-emission trucks in total truck fleet	High ambition	• **29%** by **2030** • **50% by 2040** • **50%** by **2050**	• **4%** by **2030** • **49% by 2040** • **94%** by **2050**	• **15%** by **2030** • **82% by 2040** • **100%** by **2050**
	Low ambition			• **3%** by **2030** • **64% by 2040** • **99.7%** by **2050**
Share of zero-emission freight trains	High ambition	Same as 'Reference Scenario	• **10%** by **2030** • **95% by 2040** • **100%** by **2050**	• **10%** by **2030** • **95% by 2040** • **100%** by **2050**
	Low ambition		• **3%** by **2030** • **51% by 2040** • **90%** by **2050**	
Share of train transport in total freight transport	High ambition	Same as 'Reference Scenario	• **74% by 2030** • **77% by 2040** • **80% by 2050**	• **74% by 2030** • **77% by 2040** • **80% by 2050**
	Low ambition			
Emission intensity improvement rate for non-electrified freight transport	High ambition	• **2.2%** per year average emission intensity improvement rate for non-electrified truck transport over **2016-2050**	**2.9%** per year average emission intensity improvement rate of non-electrified transport activity by trucks over **2016-2050**	**2.9%** per year average emission intensity improvement rate of non-electrified transport activity by trucks for **2016-2050 (But note also indicator for share of electric vehicles: 100% e-truck share from 2035-2040 onwards for newly sold trucks)**
	Low ambition			
Domestic aviation				
Fuel mix: share of zero-carbon fuels	High ambition	Share of biofuels and renewable-based synthetic fuels increases from 0% today to: • **20%** by **2030** • **34%** by **2040** • **100%** by **2050**	Same as 'Reference Scenario	Share of zero carbon fuels increases starting from 0% today: • **43%** by **2030** • **71%** by **2040** • **100%** by **2050**
	Low ambition	Share of biofuels increases from 0% today to: • **9%** by **2030** • **50%** by **2040**		
Emission intensity improvement	High ambition	**1%** per year average emission intensity improvement rate over **2016-2050**	Same as 'Reference Scenario	**1%** per year average emission intensity improvement rate over **2016-2050**
	Low ambition			

1.5°C Paris Agreement compatible scenarios

To be in line with a 1.5°C compatible pathway, passenger transport-related emissions must decrease to almost zero around mid-century (Kuramochi et al., 2018). Correspondingly, zero emission cars would constitute the whole fleet on the road by 2050. This implies that the last fossil fuel powered car would have to be sold roughly before 2035, assuming a 15-year lifetime (Kuramochi et al., 2018).

Zero emissions technologies for passenger vehicles, in particular electric vehicles (EVs), are already advanced and their market share is increasing. Also a renewed wave of interest for low-carbon and zero carbon freight has recently emerged and production of electric trucks has already been announced by several major companies (Climate Action Tracker, 2018d). The transition of the transport sector to a zero-emission system will be further supported by a reduction and modal shift of the demand for transport (Climate Action Tracker 2016)(Climate Action Tracker, 2016)(Climate Action Tracker, 2016)(Climate Action Tracker, 2016)(Climate Action Tracker, 2016)(Climate Action Tracker, 2016)(Climate Action Tracker, 2016).

Therefore, modal shift and electrification of the transport sector must be seen as complementary measures and not as alternatives. Additionally, a substantial improvement of emission intensity of new, non-electric vehicles is an important intermediate measure until the full electrification of the passenger and freight transport sector on land is achieved by mid-century. Also, change of fuel mix and use of biofuels or synthetic fuels produced with hydrogen or renewable-based liquid fuels plays an important role for modes of transport with limited possibilities for electrification such as aviation and maritime transport.

Use of sustainably produced biofuels in the short to medium-term as well as use of fuels produced with hydrogen or renewables-based liquid fuels (the so-called electrofuels) could be of particular interest also for the decarbonisation of the freight transport sector (Climate Action Tracker, 2018d). Apart from biofuels, all these options either imply a direct use of electricity via battery-electric vehicles (BEVs) or indirect use of electricity derived from renewable energy by applying hydrogen produced via renewable electrolysis in hydrogen-powered fuel cell vehicles (H_2-FCEVs) or use of other renewable-based synthetic fuels.

Lacking a clear benchmark for a Paris compatible modal shift as well as emission intensity levels of new cars, we apply the levels identified in the most ambitious end of best-in-class scenarios also reflected in the 1.5°C compatible scenario, combined with the electrification of the passenger and freight transport on land according to the 1.5°C Paris Agreement compatible benchmarks identified in the literature.

Land-based passenger transport

Paris Agreement compatible deployment of electric vehicles in passenger transport are combined with the modal shift and CO_2 standards for new non-electric cars from the high ambition case of *'Applying best-in-class level(s)'scenario* as well as fuel mix from the high ambition case of national scenario:

- **Electrification of personal vehicles:** The share of electric cars in new personal car sales would reach to 100% before 2035 and will constitute 100% of the total vehicle stock by 2050. The share of electric cars in new sales is modelled with a s-curve that reaches 100% by 2035. With a 15-year assumed lifetime for personal vehicles, the new sales were translated into the share of the total fleet via a simplified stock turnover model. This implies an indicator level of 38% share of EVs in total stock by 2030, 95% by 2040 and 100% by 2050.
- **Electrification of buses:** For buses, the share of electric buses is assumed to increase from 0% today to 100% share of new bus sales by 2030 and reach fully electrified bus fleet by 2040 similar to *'Applying best-in-class level(s)'scenario* described in the following. With a 12-year assumed lifetime for buses, the new sales were translated into the share of the total fleet via a stock turnover model. This implies an indicator level of 67% share of e-buses in total stock by 2030 and 100% by 2040 using a simplified stock turnover model.
- **Modal shift:** The share of public transport is assumed to increase from 12% in 2015 to 33.5% in 2050 corresponding to the most ambitious end of the *'Applying best-in-class level(s)'scenario*.
- **Emission intensity improvement:** Penetration of EVs will not alone guarantee a sustainable, emissions free transport sector. Simultaneous decarbonisation of the power sector is an indispensable requisite to fully decarbonise the emissions from the transport sector by mid-century. Alongside, emission intensity improvements of new cars is an

important, intermediate complementary measure to achieve a clean transport sector. Introducing stringent standards for emission intensity of new vehicles would simultaneously provide further incentives for a higher penetration of EVs and thus brings a two-fold benefit.

Lacking a clear benchmark for emission intensity levels of new cars, we apply the levels identified in *'Applying best-in-class level(s)'scenario* based on the EU emissions intensity targets for new cars which need to continuously decrease from current levels reaching the fuel economy target of 95 gCO_2/vkm by 2021 and declining further by 15% (81 gCO_2/vkm) in 2025 and by 37.5% in 2030 (59 gCO_2/vkm) (European Commission 2019). We assume that the emission intensity of new cars further declines after 2030 based on the most ambitious and of the scenarios as specified in (E3MLab & IIASA 2016). However, this is only relevant up to 2035, given the assumption of 100% electrification for new sales by 2035. The EU emission standards apply to the average for the fleet of all new vehicles.

Translation of those targets to the indicator level (intensity improvement rate for non-electrified personal vehicles) for the purpose of quantification with PROSPECTS Australia scenario evaluation tool has been performed by taking the new vehicle stock and the split between EVs and ICEs into account for each scenario category and applying a simplified stock turnover model. For buses, we take into account the recent EU emissions intensity targets for new HDVs which need to continuously decrease by 15% rel. to 2019 in 2025 and by at least 30% in 2030 (European Commission 2019).

Freight Transport

- **Share of zero-emission trucks**: To be compatible with the Paris Agreement's long-term goal, freight trucks need to be almost fully decarbonised by around 2050 (Climate Action Tracker, 2018d). Considering an average lifetime of 15 years, the last truck running on fossil fuel would need to be phased out between 2035 (most ambitious end) and 2040 (least ambitious end). The share of electric trucks in new sales is modelled with a s-curve that reaches 100% by 2035 (most ambitious end) and 2040 (least ambitious end).
- **Share of zero-emission freight trains:** Lacking a clear 1.5°C compatible benchmark for electrification of freight railways, we apply the level as identified in the most ambitious end of the *'Applying best-in-class level(s)'scenario*. This implies an increase of the share of zero-emission freight trains from today level in Australia (1%) to 100% by 2050.
- **Modal shift:** Lacking a clear 1.5°C compatible benchmark for modal shift, we apply the modal shift from road freight transport to rail transport as identified in the most ambitious end of *'Applying best-in-class level(s)'scenario*. This implies an increase of the share of train transport in total freight transport activity from today level in Australia (66%) to 80% by 2050.
- **Emission intensity improvement:** Alongside strong penetration of zero-emission trucks, emission intensity improvement of new trucks is an important, intermediate complementary measure to achieve a clean transport sector. Introducing stringent standards for emission intensity of new vehicles would simultaneously provide further incentives for a higher penetration of electric trucks and thus brings a two-fold benefit. Lacking a clear benchmark for emission intensity levels of new trucks, we apply the levels identified in *'Applying best-in-class level(s)'scenario* based on the EU emissions intensity targets for new HDVs which need to continuously decrease by 15% rel. to 2019 in 2025 and by at least 30% in 2030 (European Commission 2019). We assume that the emission intensity of new trucks further declines after 2030, following the similar rate of reduction. However, this is only relevant up to 2035 (most ambitious end) and 2040 (least ambitious end), given the assumption of 100% electrification for new sales by 2035 and 2040 for the highest and lowest end of ambition, respectively. The EU emission standards apply to the average for the fleet of all new vehicles. Translation of those targets to the indicator level (intensity improvement rate for non-electrified trucks) for the purpose of quantification with PROSPECTS Australia scenario evaluation tool has been performed

by taking the new vehicle stock and the split between electric and non-electric trucks into account for each scenario category and applying a simplified stock turnover model.

Domestic aviation

- **Share of zero carbon fuels:** Decarbonising the mobility sector including all modes of transport is crucial for the transition to a low-carbon economy in line with the Paris Agreement (Climate Action Tracker, 2018d). Sustainable biofuels as well as zero-carbon synthetic fuels produced using electricity derived from renewable energy are viewed as an important option in decarbonising the transport sector, particularly where direct electrification might not be still viable such as aviation. Therefore, we assume that the share of zero carbon fuels including sustainable biofuels as well as renewable-based synthetic fuels increases from 0% (today) to 100% by 2050. For aviation a range of technologies are emerging based on zero emissions fuels and/or propulsion systems. International Renewable Energy Agency (IRENA) has reported on a variety of pathways to produce renewable jet fuel, short range electric aircraft, and hybrid electric propulsion systems (IRENA, 2017). Here we assume full decarbonisation by 2050, which in the case of aviation might imply the need for negative CO_2 emissions to compensate for remaining fossil fuel use if decarbonisation is not achieved by 2050 (Climate Analytics, 2019a).
- **Emission intensity improvement:** Lacking a clear 1.5°C compatible benchmark for emission intensity improvement of aviation transport, we apply the level as identified for the *'National Scenarios'* based on the deep decarbonisation pathway from (ClimateWorks Australia, 2014).

Applying best-in-class levels

For selected indicators, fuel economy standards as well as modal shift and penetration of electric vehicles, there exist numerous illustrative examples of regulations around the world and international and regional frontrunners paving the way towards a sustainable transport system.

For electric mobility, Norway's support for electric cars serves as a good example. The global market share for electric vehicles (EVs) was only 0.8% in 2016 (IEA, 2018b). However, in Norway, EVs (including plug-in hybrids) accounted for nearly 30% of new cars in 2016 (IEA, 2018c). The reason for the high diffusion rate of electric cars in Norway is due to generous public support. For example, in Norway, EVs are exempt from import duty and value-added tax, while heavy duties and taxes are imposed on poor fuel efficiency gasoline cars. This makes the actual price of EVs lower than that of gasoline cars. In addition, the cost of ownership and operation is lower due to automobile tax and highway toll exemption for EVs. As a result, EV owners receive more economic merit compared to gasoline car owners. Australia lacks far behind in terms of adoption of electric vehicles (Climate Analytics, 2019g).

With respect to share of public transport, Australian cities all performed worse than global counterparts due to a lack of developed metro rail systems; the share of total trips by public transport, cycling and walking were also low[19]. Commuters make up a large proportion of passenger kilometres travelled, with 60.2% of these travelling to work using a private vehicle. Light passenger vehicles account for approximately 75% of the vehicles on our roads (Commonwealth of Australia, 2016). Domestically, passenger rail growth has outpaced other surface transport modes over recent years, but still makes up only a small portion of passenger kilometres. Share of urban public transport and rail accounted for about 12% of total passenger transport activity in Australia (9.7% when including domestic aviation) in 2015 (BITRE 2017). Based on passenger kilometres travelled, public transport usage is projected to grow by 32% across all capital cities between 2011 and 2030 (Commonwealth of Australia, 2013).

Austria has achieved the highest share of railways in the modal split for passenger transport among all EU countries. In 2015, the share of railways (11.2%) and public urban transport (6.7%) was well above the EU average: 7.6% for railways and 1.8% for public urban transport (European Commission, 2018). Additionally, the Czech Republic records a relatively low use of passenger cars. In 2015, car trips represented about 67% of the passenger-kilometres travelled on land which is 14.2% below the EU average. On the other hand, the Czech Republic records a much

[19] https://www.news.com.au/finance/economy/australian-economy/australian-cities-lag-behind-on-key-global-competitiveness-measure/news-story/778a8a43b4e04b63f568b79bf58137d2

higher use of buses and coaches than the EU average (15.6% versus 9.4% on average in the EU). Regarding rail passenger transport, this mode of transport is slightly higher than the EU average (7.8% vs. 7.6%). Use of public urban transport is very high at 9.5% in comparison with 1.8% on average in the EU. According to the historical trends, the share of public transport has increased by around 0.5% p.a. in Austria and Czech Republic through the period 2007-2016 (European Commission, 2018).

Australia lags behind many other countries in light vehicle efficiency. While the efficiency of Australia's light vehicle fleet is improving over time, more can be done. Current level of the emissions intensity of the Australian light vehicle fleet reaches to 192 gCO_2/km (Australian Government Climate Change Authority, 2014). With respect to fuel economy of new vehicles, the EU sets one of the strictest standards in the world. As the CO_2 emissions are proportional to the consumption of fuel, restrictions on CO_2 emissions have the same impact as fuel economy regulations. On April 23, 2009, the European Parliament and the Council approved regulations setting a target of 130 gCO_2/vkm (5.6 l/100km or 42 mpg) for the average emissions of new cars to be phased-in by 2015. A target of 95 gCO_2/vkm (4.1 l/100km or 57.6 mpg) has been established for 2020/2021. On December 17, 2018, representatives of the European Commission, the European Parliament, and the European Council agreed on a compromise for the European Union (EU) regulation setting binding carbon dioxide (CO_2) emission targets for new passenger cars and light-commercial vehicles for 2025 and 2030. The agreed-upon targets aim to reduce the average CO_2 emissions from new cars by 15% in 2025 and by 37.5% in 2030, both relative to a 2021 baseline (ICCT, 2019). Applying the new agreed reduction targets compared to 2021, this leads to 81 gCO_2/vkm by 2025 and 59 gCO_2/vkm by 2030.

Over three quarters of Australia's non-bulk freight is carried on roads (BITRE 2017; Commonwealth of Australia 2016). On the other hand, only 17% of Australia's bulk transport is carried on roads. Australia's rail networks play a key role in meeting the national freight task and supporting the economy. Rail accounts for more than half of freight activity in Australia, up from 36% in 2000 (BITRE 2017; Commonwealth of Australia 2016). Australia has thus a comparatively high share of freight by rail. In other comparable large countries, rail freight represents a smaller percent. In the US, rail freight represents 10% of the total freight task (US Bureau of Transportation Statistics, 2017). In Canada rail freight represents 21% of rail freight of goods produced in Canada (Transport Canada, 2016). In China rail freight represents 8.6% (Peoples Republic of China, 2018), and 18% of the freight task in the EU (Rail Freight Forward, 2019). However, the EU has a goal of "30% of road freight over 300 km should shift to other modes such as rail or waterborne transport by 2030, and more than 50% by 2050" (European Commission, 2011). These examples show that, in theory, there is a potential to increase the share of rail freight if regulatory measures are taken to incentivise railway transport over road transport. Similar to the EU case, Australia could transport freight across large distances. 30% of Australian road freight could swap to rail by 2030 and more than 50% by 2050. Road freight accounts for 213.9 billion tkm (bulk and non-bulk freight) and a further 30% of road freight could be transferred to rail by 2030 (64 billion tkm) and 50% by 2050 (107 billion tkm) (Bureau of Infrastructure & Australian (BITRE)., 2018).

The IEA's report on "The Future of Rail" released in January 2019 depicts a picture of electrification of freight railways in different countries. According to the report, the electrification rate of freight trains in 2016 was highest in Japan (about 90%), followed by Russia (about 83%) and Europe (about 80%). The electrification rate of freight trains was zero in North America in the entire time series (IEA, 2019b). Additionally, Switzerland is in the global forefront in electrification of freight railways. Nearly 100% of railways, both passenger and freight in Switzerland is electrified. And majority of the electricity for traction power also comes from renewable sources (Global Railway Review 2017 and Statista 2019[20]).

Passenger Transport – High ambition

- **Electrification of personal vehicles:** PricewaterhouseCoopers Consulting (Australia) Pty Ltd was engaged by the Electric Vehicle Council (EVC), the NRMA and the St Baker Energy Innovation Fund to undertake an economic impact assessment of an electric vehicle (EV) growth scenario. The scenario analysis by PwC assumes Australia achieves a

[20] Link to the data sources: https://www.globalrailwayreview.com/article/31692/sbb-track-towards-energy-efficiency/ and https://www.statista.com/statistics/451522/share-of-the-rail-network-which-is-electrified-in-europe/

battery electric vehicle (BEV) growth rate similar to that of the world leader Norway. The scenario is referred to as AU 50@30 and assumes that by 2030, 57% of new car sales will be BEV (PwC 2018). In their analysis BEV refers to fully electric cars and do not include plug-in hybrid electric vehicles (PHEVs). We further extrapolate this target and assuming electric cars would constitute 100% of new car sales by 2042. With a 15-year assumed lifetime for personal vehicles, the new sales were translated into the share of the total fleet via a stock turnover model. Additionally, we assume a linear interpolation between today and the target years.

- **Electrification of buses:** For buses, as informed by California's legislation we assume that electric buses reach a 100% share of new bus sales by 2030 and reach fully electrified bus fleet by 2040 (YaleEnvironment360, 2018). With a 12-year assumed lifetime for personal vehicles, the new sales were translated into the share of the total fleet via a stock turnover model.
- **Modal shift:** Taking Czech Republic as the frontrunner among European countries concerning the share of public transport in passenger transportation, we assume a public transport share of 33.5% in total road and rail transport activity, while the target year is set to 2050. This implies more than doubling the current share of public transport in the Australia (12%) by mid-century. The share of public transport is then modelled with a s-curve that reaches 33.5% in 2050.
- **Emission intensity improvement:** For emission standards of new cars, we apply the EU target of 95 gCO_2/vkm for 2020/2021. According to the recently agreed EU standards for new LDVs, an emission intensity of 81 gCO_2/vkm is assumed for 2025 and this further declines to 59 gCO_2/vkm by 2030. We assume that the emission intensity of new cars further declines after 2030 based on the policy scenarios as developed through the Impact Assessment work of the European Commission (E3MLab & IIASA, 2016). However, this is only relevant up to 2035, given the assumption of 100% electrification for new sales by 2042. We took the reference developments of annual activities in vehicle-kilometres travelled, total and new vehicle stock as well as the share of EVs and as input. By assuming an average life expectancy of 15 years and adding new cars with the efficiency standards specified above using a stock turnover model, we calculated the average emission intensity improvement rate of non-electrified personal vehicle transport activity as required for input to PROSPECTS Australia scenario evaluation tool. For buses, we take into account the recent EU emissions intensity targets for new HDVs which need to continuously decrease by 15% compared to 2019 in 2025 and by at least 30% in 2030 (European Commission 2019).

Passenger Transport – Low ambition

- **Electrification of personal vehicles:** Similar to the High ambition case, we assume 57% of new car sales will be BEV based on the scenario analysis conducted in (PwC 2018). We further extrapolate this target and assume a linear increase to 100% share of electric cars in new sales achieved already before 2050. With a 15-year assumed lifetime for personal vehicles, the new sales were translated into the share of the total fleet via a stock turnover model.
- **Electrification of buses:** Similar to the High ambition case, we assume e-buses would constitute 100% share of new bus sales by 2030 and reach fully electrified bus fleet by 2040 (YaleEnvironment360, 2018). With a 12-year assumed lifetime for personal buses, the new sales were translated into the share of the total fleet via a stock turnover model.
- **Modal shift:** Taking Austria as EU frontrunner next to Czech Republic concerning the share of public transport in passenger transportation, we assume a public transport share of 27.4% in total road and rail transport activity, while the target year is set to 2050. The share of public transport is then modelled with a s-curve that reaches 27.4% in 2050.
- **Emission intensity improvement:** Similar to the high ambition case, we apply the EU target of 95 gCO_2/vkm for 2020/2021 as well as the recently agreed EU standards for new LDVs, an emission intensity of 81 gCO_2/vkm for 2025 and 59 gCO_2/vkm by 2030. We assume that the emission intensity of new cars further declines after 2030 based on the policy scenarios as developed through the Impact Assessment work of the European Commission (E3MLab & IIASA, 2016). We took the reference developments of annual activities in vehicle-kilometres travelled, total and new vehicle stock as well as the share

of EVs as input. By assuming an average life expectancy of 15 years and adding new cars with the efficiency standards specified above using a stock turnover model, we calculated the average emission intensity improvement rate of non-electrified personal vehicle transport activity as required for input to PROSPECTS Australia scenario evaluation tool.

Freight Transport

- **Share of zero-emission trucks**: The benchmark is inspired by 30% electric trucks in new truck sales by 2030 in entire EU28 that can be achieved through a combination of different policies support for fast uptake of e-trucks being discussed (Climate Action Tracker, 2018d). The share of electric trucks in new sales is modelled with a s-curve.
- **Share of zero-emission freight trains:** The benchmark is inspired by the electrification rate of freight railways already achieved by international frontrunners, for instance, Japan (90%) and in Switzerland (100%), where majority of the electricity for traction power also comes from renewable sources. Here, we assume that the share of zero-emission freight trains increases from today level in Australia (1%) to 90% by 2050 for the least ambitious end and 100% by 2050 for the most ambitious end following an s-curve pattern.
- **Modal shift**: Rail accounts for about 66% of freight activity in Australia, up from 36% in 2000 (BITRE 2017; Commonwealth of Australia 2016). Based on the EU target as explained above, we assume that Australia could transport freight across large distances. 30% of Australian road freight could swap to rail by 2030 and more than 50% by 2050 (please see further details above). Road freight accounts for 213.9 billion tkm (bulk and non-bulk freight) and a further 30% of road freight could be transferred to rail by 2030 (64 billion tkm) and 50% by 2050 (107 billion tkm) (Bureau of Infrastructure & Australian (BITRE)., 2018). This implies an increase of the share of rail freight in Australia to 74% by 2030 and 80% by 2050.
- **Emission intensity improvement:** Alongside strong penetration of zero-emission trucks, emission intensity improvements of new trucks is an important, intermediate complementary measure to achieve a clean transport sector. Introducing stringent standards for emission intensity of new vehicles would simultaneously provide further incentives for a higher penetration of electric trucks and thus brings a two-fold benefit. We apply EU emissions intensity targets for new HDVs which need to continuously decrease by 15% rel. to 2019 in 2025 and by at least 30% in 2030 (European Commission 2019). We assume that the emission intensity of new trucks further declines after 2030, following the same rate of reduction.

National scenarios

The study conducted by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) [21] provides the detail behind the transport projections underpinning the Australian contribution to the United Nations Sustainable Development Solutions Network (UN SDSN) and Institute for Sustainable Development and International Relations (IDDRI) Deep Decarbonisation Pathways Project led by ClimateWorks Australia and the Australian National University (ANU). CSIRO's Energy Sector Model (ESM) is applied to develop the transport sector projections. ESM minimises the cost of meeting transport demand and is primarily an economic modelling framework. The study thus provides technological least-cost transport sector projections. Additionally, the Institute of Sustainable Futures (ISF) at the University of Technology Sydney has produced an economic and technical scenario model for a transition towards a renewable energy system (Sven Teske et al., 2016a). The model describes Australia's future energy system, including an assessment of technology pathways and cost implications of three future energy scenarios.

For electric mobility, the modelled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) envisages that internal combustion engines will be completely phased out of light-duty road vehicles by 2050 in favour of hybrid, fully electric, plug-in hybrid electric and fuel cell vehicles. However, the scenario assumes a remaining use of petrol associated with plug-in hybrid electric vehicles. For the heavy duty sector, the modelled pathway

[21] An updated version published recently (ClimateWorks Australia, 2020a) was not available at the time of this scenario analysis.

by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) also envisages that the heavy-duty sector decarbonization reaches saturation point in the 2040s due to assumed limits to electrification of freight tasks. It assumes a high share of natural gas and continued use of diesel through to 2050.

The 'Advanced Renewables' Scenario by (Sven Teske et al., 2016a) envisages 100% share of zero emission vehicles in the Australia's road transport sector, while direct use of electricity reaches to 72% and the rest is provided by zero carbon fuels including biofuels, hydrogen and other synthetic fuels generated using renewable electricity. Additionally, according to the modelling done by Energeia for Australian Renewable Energy Agency (ARENA) and Clean Energy Finance Corporation (CEFC), there would be steady rise in sales of Plug in Electric Vehicles (PEVs) (including Battery Electric Vehicles and Plug-in Hybrid Electric Vehicles) by 2026 driven by falling PEV prices supported by falling battery prices, increased model availability by Original Equipment Manufacturers and an increasing differential between petrol and electricity prices. According to the model, the cumulative EVs uptake would reach 100%, 95% under Accelerated Intervention and Moderate Intervention scenarios respectively by 2050 (ARENA, 2018).

Concerning the energy intensity improvement rates, the modelled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) assumes that the energy intensity of non-electric passenger fleet decreases over 2016-2050: 75%: Cars and 50%: buses. The energy intensity of trucks also decreases by 75% until 2050.

With respect to modal shift, the study assumes fast rail shifts 15% of passenger travel away from aviation. However, limited road to rail mode shifting occurs in freight transport due to logistical constraints.

Concerning the adoption of zero carbon fuels for air transport, the modelled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) assumes that up to 50% of aviation can adopt biofuels. Additionally, the energy intensity of air transport decreases by about 1% p.a. corresponding to a total decrease of 33% until 2050. The 'Advanced Renewable' Scenario by (Sven Teske et al., 2016a) envisages a 100% share of zero carbon fuels in aviation transport, including biofuels as well as synthetic fuels generated using renewable electricity.

Passenger Transport on land – High ambition

- **Electrification of personal cars:** According to the modelled pathway by (ARENA, 2018), the share of electric cars in total passenger car fleet reaches to 100% for the most ambitious modelled scenario "Accelerated Intervention", which we apply here for the highest ambition end of *"National Scenarios"*. This pathway implies a share of electric cars in total vehicle stock of 28% by 2030, while it continuously rises to 73% by 2040 and 100% by 2050.
- **Electrification of buses:** According to the modelled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) for heavy duty sector, we assume that the share of electric buses in total vehicle fleet reaches to 29% by 2030, while it saturates at 50% by 2040.
- **Modal shift:** According to the deep decarbonisation scenario by (ClimateWorks Australia, Australian National University (ANU), et al., 2014), fast rail shifts 15% of passenger travel away from aviation. Thus, the share of (domestic) aviation in total passenger transport reduces in favour of rail transport. We further combine this with the activity projections and modal split based on (IEA MoMo., 2017) as used for Reference scenario projections in PROSPECTS Australia scenario evaluation tool. On this basis, the share of passenger rail transport would increase to 18% of total passenger transport activity by 2050. Correspondingly, the share of public transport would constitute 28% of total passenger road and rail transport activity by 2050.
- **Emission intensity improvement:** According to the deep decarbonisation scenario by (ClimateWorks Australia, Australian National University (ANU), et al., 2014), we assume that the energy intensity of non-electric fleet decreases by 2.2% p.a. for passenger cars and 1.5% p.a. for buses over 2016-2050 corresponding to a total decrease of 75% until 2050 for personal cars and a total decrease of 50% for buses, respectively.

Passenger Transport on land – Low ambition

- **Electrification of personal cars:** The modelled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) envisages that internal combustion engines will be completely phased out of light-duty road vehicles by 2050 in favour of hybrid, fully electric, plug-in hybrid electric and fuel cell vehicles (share of 5.45% for hybrid and 35.15% for PHEV, 59.40% for fully electric cars including FCEV, and BEV). Here, we assume a 50% share of hybrid and PHEV vehicles driven as fully electric. Based on this, for the low ambition scenario, the electrification rate of passenger car fleet reaches to 28% by 2030, while it rises to 65% by 2040 and 80% by 2050.
- **Electrification of buses:** Similar to the high ambition case based on the modelled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) for heavy duty sector, we assume that the share of electric buses in total vehicle fleet reaches to 29% by 2030, while it saturates at 50% by 2040.
- **Modal shift:** Like the high ambition case, we assume that the share of passenger rail transport would increase to 18% of total passenger transport activity by 2050. Correspondingly, the share of public transport would constitute 28% of total passenger road and rail transport activity by 2050.
- **Emission intensity improvement:** Similar to the high ambition case based on the deep decarbonisation scenario by (ClimateWorks Australia, Australian National University (ANU), et al., 2014), we assume that the energy intensity of non-electric fleet decreases by 2.2% p.a. for passenger cars and 1.5% p.a. for buses over 2016-2050.

Freight Transport

- **Electrification:** The modelled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) envisages that the heavy-duty sector reaches saturation point in the 2040s due to limits to electrification of freight tasks. Based on this scenario, we assume that the share of electric trucks in total vehicle fleet reaches to 29% by 2030, while it saturates at 50% by 2040. This share includes FCEV, BEV and hybrid as well as PHEV while we assume a 50% share of hybrid vehicles and PHEV driven as fully electric.
- **Emission intensity improvement:** According to the deep decarbonisation scenario by (ClimateWorks Australia, Australian National University (ANU), et al., 2014), we assume that the energy intensity of non-electric trucks decreases by 2.2% p.a. over 2016-2050 corresponding to a total decrease of 75% until 2050.

Domestic Aviation – High ambition

- **Share of zero carbon fuels:** For the High ambition case we assume that the share of biofuels and renewable-based synthetic fuels increases to 100% by 2050 based on the 'Advanced Renewable' Scenario by (Teske et al. 2016).
- **Emission intensity improvement:** Energy intensity of air transport decreases by 1% p.a. corresponding to a total decrease of 33% until mid-century according to the modeled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014).

Domestic Aviation – Low ambition

- **Share of zero carbon fuels:** For the Low ambition scenario, we assume that the share of biofuels increases from 0% today to 50% by 2040 based on the modelled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014).
- **Emission intensity improvement:** Similar to the high ambition scenario, we assume that the energy intensity of air transport decreases by 1% p.a. corresponding to a total decrease of 33% until mid-century according to the modeled pathway by (ClimateWorks Australia, Australian National University (ANU), et al., 2014).

4.2.2.2 Quantification of emission levels with PROSPECTS Australia

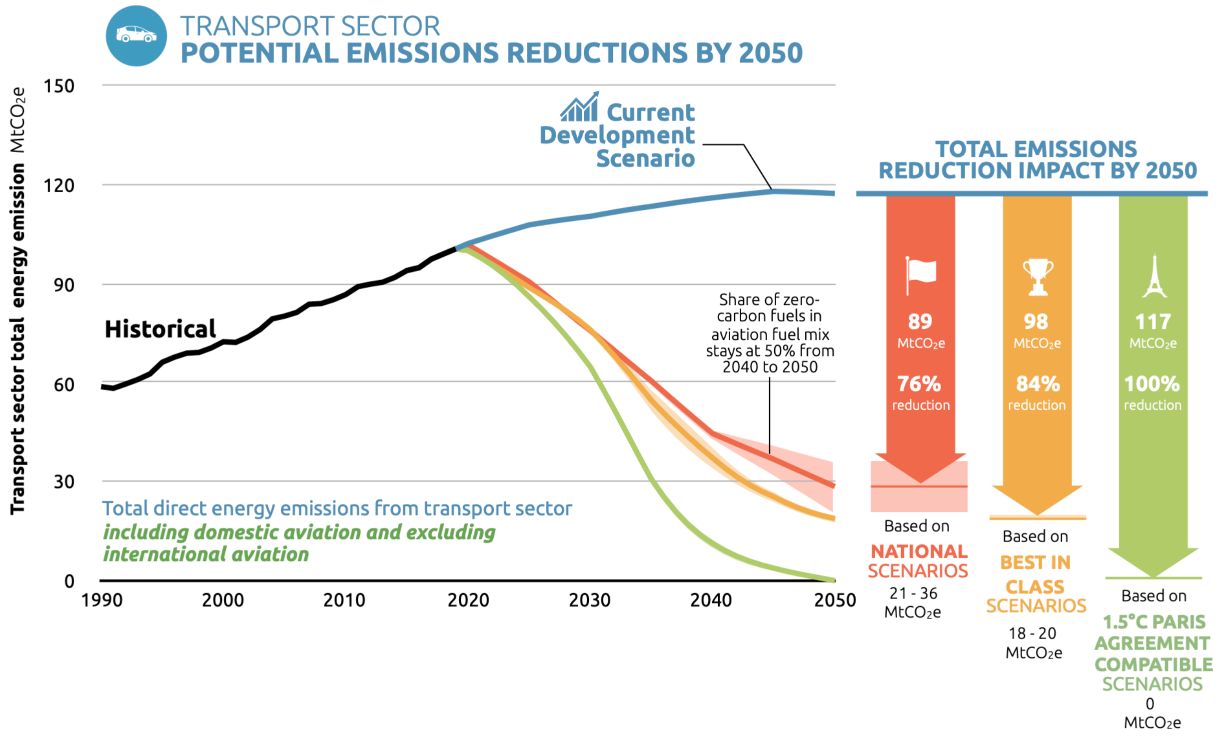


Figure 30 Overview of sectoral emission pathways under Reference scenario projections and different levels of accelerated climate action in Australia's passenger and freight transport sector (covering freight transport, passenger transport including domestic aviation) excluding electricity related emissions;

Figure 30 illustrates the emissions trajectories from Australia's passenger and freight transport (including domestic aviation) until 2050 for different scenario categories, while enhanced climate action in the transport sector is further combined with decarbonisation of the electricity sector. This reveals how by applying mitigation measures on the demand side such as strong electrification of the transport sector and modal shift combined with a simultaneous decarbonisation of the electricity sector, significant reduction of emissions can be achieved by mid-century.

Under reference scenario projections, the emissions from Australia's transport sector (including electricity-related emissions) would keep increasing to 114 $MtCO_2/a$ by 2030 and 120 $MtCO_2e/a$ by 2050, i.e. 31% and 43% above 2005 levels respectively. The emissions excluding electricity related emissions from the transport sector would rise to 110 $MtCO_2/a$ by 2030 from 94 $MtCO_2/a$ in 2015, which is also quite consistent with the government projections (Australian Department of the Environment and Energy (DEE)., 2019a).

In contrast to the reference scenario, all scaled-up climate action pathways imply instead deep emissions reductions in the transport sector:

- The '**1.5°C Paris Agreement compatible'** pathway substantially reduces emissions and leads to the full decarbonisation of the transport sector by mid-century. This is mainly driven by the strong electrification of both passenger and freight transport sectors as well as increasing the share of biofuels and renewable-based synthetic fuels in particular for domestic aviation. Further influencing factors include modal shift towards a higher share of public transport in the passenger transport as well as modal shift towards a higher share of freight trains, also emission intensity improvement of the remaining non-electric vehicles.

- The '**Applying best-in-class levels'** pathway also implies an immediate reduction of emissions. The total transport related emissions in 2050 vary between 18 and 20 $MtCO_2e/a$ for the high and low ambition case, respectively.

- The '**National scenarios'** pathway reveals a broader range across the upper and lower ambition end. The high ambition end implies a substantial reduction of emissions and the 2050 emissions are only slightly above the 'Applying best-in-class levels' scenario. The upper trajectory reduces emissions to around 21 $MtCO_2e$/a in 2050, i.e. around 83% below reference scenario projections.

All the three scenarios in the ANO 2019 report (Brinsmead et al., 2019)foresee a decline in the share of oil and gas and increase in the share of electricity, hydrogen and biofuels in the transport fuel mix. However, even the most ambitious Green and Gold scenario project the share of oil to be 44% in transport fuel mix in 2060 (Brinsmead et al., 2019). In the context of the Paris Agreement compatible pathway analysed by us, the transport sector would be completely decarbonized by 2050 primarily by means of electrification and substitution of fossil fuels with biofuels or synthetic fuels, along with a considerable shift towards public modes of transport from private modes.

4.3 Industry sector

Greenhouse gas emissions from the industry sector (see chapter 2.4) include emissions from direct combustion in energy, mining, and manufacturing, as well as in agriculture and fisheries, and industrial process emissions and fugitive emissions from extraction and processing of coal, gas, and oil.

In some industry sectors, greenhouse gas emissions originate not only from fuel combustion to generate heat or electricity, but also from fuel combustion needed to start certain chemical reactions (e.g. reduction of iron with coking coal in a blast furnace to produce steel), or from the chemical reactions that take place during the industrial processes (e.g. calcination of limestone during cement production (CAT, 2017). Apart from increasing efficiency and decarbonising energy supply, decarbonisation of these sectors requires a shift in production methods (including more circular production routes) or in product use (CAT, 2017). Steel and cement manufacturing are among the most carbon intensive industries involving process emissions and are therefore analysed separately from other manufacturing and energy industry sectors.

With a rapid increase in production of liquified natural gas (LNG) for export, LNG processing is one of the fastest-growing sources of direct combustion emissions in Australia's industry sector. Increasing gas extraction is also leading to more fugitive emissions (Climate Analytics, 2018a). The LNG processing sector as well as fugitive emissions are analysed in Sections 4.5.1 and 4.5.4 respectively.

4.3.1 Iron & steel, cement and other manufacturing industries and agriculture and fisheries energy

In this section, we analyse the iron and steel production industry and cement production as separate sectors in addition to an aggregated "Other manufacturing industry" sector that includes heavy industry (chemicals and petrochemicals, non-ferrous metals, transport equipment, machinery, mining and quarrying) and light industry (food and tobacco, paper and pulp, wood products, textile and leather, other). This does not include the LNG processing sector, which we analyse separately (section 4.5.1). We quantify energy related emissions from direct combustion as well as process related emissions. Fugitive emissions from extraction and processing of coal, gas and oil are quantified separately (section 4.5.4).(See methodological annex for overview of sectoral coverage and definitions).

The Paris Agreement compatible sectoral trajectories fully decarbonise the Australian iron and steel industry by 2050. This is mainly driven by changing the production method, replacing the Blast Oxygen Furnace (BOF) method which is currently mostly used in the Australian steel manufacturing (based on coking coal) with the increased use of electric arc furnaces (which is currently only used for manufacturing secondary steel out of scrap) and direct reduction with renewable hydrogen. This relies on the electricity supply sector to swiftly decarbonise and to be fully decarbonised before 2050 in line with the Paris Agreement temperature goal.

Similarly, the cement manufacturing achieves carbon neutrality by mid-century. This is mainly driven by replacing conventional production methods with new, low-carbon alternatives such as geopolymer cement instead of carbon-intensive process of producing Portland Cement from limestone. It can also include the need to take up remaining carbon emissions. While often the need for Carbon Capture and Storage (CCS) is assumed for decarbonising cement production, other technologies are available such as mineral carbonation that can be implemented at lower cost (BZE 2018). We follow this with the Paris Agreement compatible scenario trajectory.

Other industry sectors also achieve carbon neutrality by mid-century, using the abundance of Australia's renewable electricity to electrify various industry sectors to eliminate emissions from industrial heat provision as well as switch to hydrogen and other renewable-based synthetic fuels as a replacement to fossil fuel feedstocks such as for ammonia production.

In a national energy system scenario analysed earlier the industry sector (like other energy sectors) is fully decarbonised by 2050 (Hare et al. 2018; Teske et al. 2016). This scenario shows that the existing coal and gas demand in industry and mining can be eventually replaced by renewable energy.

A key complementary strategy to reduce emissions and costs across all industry sectors is increase energy efficiency. and there are large untapped potentials for energy efficiency across Australia's industry particularly in manufacturing. However, energy efficiency cannot be the only focus for decarbonisation of industry and needs to be complementary to decarbonisation in particular through electrification, which in itself also increases energy efficiency.

Table 21 provides an overview of scenario analysis results in the Australian iron and steel, cement, and other industry sectors. Figure 31 displays the resulting emissions trajectories for all scenarios after quantification with the PROSPECTS Australia scenario evaluation tool.

Table 21: Outcome overview of the scaling up climate action analysis in the Australia's iron & steel, cement and other industry sectors

<table>
<tr><th rowspan="2">Indicator</th><th></th><th colspan="3">Indicator values for scenario categories</th></tr>
<tr><th>Reference Scenario Projections (REF)</th><th>National scenarios</th><th>Applying best-in-class level(s)</th><th>1.5°C compatible scenarios</th></tr>
<tr><td colspan="5">Iron & Steel</td></tr>
<tr><td>Production method</td><td>Blast Oxygen Furnace (BOF) using coking coal continues to be the main production method with a share of 76%, and the share of secondary steel production with Electric Arc Furnace (EAF) does not increase beyond a share of 24%.

Share of BOF:
(77% by 2015)
• 76% by 2030
• 76% by 2040
• 76% by 2050
Share of EAF-Scrap (23% by 2015):
• 24% by 2030</td><td>Share of BOF:
• 51% by 2030
• 25% by 2040
• 0% by 2050
Share of EAF-Scrap:
• 30% by 2030
• 36% by 2040
• 42% by 2050
Share of EAF-DRI:
• 19% by 2030
• 39% by 2040
• 58% by 2050</td><td colspan="2">Share of BOF:
• 51% by 2030
• 25% by 2040
• 0% by 2050
Share of EAF-Scrap:
• 30% by 2030
• 36% by 2040
• 42% by 2050
Share of EAF-DRI:
• 19% by 2030
• 39% by 204
• 58% by 2050</td></tr>
</table>

	• **24% by 2040** • **24% by 2050**		
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Mainly based on data from WorldSteel.	*Inspired based on* (Beyond Zero Emissions, 2018) *and* (ClimateWorks Australia, Australian National University (ANU), et al., 2014)	*Based on benchmark specified in* (Kuramochi et al., 2018); (Beyond Zero Emissions, 2018) *and* (ClimateWorks Australia, Australian National University (ANU), et al., 2014)
Direct energy fuel mix (excl. coke)	Coal share: **15% (2030); 17% (2040); 36% (2050)** Oil share: **5% (2030); 4% (2040); 4% (2050)** Natural gas share: **81% (2030); 79% (2040); 60% (2050)** Biofuels share: **0% (2030); 0% (2040); 0% (2050)** Hydrogen/synthetic fuels share: **0% (2030)**; **0% (2040)**; **0% (2050)**	**Higher Ambition:** • **Coal share reduces from today to 0% by 2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Biofuels share: **0% (2030); 0% (2040); 0% (2050)** • Hydrogen/synthetic fuels share: **0% (2030); 13% (2040); 100% (2050)** **Lower Ambition:** • Coal share reduces from today to **9%** (**2030); 4% (2040); 0% (2050)** • Oil share reduces from today **to 3%** (**2030); 2% (2040); 0% (2050)** • Natural gas share increases from today to **88%** by **2030**; **94% (2040)** and **100% (2050)** • Biofuels share: **0% (2030); 0% (2040); 0% (2050)** • Hydrogen/synthetic fuels share: **0% (2030); 0% (2040); 0% (2050)**	**Lower Ambition:** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Biofuels share: **0% (2030); 0% (2040); 0% (2050)** • Hydrogen/synthetic fuels share increases from **2030 onwards** to **13% (2040) and 100% (2050)**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Mainly based on RTS Scenario from IEA ETP.	*Inspired based on* (Beyond Zero Emissions, 2018) *and further detail scenario-specific assumptions by Author*	*No specifically defined benchmark for Paris Agreement compatibility for direct energy fuel mix in steel industry. Accordingly, the levels from the most ambitious end of 'National Scenarios' applied for the high and low ambition case, respectively.*
		Cement	
Clinker to cement ratio	The clinker to cement ratio reduces from 78% today to: • **75.5%** by **2030** • **74%** by **2040** • **73%** by **2050**	**Higher Ambition** The clinker to cement ratio reduces from 78% today to: • **70%** by **2030** • **55%** by **2040** • **30%** by **2050** **Lower Ambition** The clinker to cement ratio reduces from 78% today to: • **72%** by **2030**	The clinker to cement ratio reduces from 78% today to: • **70%** by **2030** • **55%** by **2040** • **30%** by **2050**

		• **63%** by **2040** • **47%** by **2050**	
	Based on PROSPECTS Australia scenario evaluation tool developed by Climate Action Tracker (2018).	*Inspired based on* (Beyond Zero Emissions, 2017) for the higher ambition and (ClimateWorks Australia, Australian National University (ANU), et al., 2014) for the lower ambition	*No specifically defined benchmark for Paris Agreement compatibility for clinker to cement ratio. Accordingly, the levels from the most ambitious end of 'National Scenario' applied.*
Process emission intensity	Remains constant at **0.53 $MtCO_2e$/Mt clinker** over **2015-2050**	**Higher Ambition:** The process emission intensity reduces from 0.53 $MtCO_2e$/Mt clinker today to: • **0.35** by **2030** • **0.18** by **2040** • **0** by **2050** **Lower Ambition:** Same as Reference Scenario	The process emission intensity reduces from 0.53 $MtCO_2e$/Mt clinker today to: • **0.35** by **2030** • **0.18** by **2040** • **0** by **2050**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018).	*Inspired based on* (BZE 2017) *for the high ambition*	*Based on the assumption that alternatives to Ordinary Portland Cement, such as geopolymer cement would be applied.* (BZE 2017) *states that raw materials for geopolymer cement are already available in Australia and this could be one of the strategies to achieve zero emissions from the sector. Also inspired from* (WWF, 2018a) *that emphasize the role of Supplementary Cementitious Materials (SCM) as alternatives to clinker.*
Direct energy fuel mix	Coal share: **12% (2030); 10% (2040); 7% (2050)** Oil share: **5% (2030); 4% (2040); 3% (2050)** Natural gas share: **82% (2030); 85% (2040); 88% (2050)** Biofuels share: **1.5% (2030); 1.4% (2040); 1% (2050)** Hydrogen/synthetic fuels: **0% (2030); 0% (2040); 0% (2050)**	**Higher Ambition:** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Biofuels share: **1.5% (2030); 1.4% (2040); 1% (2050)** • Hydrogen/synthetic fuels share increases from **2030** onwards to **24% (2040)** and **99% (2050)** **Lower Ambition:** • Coal share reduces from today to **14% (2030); 7% (2040); 0% (2050)** • Oil share reduces from today **to 5% (2030); 2% (2040); 0% (2050)** • Natural gas share increases from today to **80%** by **2030**; **89% (2040)** and **99% (2050)** • Biofuels share: **1.5% (2030); 1.4% (2040); 1% (2050)**	• Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Biofuels share: **1.5% (2030); 1.4% (2040); 1% (2050)** • Others (Hydrogen/synthetic fuels) share increases from **2030** onwards to **24% (2040)** and **99% (2050)**

		• Hydrogen/synthetic fuels: **0% (2030); 0% (2040); 0% (2050)**	
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Mainly based on RTS Scenario from IEA ETP.	*Inspired based on* (BZE 2017) *and* (Ueckerdt et al., 2019b) *supplemented with own assumptions due to lack of direct benchmarks*	*Inspired based on different sources:* (BZE 2017; *CAT 2017;* Kuramochi et al. 2018; Ueckerdt et al. 2019) *supplemented with own assumptions due to lack of direct benchmarks according to the most ambitious end of "National Scenarios".*
Direct energy intensity improvement rate	**3.4 PJ/Mt of clinker** in 2015 and reduces by an average rate of **0.35 % p.a. over (2016-2050)**	Same as 'Reference Scenario	Reducing from 3.4 PJ/Mt of clinker today by an average rate of **-0.72% p.a.** from 2020 onwards
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main data source is RTS Scenario from IEA ETP.	*Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main data source is RTS Scenario from IEA ETP.*	*Based on* (Edelenbosch et al., 2017)
Electricity intensity improvement rate	**0.09 TWh/Mt of cement** in 2015 and reduces by an average rate of **-0.45% p.a. over (2016-2050)**	Same as 'Reference Scenario	Reducing from 0.09 TWh/Mt of cement today by an average rate of **-3.4% p.a.** from 2020 onwards
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main data source is RTS Scenario from IEA ETP.	*Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main data source is RTS Scenario from IEA ETP.*	*Based on* (WWF, 2008)
Other manufacturing industries			
(Direct) Electrification rate	Heavy industry: **34%** over **(2015-2050)** Light industry: **16%** over **(2015-2050)**	Higher Ambition: Heavy industry: **2030: 51%** **2040: 67%** **2050: 80%** Light industry: **2030: 35%** **2040: 59%** **2050: 80%** Lower Ambition: Heavy industry: **2030: 36%** **2040: 38%** **2050: 40%** Light industry: **2030: 23%** **2040: 31%** **2050: 40%**	Heavy industry: **2030: 51%** **2040: 67%** **2050: 80%** Light industry: **2030: 35%** **2040: 59%** **2050: 80%**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018).	*Inspired based on (BZE 2018) and* (Ueckerdt et al. 2019) *for the high ambition and* (Ueckerdt et al. 2019) *for the Low ambition*	. *No specifically defined benchmark for Paris Agreement compatibility of electrification rate of other industry sectors. Accordingly, the levels from the High ambition end of 'National Scenario' is applied.*
Direct energy fuel mix	**<u>Heavy industry:</u>** Coal share: **9% (2030); 8% (2040); 7% (2050)**	**Higher Ambition:** **<u>Heavy industry:</u>** • Coal share reduces from today to **0%** by **2050**	**50** **Lower Ambition:** **<u>Heavy industry:</u>** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today to **0%** by **2050**

	Oil share: **29% (2030); 29% (2040); 27% (2050)** Natural gas share: **60% (2030); 61% (2040); 63% (2050)** Waste share: **1% (2030); 1% (2040); 1% (2050)** Biofuels share: **0.5% (2030); 0.8% (2040); 0.2% (2050)** Hydrogen/synthetic fuels/non-biomass renewables share: **0% (2030); 0% (2040); 0% (2050)** **<u>Light industry:</u>** Coal share: **5% (2030); 4% (2040); 4% (2050)** Oil share: **15% (2030); 14% (2040); 13% (2050)** Natural gas share: **24% (2030); 21% (2040); 18% (2050)** Waste share: **0% (2030); 0% (2040); 0% (2050)** Biofuels share: **56% (2030); 61% (2040); 65% (2050)** Hydrogen/synthetic fuels/non-biomass renewables share: **0% (2030); 0% (2040) ;0% (2050)**	• Oil share reduces from today to **0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Waste share: **1% (2030); 0% (2040); 0% (2050)** • Biofuels share: **4% (2030); 4% (2040); 4% (2050)** • Hydrogen/synthetic fuels/non-biomass RE share increases from **2030** onwards to **13% (2040)** and **96% (2050)** **<u>Light industry:</u>** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Waste share: **0% (2030); 0% (2040); 0% (2050)** • Biofuels share: **59% (2030); 59% (2040); 59% (2050)** • Hydrogen/synthetic fuels/non-biomass RE share increases from **2030** onwards to **3% (2040)** and **41% (2050)** **Lower Ambition:** **<u>Heavy industry:</u>** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share increases from today to **60% (2030); 72% (2040); 83% (2050)** • Waste: **1% (2030); 1% (2040); 1% (2050)** • Biofuels: **11% (2030); 13% (2040); 16% (2050)** • Hydrogen/synthetic fuels/non-biomass renewables: **0% (2030); 0% (2040); 0% (2050)** **<u>Light industry:</u>** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050**	• Natural gas share reduces to **0%** by **2050** • Waste share: **1% (2030); 0% (2040); 0% (2050)** • Biofuels share: **4% (2030); 4% (2040); 4% (2050)** • Hydrogen/synthetic fuels/non-biomass RE share increases from **2030** onwards to **13% (2040)** and **96% (2050)** **<u>Light industry:</u>** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Waste share: **0% (2030); 0% (2040); 0% (2050)** • Biofuels share: **59% (2030); 59% (2040); 59% (2050)** • Hydrogen/synthetic fuels/non-biomass RE share increases from **2030** onwards to **3% (2040)** and **41% (2050)**

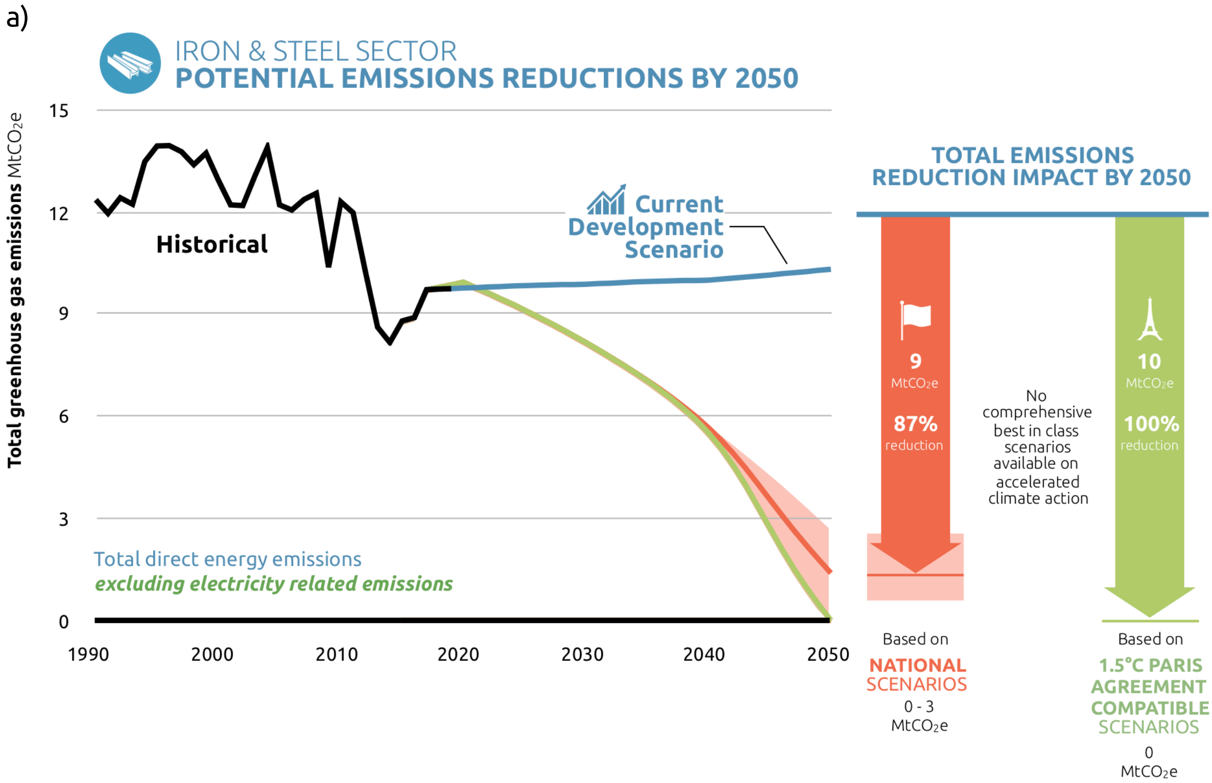
		• Natural gas share increases from today to **28% (2030); 28% (2040); 29% (2050)** • Waste: **0% (2030); 0% (2040); 0% (2050)** • Biofuels: **61% (2030); 66% (2040); 70% (2050)** • Hydrogen/synthetic fuels/non-biomass renewables**: 0% (2030); 0% (2040) ;0% (2050)**	
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018). Main data source is RTS Scenario from IEA ETP.	*Inspired based on (BZE 2018; Teske 2016) and (CWA 2014) for the higher ambition and lower ambition, respectively and further detail scenario-specific assumptions by Author.*	*Inspired based on different sources: (BZE 2018; CAT 2017;* Kuramochi et al. 2018; Ueckerdt et al. 2019; Teske et al., 2016) *supplemented with own assumptions due to lack of direct benchmarks for every fuel according to the most ambitious end of "National Scenarios".*
Process emissions intensity	Remains constant over time at **91 $MtCO_2e$/US$** over **(2015-2050)**	**Higher Ambition:** Reduces from today (91 $MtCO_2e$/US$) to: • **2030: 52** ($MtCO_2e$/US$) • **2040: 26** ($MtCO_2e$/US$) • **2050: 0** ($MtCO_2e$/US$) **Lower Ambition:** Same as Reference Scenario	Reduces from today (91 $MtCO_2e$/US$) to: • **2030: 52** ($MtCO_2e$/US$) • **2040: 26** ($MtCO_2e$/US$) • **2050: 0** ($MtCO_2e$/US$)
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018).	*Inspired based on (BZE 2018) for the higher ambition case*	*No specifically defined benchmark for Paris Agreement compatibility for process emission intensity. Accordingly, the levels from the High ambition end of 'National Scenario'.*
Overall energy intensity	**Heavy industry:** Reducing from **0.0026 PJ/million US$ today** by an average rate of **-3.2%** from **2016** onwards. **Light industry:** Reducing from **0.0010 PJ/million US$ today** by an average rate of **-1.4%** from **2016** onwards.		Reducing from **0.0036 PJ/million US$ today** by an average rate of **-4.8%** from **2020** onwards.
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018).		*Inspired based on the case of UK, having the lowest level of energy intensity in terms of weighted energy consumption per dollar of industrial GDP according to* (Castro-Alvarez et al., 2018)
Agriculture, forestry and fishing			
(Direct) Electrification rate	Agriculture, forestry and fishery: **7.3%** over **(2015-2050)**	**Higher Ambition:** Agriculture, forestry and fishery: **2030: 35%** **2040: 79%** **2050: 100%**	Agriculture, forestry and fishery: **2030: 35%** **2040: 79%** **2050: 100%**

		Lower Ambition Same as reference scenario	
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018).	*Higher ambition inspired based on Advanced Renewables scenario of Teske et al., 2016 to have 100% renewable energy supply in industry sector by 2050.* *Lower ambition based on PROSPECTS Australia tool developed by Climate Action Tracker (2018).*	*Inspired based on Advanced Renewables scenario of Teske et al., 2016 to have 100% renewable energy supply in industry sector by 2050.*
Overall Energy Intensity	Overall energy intensity **0.0041PJ/million US$** kept constant over **(2015-2050).**	Overall energy intensity **0.0041PJ/million US$** kept constant over **(2015-2050).**	Overall energy intensity **0.0041PJ/million US$** reducing at an average rate of **-4.8%** from **2020** onwards. **).**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018).	*Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018).*	*Inspired based on the case of UK, having the lowest level of energy intensity in terms of weighted energy consumption per dollar of industrial GDP according to* (Castro-Alvarez et al., 2018) .
Direct energy fuel mix	• Coal Share: **0% (2030); 0% (2040); 0% (2050)** • Gas Share: **1% (2030); 1% (2040); 1% (2050)** • Oil Share: **99% (2030); 99% (2040); 99% (2050)** • Biofuel Share: **0% (2030); 0% (2040); 0% (2050)** • Waste Share:**0% (2030); 0% (2040); 0% (2050)** • Others Share: **0% (2030); 0% (2040); 0% (2050)**	• Coal Share: **0% (2030); 0% (2040); 0% (2050)** • Gas Share: **1% (2030); 1% (2040); 1% (2050)** • Oil Share: **99% (2030); 99% (2040); 99% (2050)** • Biofuel Share: **0% (2030); 0% (2040); 0% (2050)** • Waste Share:**0% (2030); 0% (2040); 0% (2050)** • Others Share: **0% (2030); 0% (2040); 0% (2050)**	• Coal Share: **0% (2030); 0% (2040); 0% (2050)** • Gas Share: **1% (2030); 1% (2040); 1% (2050)** • Oil Share: **95% (2030); 92% (2040); 89% (2050)** • Biofuel Share: **3% (2030); 7% (2040); 10% (2050)** • Waste Share:**0% (2030); 0% (2040); 0% (2050)** • Others Share: **0% (2030); 0% (2040); 0% (2050)**
	Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018).	*Based on PROSPECTS Australia tool developed by Climate Action Tracker (2018).*	*Inspired by FAO 2016, which states gradual increase in adoption of renewable energy in agriculture sector as an approach to attain energy-smart agriculture.*

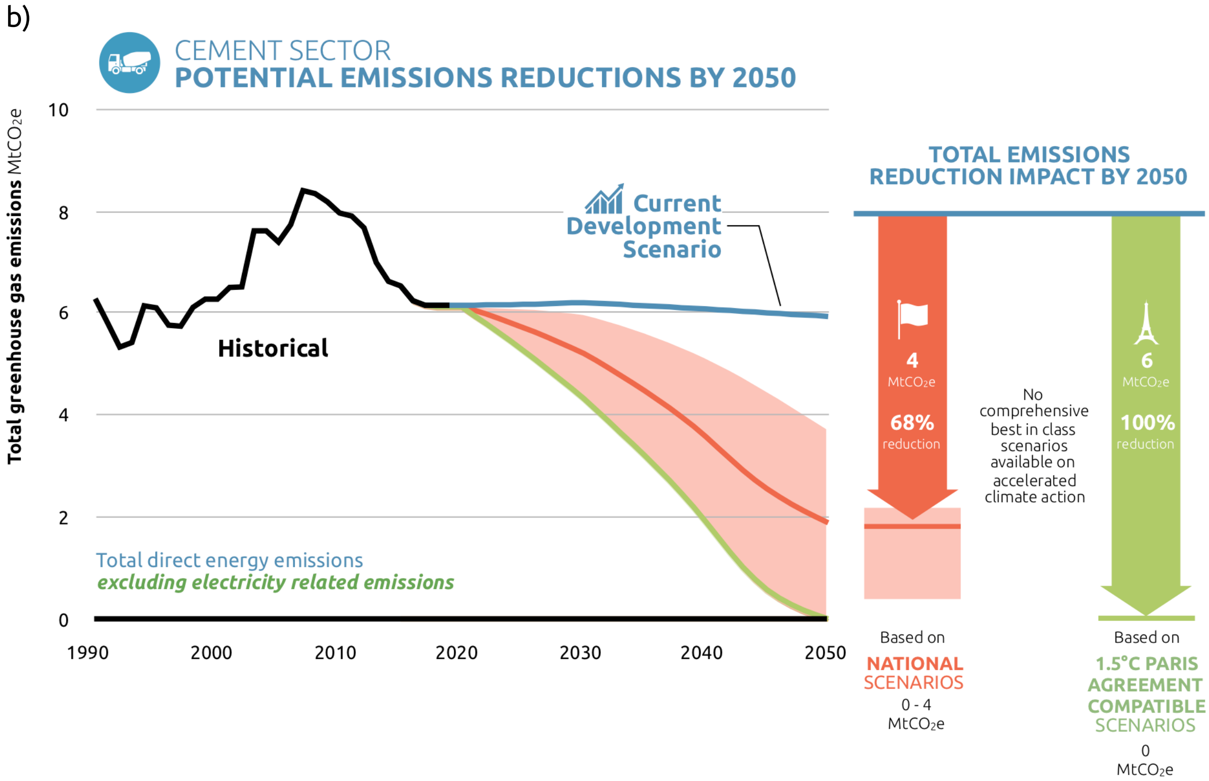
Required policy measures for sectoral transformation	Remaining challenges threatening implementation
⇨ Replace the ineffective safeguard mechanism with an effective carbon pricing and policies to incentivise energy efficiency such as mandatory energy audits, and incentives to introduce energy management systems. ⇨ Establish a defined Paris-compatible decarbonisation pathway and strategy for the sector, align current policy, and ensure energy and material efficiency as well as transformation towards zero emissions are priorities. ⇨ Embed this pathway and strategy in the development of an economy wide decarbonisation strategy building on competitive advantages and opportunities for new industries and employment, involving all stakeholders, including trade unions and civil society, as well as regions and local communities, to enable broad buy -in	⇨ Industry-government patronage networks allows industry to operate business-as-usual practises and creates preferential treatment such as exemptions and approvals at the expense of the taxpayer, the environment and emissions levels. ⇨ Tax subsidies for the fossil fuel sector does not create an environment to encourage innovation but sets a course for business-as-usual, without cost reduction solutions, energy efficiency or implementation of renewable alternatives in the sector. ⇨ Lack of development of a long-term strategy and pathway across all sectors in line with the Paris Agreement leads to neglecting the need to address decarbonisation of the industry sector and reap benefits building on Australia's advantages through

- ⇨ Develop targeted industry sector specific research, development and deployment initiatives consistent with the decarbonisation pathway.
- ⇨ The hydrogen strategy under development should focus on renewable hydrogen and be linked to a decarbonisation strategy for the sector and the whole economy.
- ⇨ creation of new industries such as zero emissions steel export
- ⇨ Hydrogen policy could be used to prop up the fossil fuel and LNG sector rather than support a renewable transition in the industry sector.

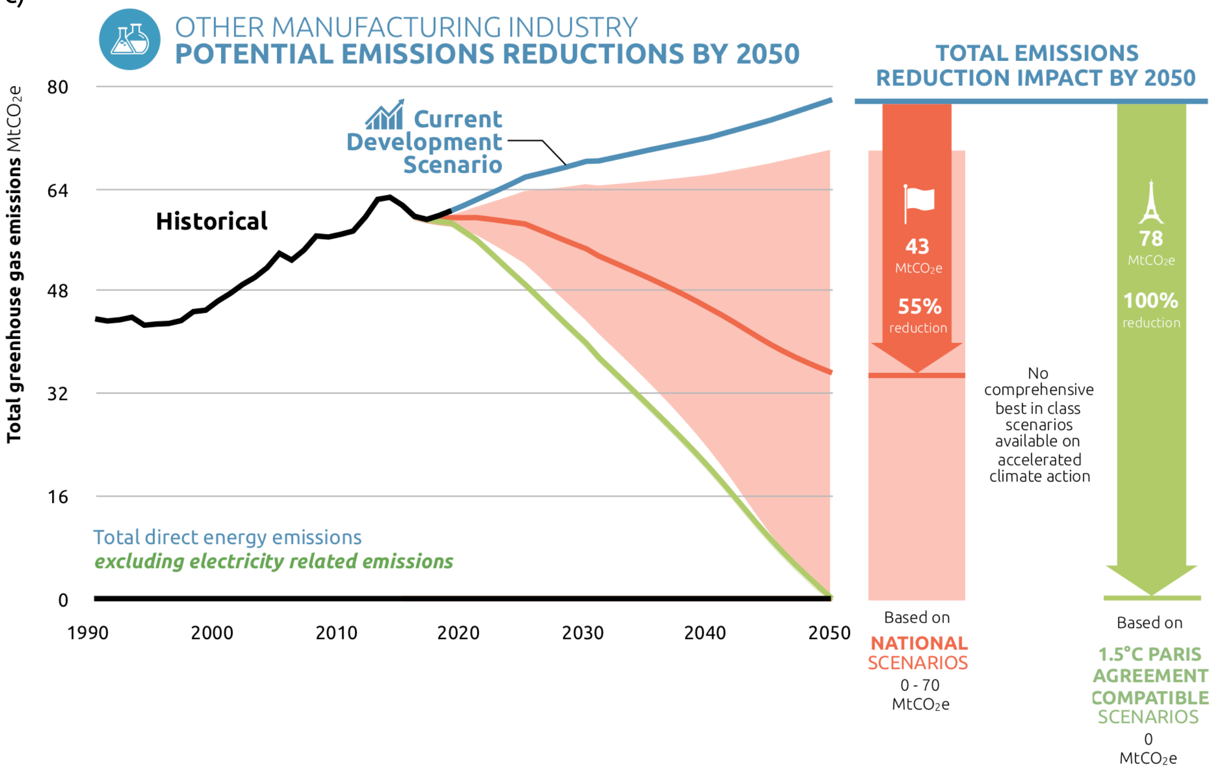
a)



b)



c)



d)

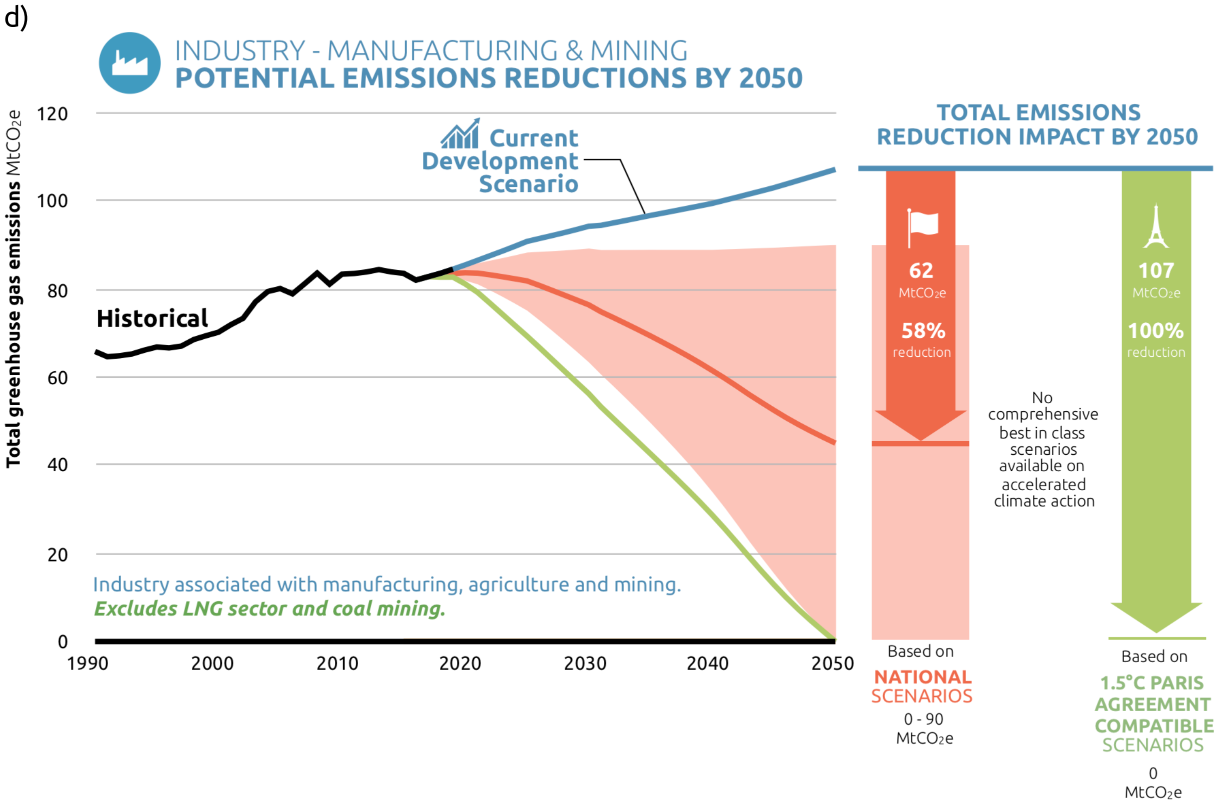


Figure 31 Overview of sectoral emission pathways under Reference scenario projections and different levels of accelerated climate action in Australia's industry sector excluding electricity-related emissions: (a) Iron & Steel (b) Cement (c) Other industry (d) Total industry (Manufacturing, agriculture, mining, without LNG sector and without coal mining).

4.3.2 Context for scaling up climate action in the industry sector

Inefficient with no effective policy

Australia's manufacturing sector - one of the main sources of greenhouse gas emissions from industry - is effectively standing still on energy efficiency, losing out on the benefits other countries' industries are getting from improving their energy efficiency (Climate Analytics, 2018a). The IEA (IEA, 2017a) finds Australia is one of the few countries of a total of 28 analysed by the IEA that is making no real progress in energy efficiency across countries and sectors. The IEA highlights the importance of policy development examples in the EU and China (Climate Analytics 2018 – ref. industry factsheet).

Australia is rated one of the world's worst in terms of energy. The 2018 International Energy Efficiency Scorecard by the American Council for an Energy-Efficient Economy (ACEEE) rates Australia 22nd out of 25 countries for energy efficiency in industry, falling from 10th place in 2014 (Castro-Alvarez et al., 2018).

The Australian government has a track record of retaining close networks with the industry sector, allowing preferential treatment such as exemptions and approvals at the expense of the tax payer, the environment and emissions levels (Market Forces, 2019; ODI, 2015), or for example, the extraordinary efforts to support the Adani coal mine project (ACF, 2017; Ogge & Campbell, 2018).

Chapter two demonstrated Australia does not have a strategy in place to achieve decarbonization. Very few government publications tackle the issue of decarbonizing industry, one example is the CSIRO's (2017) Low Emissions Technology Roadmap, assessing direct combustion by industry and fugitive emissions. Independent research institute have filled the government's knowledge void in decarbonizing industry. Sector specific analysis can be found in the works of Beyond Zero Emissions who have analyzed possibilities into electrification of industry and decarbonizing cement production (BZE, 2017, 2018). A sectoral roadmap for mining and manufacturing was produced by The Australian Alliance for Energy Productivity (2016). ClimateWorks Australia (2014) developed Pathways to Deep Decarbonisation which included industry decarbonization. These analyses need to be translated into sector specific policy.

LNG exports driving increase in emissions

Fast ramping up of LNG processing has contributed most to the recent increase in overall emissions. Apart from planned capture of CO_2 and storage in geological formations at on LNG plant in Western Australia, the Gorgon plant, very few greenhouse gas mitigation measures have been announced or planned at any scale in Australian LNG facilities.

Global implementation of the Paris Agreement means that the recent growth in the use of natural gas cannot continue, whether for the power sector or in other applications (Climate Analytics, 2019a).

There is currently no strategy to prepare for a transition of this sector, despite its significant and increasing contribution to emissions and the need for a global fossil fuel phase out.

Energy and money savings

Creating energy efficient practices reduces the need for energy and its associated costs, while reducing emissions, creating a win-win scenario. Energy efficiency standards can create annual energy and financial savings of over 10% (Climate Analytics, 2018a). Improved energy productivity can provide a competitive advantage for companies, through increasing energy efficiency, profit generation (Climate Analytics, 2018a).

Current policy does not provide incentives to reduce emissions in the industry sector (see chapter 2). The industry sector benefits from fossil fuel tax subsidies (Market Forces, 2019), which incentivises business-as-usual operations and energy intensive practices. Without subsidies, companies would have to cope with higher costs, or develop innovative solutions for energy efficiency, or cheaper renewable alternatives for the sector.

New economic opportunities for Australia

Australia's vast renewable energy potential, the level of technical capacity, and proximity to Asian markets with high energy demand, provides a unique opportunity for renewable energy export, as a 'global renewable energy superpower" (Climate Analytics, 2018a). **Green hydrogen offers the capabilities for renewable export, as may direct electricity export via HVDC cable to South East Asia[22].** It also offers opportunities to decarbonise energy intensive industry, where electrification is not possible, for example with steel production (Climate Analytics, 2018a).

While Australia currently only manufactures a relatively small amount of steel (0.3% of world output) it is the largest exporter of iron ore and coking coal – the two key raw materials for the currently mainly used production method of steel, the Blast Oxygen Furnace (BOF) using coking coal BZE 2018a (Beyond Zero Emissions, 2018).

With optimal renewable energy resources and large iron ore resources, Australia is well placed to become a global leader in producing and exporting zero emissions steel and other zero emissions energy intensive products (Wood & Dundas, 2020). This can create new sustainable value chains and manufacturing jobs.

The National Hydrogen Strategy currently under development needs to focus on renewable energy, and how it can decarbonise industry, and needs to be embedded in an overall decarbonisation strategy.

The IEA has, already in 2017, pointed out the vast opportunities in Australia based on the "extreme abundance of solar and wind resources" to spur international trade in renewables-based, hydrogen-rich chemicals and fuels (IEA, 2017b).

Renewable energy alternatives exist for all applications of industrial natural gas use, not only for power generation but also for lower output temperatures and high temperature thermal processes as well as chemical feedstock, as studied by ARENA (2015). Recent interest internationally (International Renewable Energy Agency, 2019) and nationally (COAG Energy Council, 2019b) in the development of strategies for renewable hydrogen offer opportunities for a faster decarbonisation of industry sectors (Climate Analytics, 2019c).

4.3.3 Scenario analysis for scaling up climate action in the industry sector

4.3.3.1 Identification of indicator levels

Table 22 provides an overview of indicator levels identified for the three different scenario categories in the Australia's industry sectors. The upper part presents the respective

[22] https://regenpower.com/news/powering-singapore-sun-cable-project/

benchmarks specified in relevant literature. The lower part shows how these benchmarks were translated into indicator levels to provide input for the PROSPECTS Australia scenario evaluation tool.

Table 22 Overview of different benchmarks specified in the literature and translation into indicator levels for analysis of scaling up climate action in the steel, cement and other industry sector with PROSPECTS Australia scenario evaluation tool

Indicator	National scenarios	Applying best-in-class level(s)	1.5°C compatible scenarios
Iron & Steel			
Production method	According to the scenario analysis by (BZE 2018), foreseeing 100% electrification of Australia's industry sector as well as use of hydrogen for steel production. Share of BOF becomes zero by 2050, while the share of electric arc furnaces and direct reduction with use of hydrogen plays an important role as a new production method. The scenario analysis by (Burdon et al., 2019) also identifies hydrogen (hydrogen-DRI) as a promising alternative to fossil fuels for steel production in Australia. in contrast , the scenario analysis by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) envisages an increase to 42% share of EAF using domestic scrap by 2050. In line with the global IEA projection, a replacement of 50% of coking coal by 2050 with Biomass and the use of Carbon Capture and Storage (CCS), reducing process emissions by 75% by 2050. *Based on* (Beyond Zero Emissions, 2018) *and* (ClimateWorks Australia, Australian National University (ANU), et al., 2014)	According to (Kuramochi et al., 2018) the last conventional blast furnace should be built by 2020. After that low carbon technologies such as direct reduction and electrolysers need to be used in the long-term. *Based on benchmark specified in* (Kuramochi et al., 2018)	
Direct energy fuel mix	According to the scenario analysis by (BZE 2018), zero carbon steel is made with renewable hydrogen as reducing agent, use of natural gas or alternatively hydrogen or synthetic methane as fuel for heating which requires no coal *Based on* (Beyond Zero Emissions, 2018)	*No specifically defined benchmark for Paris Agreement compatibility for direct energy fuel mix in steel industry. Accordingly, fuel mix as defined in the high ambition end of the 'National' scenarios is used.* *Based on (BZE 2018a)*	
Direct energy intensity	*No specifically defined benchmark for to direct energy intensity for 'National Scenarios'. Accordingly, the levels from the 'Reference Scenario' is applied.* .	*No specifically defined benchmark for to direct energy intensity for 'National Scenarios'. Accordingly, the levels from the 'Reference Scenario' is applied.* .	
Electricity intensity	*No specifically defined benchmark for to electricity intensity for 'National Scenarios'. Accordingly, the levels from the 'Reference Scenario' is applied.* .	*No specifically defined benchmark for electricity intensity for 'National Scenarios'. Accordingly, the levels from the 'Reference Scenario' is applied.* .	

Cement		
Clinker substitution	The study conducted by (BZE 2017) outlines how Australia can move to a zero-carbon cement industry. One proposed strategy is to develop high blend-cements with reduced clinker content. Portland cement now includes an average of 20-30% of clinker substitutes but this could be increased to 70% based on the analysis conducted in (BZE 2017). The study conducted by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) also indicates that Clinker substitution can increase to 40% (or more if new technologies are developed) *Based on (BZE 2017) and (CWA 2014)*	*No specifically defined benchmark for Paris Agreement compatibility for clinker substitution ratio. Accordingly, clinker substitution ratio as defined in the most ambitious end of 'National' scenarios is applied.* (BZE 2017).
Production method	*According to the first decarbonisation strategy as proposed by (BZE 2017) for substitution of carbon-intensive limestone-based Portland cement with geopolymer cement involving zero process emissions* *Based on (BZE 2017)*	*According to the strategies proposed by different studies to move towards zero-carbon cement in line with the Paris Agreement temperature target (BZE 2017; WWF 2018) considering substitution of carbon-intensive limestone-based Portland cement with geopolymer cement involving zero process emissions* *Based on (BZE 2017; BZE 2018; WWF 2018)*
Direct energy fuel mix	A shift towards zero-carbon sources of energy plays an important role in achieving zero-carbon cement. As indicated also by various studies like (BZE 2018, Ueckerdt et al. 2019), hydrogen could be used as a fuel in industry sectors which are hard to electrify, like cement. *Based on* (Beyond Zero Emissions, 2018) *and (Ueckerdt et al. 2019)*	A shift towards zero-carbon sources of energy plays an important role in achieving zero-carbon cement according to several studies (Kuramochi et al. 2018; Climate Action Tracker 2017). In (Climate Action Tracker 2017), which looks into decarbonisation of heavy industry as a key to achieve deep cuts in emissions in line with the Paris Agreement's long-term temperature goal. In their most ambitious scneario, they consider 100% renewables in the cement sector to be achieved by 2050. *Based on (CAT 2017; BZE 2018; Kuramochi et al. 2018; Ueckerdt et al. 2019)*
Direct energy intensity	*No specifically defined benchmark for to direct energy intensity for 'National Scenarios'. Accordingly, the levels from the 'Reference Scenario' is applied.* .	The multi-model comparison study conducted in (Edelenbosch et al. 2017) applies different integrated assessment and energy system models to provide a detailed comparison of industrial sector projections over 2010-2050. According to the most ambitious end of their modelled scenarios the direct energy intensity in cement sector reduces by an average rate of -1.31 % p.a.. *Based on* (Edelenbosch et al., 2017)
Electricity intensity	*No specifically defined benchmark for to electricity intensity for 'National Scenarios'. Accordingly, the levels from the 'Reference Scenario' is applied.* .	The study conducted by (WWF 2008) outlines a pathway towards low-carbon cement industry. Based on their measure to reduce the net electrical consumption of all cement plants to 40 kWh/t clinker *Based on* (WWF, 2008)

Other manufacturing industries		
Electrification rate	100% electrification of Australia's industry sector (direct + indirect electrification through use of hydrogen) is envisaged by the study conducted in (BZE 2018). Additionally, the study conducted by (Ueckerdt et al. 2019) considerers a moderate electrification rate of 40% as the lower ambition level in their "NDC Scenario" and 80% electrification rate as the higher ambition level in their "Leadership Scenario".	Renewable/zero-emission electricity can be used to power any industrial heat process. Electrifying industry would enable Australia to become a world leader in energy-intensive, zero-carbon manufacturing. The key role of strong electrification (up to 80%-100% direct as well as indirect electrification through use of hydrogen) has been envisaged by various studies (e.g. BZE 2018; Ueckerdt et al., 2019) as a key strategy to achieve carbon neutrality in Australia's industry sector in line with the Paris Agreement. *Based on* (Beyond Zero Emissions, 2018) *and (Ueckerdt et al. 2019)*
	Based on (Beyond Zero Emissions, 2018) *and (Ueckerdt et al. 2019) for the High Ambition and (Ueckerdt et al. 2019) for the Low Ambition*	
Direct energy fuel mix	The 'Advanced Renewables Scenario' developed by (Teske 2016) foresees 100% share of renewables in Australia's industry sector by 2050.The role of renewable hydrogen and synthetic fuels for (indirect) electrification of industrial heat processes and thus achieving carbon-neutrality in Australia's industry sector has been emphasised for instance in (BZE 2018; Teske 2016). Additionally, in Deep Decarbonisation Pathway from (CWA 2014), most coal and oil use in other manufacturing industreis are shifted to gas. 15 percent of remaining gas use is shifted to biomass.	A shift towards zero-carbon sources of energy plays an important role in achieving zero-carbon industry according to several studies (Kuramochi et al. 2018; Climate Action Tracker 2017). In (Climate Action Tracker 2017), which looks into decarbonisation of heavy industry as a key to achieve deep cuts in emissions inline with the Paris Agreement's long-term temperature goal. *Based on (Teske 2016; CAT 2017; BZE 2018; Kuramochi et al. 2018; Ueckerdt et al. 2019)*
	Based on (Beyond Zero Emissions, 2018) *and (Teske 2016) for the High Ambition and (CWA 2014) for the Low Ambition*	
Process emissions	According to the decarbonisation strategies as proposed by (BZE 2018) for substitution of fossil fuel feedstocks with renewable hydrogen in various industrial processes such as ammonia production to achieve carbon neutrality in Australia's industry sector.	*No specifically defined benchmark for Paris Agreement compatibility for process emission intensity. Accordingly, the process emission intensity as defined in the most ambitious end of 'National scenarios' is used.*
	Based on (Beyond Zero Emissions, 2018) *for the High Ambition*	
Energy efficiency	*No specifically defined benchmark for to direct energy intensity for 'National Scenarios'. Accordingly, the levels from the 'Reference Scenario' is applied.*	Inspired based on the case of UK, having the lowest level of energy intensity in terms of weighted energy consumption per dollar of industrial GDP *Based on* (Castro-Alvarez et al., 2018)

Agriculture, forestry and fishery		
Overall Energy Intensity	*No specifically defined benchmark for to direct energy intensity for 'National Scenarios'. Accordingly, the levels from the 'Reference Scenario' is applied.* .	. Several studies (CEFC 2018; Australian Government 2015) identify opportunities to improve energy efficiency in agriculture sector of Australia by adoption of modern technology and comprehensive use of precision agriculture. The ambition is inspired based on the case of UK, having the lowest level of energy intensity in the industry sector terms of weighted energy consumption per dollar of industrial GDP. *Based on* (Castro-Alvarez et al., 2018)
Electrification rate	*Higher ambition based on the 'Advanced Renewable Scenario' developed by (Teske 2016) which foresees a 100% share of renewables in Australia's industry sector by 2050. Accordingly,* a s-curve is adopted from 2021 onwards for the electrification rate to reach from 7% today to 100% in 2050. *For the lower ambition, the levels from the 'Reference Scenario' is applied.* .	. The 'Advanced Renewables Scenario' developed by (Teske 2016) foresees 100% share of renewables in Australia's industry sector by 2050. Accordingly, a s-curve is adopted from 2021 onwards for the electrification rate to reach from 7% today to 100% in 2050. *Based on (Teske 2016)*
Direct energy fuel mix	*No specifically defined benchmark for to direct energy intensity for 'National Scenarios'. Accordingly, the levels from the 'Reference Scenario' is applied.* .	. Several studies (FAO 2016; CEFC 2018; Australian Government 2015) recommend the adoption of renewable energy technologies such as biomass and solar for electricity and heat generation, as well as other applications like irrigation, pumping, processing and drying. In the higher ambition, the share of biofuels increases gradually in the direct energy fuel mix which is complemented by the corresponding decrease in share of oil. *Inspired from (FAO 2016) for the High Ambition and the levels from the 'Reference Scenario' is applied for the Low Ambition*

Indicator levels for scenario analysis in the PROSPECTS Australia scenario evaluation tool

Indicator		National scenarios	Applying best-in-class level(s) / 1.5°C compatible scenarios
Iron & Steel			
Production method	High ambition / Low ambition	Starting from today's share increasing the share of EAF to **100%** by **2050** and reducing the share of BOF to **0%** by **2050.** Share of BOF: • **51%** by **2030** • **25% by 2040** • **0%** by **2050** Share of EAF-Scrap: • **30%** by **2030** • **36% by 2040** • **42%** by **2050** Share of EAF-DRI: • **19%** by **2030** • **39% by 2040** • **58%** by **2050**	Starting from today's share increasing the share of EAF to **100%** by **2050** and reducing the share of BOF to **0%** by **2050.** Share of BOF: • **51%** by **2030** • **25% by 2040** • **0%** by **2050** Share of EAF-Scrap: • **30%** by **2030** • **36% by 2040** • **42%** by **2050** Share of EAF-DRI: • **19%** by **2030** • **39% by 2040** • **58%** by **2050**
Direct energy fuel mix	High ambition	• Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share reduces to **0%** by **2050**	• Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Biofuel share: **0% (2030); 0% (2040); 0% (2050)**

		• Hydrogen/synthetic fuels share increases from **2030** onwards to **13% (2040)** and **100% (2050)** • Biofuel share: **0% (2030); 0% (2040); 0% (2050)**	• Hydrogen/synthetic fuels share increases from **2030 onwards to 13% (2040) and 100% (2050)**
	Low ambition	• Coal share reduces from today to **9%** (**2030); 4% (2040); 0% (2050)** • Oil share reduces from today **to 3%** (**2030); 2% (2040); 0% (2050)** • Natural gas share increases from today to **88%** by **2030**; **94% (2040)** and **100% (2050)** • Biofuel share: **0% (2030); 0% (2040); 0% (2050)** • Hydrogen/synthetic fuels: **0% (2030); 0% (2040); 0% (2050)**	
Cement			
Clinker to cement ratio	High ambition	The clinker to cement ration reduces from 78% today to: • **70%** by **2030** • **55%** by **2040** • **30%** by **2050**	The clinker to cement ration reduces from 78% today to: • **70%** by **2030** • **55%** by **2040** • **30%** by **2050**
	Low ambition	The clinker to cement ration reduces from 78% today to: • **72%** by **2030** • **63%** by **2040** • **47%** by **2050**	
Process emission intensity	High ambition	The process emission intensity reduces from 0.53 $MtCO_2e$/Mt clinker today to: • **0.35** by **2030** • **0.18** by **2040** • **0** by **2050**	The process emission intensity reduces from 0.53 $MtCO_2e$/Mt clinker today to: • **0.35** by **2030** • **0.18** by **2040** • **0** by **2050**
	Low ambition	Same as 'Reference Scenario	
Direct energy fuel mix	High ambition	• Coal share reduces from today to **0%** by **2050** • Oil share reduces to **0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Biofuels share: **1.5% (2030); 1.4% (2040); 1% (2050)** • Hydrogen/synthetic fuels share increases from **2030** onwards to **24% (2040)** and **99%** by **2050**	• Coal share reduces from today to **0%** by **2050** • Oil share reduces to **0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Biofuels share: **1.5% (2030); 1.4% (2040); 1% (2050)** • Hydrogen/synthetic fuels share increases from 2030 onwards to 24% (2040) and 99% by 2050
	Low ambition	• Coal share reduces from today to **14%** by **2030**, **7%** by **2040** and **0%** by **2050** • Oil share reduces to **5%** by **2030**, **2%** by **2040** and **0%** by **2050** • Natural gas share increases from today to **80%** by **2030**; **89% (2040)** and **99% (2050)** • Biofuels share: **1.5% (2030); 1.4% (2040); 1% (2050)** • Hydrogen/synthetic fuels: **0% (2030); 0% (2040); 0% (2050)**	
Direct energy intensity	High ambition	Same as "Reference scenario"	

improvement rate	Low ambition		Reducing from 3.4 PJ/Mt of clinker today by an average rate of **-0.72% p.a.** applied from 2020 onwards
Electricity intensity improvement rate		Same as “Reference scenario”	Reducing from 0.09 TWh/Mt of cement today by an average rate of **-3.4% p.a.** from 2020 onwards
Other manufacturing industries			
Electrification rate	High ambition	Heavy industry: **2030: 51%** **2040: 67%** **2050: 80%** Light industry: **2030: 35%** **2040: 59%** **2050: 80%**	Heavy industry: **2030: 51%** **2040: 67%** **2050: 80%** Light industry: **2030: 35%** **2040: 59%** **2050: 80%**
	Low ambition	Heavy industry: **2030: 36%** **2040: 38%** **2050: 40%** Light industry: **2030: 23%** **2040: 31%** **2050: 40%**	
Direct energy fuel mix	High ambition	**Heavy industry:** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today to **0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Waste share: **1% (2030); 0% (2040); 0% (2050)** • Biofuels share: **4% (2030); 4% (2040); 4% (2050)** • Hydrogen/synthetic fuels/non-biomass RE share increases from **2030** onwards to **13% (2040)** and **96% (2050)** **Light industry:** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Waste share: **0% (2030); 0% (2040); 0% (2050)** • Biofuels share: **59% (2030); 59% (2040); 59% (2050)** • Hydrogen/synthetic fuels/non-biomass RE share increases from **2030** onwards to **3% (2040)** and **41% (2050)**	**Heavy industry:** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today to **0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Waste share: **1% (2030); 0% (2040); 0% (2050)** • Biofuels share: **4% (2030); 4% (2040); 4% (2050)** • Hydrogen/synthetic fuels/non-biomass RE share increases from **2030** onwards to **13% (2040)** and **96% (2050)** **Light industry:** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share reduces to **0%** by **2050** • Waste share: **0% (2030); 0% (2040); 0% (2050)** • Biofuels share: **59% (2030); 59% (2040); 59% (2050)** • Hydrogen/synthetic fuels/non-biomass RE share increases from **2030** onwards to **3% (2040)** and **41% (2050)**
	Low ambition	**Heavy industry:** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share increases from today to **60% (2030); 72% (2040); 83% (2050)**	

		• Waste: **1% (2030); 1% (2040); 1% (2050)** • Biofuels: **11% (2030); 13% (2040); 16% (2050)** • Hydrogen/synthetic fuels/non-biomass renewables: **0% (2030); 0% (2040); 0% (2050)** **Light industry:** • Coal share reduces from today to **0%** by **2050** • Oil share reduces from today **to 0%** by **2050** • Natural gas share increases from today to **28% (2030); 28% (2040); 29% (2050)** • Waste: **0% (2030); 0% (2040); 0% (2050)** • Biofuels: **61% (2030); 66% (2040); 70% (2050)** • Hydrogen/synthetic fuels/non-biomass renewables**: 0% (2030); 0% (2040) ;0% (2050)**	
Process emissions intensity	High ambition	Reduces from today (91 $MtCO_2e$/US$) to: • **2030: 52** ($MtCO_2e$/US$) • **2040: 26** ($MtCO_2e$/US$) • **2050: 0** ($MtCO_2e$/US$)	Reduces from today (91 $MtCO_2e$/US$) to: • **2030: 52** ($MtCO_2e$/US$) • **2040: 26** ($MtCO_2e$/US$) • **2050: 0** ($MtCO_2e$/US$)
	Low ambition	Same as "Reference scenario"	
Overall energy intensity	High ambition	Same as "Reference scenario"	Reducing from 0.**0036 PJ/million US$ today** by an average rate of **-4.8%** from **2020** onwards.
	Low ambition		
Agriculture, forestry and fishery			
Electrification rate	High ambition	Agriculture, forestry and fishery: **2030: 35%** **2040: 79%** **2050: 100%**	Agriculture, forestry and fishery: **2030: 35%** **2040: 79%** **2050: 100%**
	Low ambition	Same as "Reference scenario"	
Overall energy intensity improvement rate	High ambition	Same as "Reference scenario"	Agriculture, forestry and fishery: Overall energy intensity **0.0041PJ/million US$** reducing at an average rate of **-4.8%** from **2020** onwards.
	Low ambition		

Direct energy fuel mix	High ambition	Same as "Reference scenario"	**Agriculture, forestry and fishery:** • Coal Share: **0% (2030); 0% (2040); 0% (2050)** • Gas Share remains unchanged from **1% today** to **1% (2030); 1% (2040); 1% (2050)** • Oil Share: reduces from **99% today** to **95% (2030); 92% (2040) and 89% (2050)** • Biofuel share increases from **0% today** to **3% (2030); 7% (2040); 10% (2050)** • Waste Share:**0% (2030); 0% (2040); 0% (2050)** • Others Share: **0% (2030); 0% (2040); 0% (2050)**
	Low ambition		

1.5°C Paris Agreement compatible scenarios

According to the analysis conducted by (Kuramochi et al., 2018), in a 1.5°C scenario, industrial emissions need to be reduced by well over 50% from current levels by 2050. According to the analysis conducted by (Kuramochi et al., 2018), total emissions from the iron and steel sector should halve by 2040 as compared to 2013 levels in the 2°C scenario; for 1.5°C scenario it should reduce even earlier. Correspondingly, the last conventional blast furnace should be built by 2020. Afterwards low carbon technologies such as direct reduction and electrolysers need to be deployed in the long-term (Kuramochi et al., 2018). Similar approaches are needed for other sectors, like cement, ammonia and petrochemicals.

However, since this work, the new and much larger collection of 1.5°C scenarios assessed in the Special Report on Global Warming of 1.5°C by the Intergovernmental panel on Climate Change (IPCC SR 1.5, 2019) (see Box 4.1) show a much more urgent picture. These 1.5°C pathways show global energy-related emissions of the industry sector need to be reduced already to 40-55% below 2010 by 2030 and 75-90% by 2050.

The sector also needs to maximise material efficiency to reduce primary material production. Also necessary is further development and rapid introduction of new technologies, phasing out fossil fuels and replacing by zero-carbon renewable energy sources.

Iron & steel manufacturing industry

Paris Agreement compatible deployment of new low carbon technologies in the iron & steel industry are combined with the direct energy fuel mix from the high ambition end of the "National scenario":

- **Production method:** According to (Kuramochi et al., 2018), the last conventional blast furnace will be built in 2020. Correspondingly, the share of conventional steel manufacturing route via blast furnace-basic oxygen furnace (BF-BOF) reaches to zero by 2045/2050 with a 25 to 30-year assumed lifetime. This emission-intensive technology will be replaced by low carbon technologies such as direct reduction and electrolysers. According to this, we assume 100% electrification of Australia's industry sector and use of hydrogen as reducing agent for steel making process to be achieved by 2050. Correspondingly, the share of BF/BOF reduces to zero by 2050, while the share of steel making via electric arc furnaces (both direct reduction and scrap) increases to 100% by 2050.
- **Direct energy fuel mix:** Corresponding to the 'Applying best-in-class levels' and the most ambitious end of 'national scenarios' we assume that the share of coal and other fossil fuels declines to zero by 2050 in line with the phase out of BOF technology in steel industry. Thus, there will be full replacement of fossil fuels in the direct energy consumption of iron and steel industry by renewable hydrogen and synthetic fuels achieved in 2050.

Cement manufacturing industry

Paris Agreement compatible deployment of new low carbon technologies are combined with the clinker substitution ratio and direct energy fuel mix from the most ambitious end of the "National scenarios" as well as direct energy intensity and electricity intensity improvement rates:

- **Clinker substitution:** The clinker to cement ratio reduces from today (78%) to 30% in 2050 corresponding to the most ambitious end of the *'National scenarios'*
- **Process emission intensity:** Various studies raise the necessity to shift from the carbon-intensive Portland cement to new low-carbon technologies, realising the shift to low-carbon cement industry compatible with the Paris Agreement temperature target. One major strategy proposed by different studies (BZE 2017; WWF 2018) is to replace Portland cement with geopolymer cement, which implies zero process-related emissions. This along with the parallel decarbonisation of power sector as well as use of renewables for provision of direct energy consumption in cement industry, makes the zero-carbon cement achievable. For instance, the study conducted in (WWF 2018) indicates 50% uptake of geopolymer cement is possible in 2030 with 100% uptake by 2050. Based on this and also in accordance with the most ambitious end of *'National Scenarios '*we assume the process emissions intensity reduces from today (0.53 $MtCO_2e$ / Mt clinker) to zero emission intensity by 2050 driven by full substitution of Portland cement with geopolymer cement, which implies zero process-related emissions.
- **Direct energy fuel mix:** The role of renewable energy sources and green hydrogen in achieving zero-carbon cement has been emphasised by different studies such as (CAT 2017; BZE 2018; Kuramochi et al. 2018; Ueckerdt et al. 2019). Corresponding to the most ambitious end of the *'National' scenarios'* , we assume that the share of coal and oil declines to zero by 2030. Beyond 2030, the share of natural gas also reduces continuously until full replacement by renewable hydrogen and synthetic fuels achieved in 2050.
- **Direct energy intensity improvement:** The multi-model comparison study conducted in (Edelenbosch et al. 2017) applies different integrated assessment and energy system models to provide a detailed comparison of industrial sector projections over 2010-2050. Inspired from the source, we assume that the direct energy intensity reduces from today (3.4 PJ/Mt of clinker) by an average rate of -0.72 % p.a. which is about twice the average annual growth rate in the reference scenario.
- **Electricity intensity improvement:** By reducing electricity intensity of cement plants, further emission reductions can be achieved. The study conducted by (WWF 2008) outlines a pathway towards low-carbon cement industry. Based on their measure to reduce the net electrical consumption of all cement plants to 40 kWh/ t clinker, we apply an average electricity intensity reduction rate of -3.4 % p.a. from 2020 onwards.

Other manufacturing industries

Paris Agreement compatible deployment of new low carbon technologies and strong electrification of Australia's industry sector are combined with the energy intensity improvement and direct energy fuel mix from the "Applying best-in-class-levels" and most ambitious end of the "National scenarios" as well as phasing out process emissions by replacing fossil fuel feedstocks with green hydrogen in various industrial processes such as in ammonia production and petrochemicals:

- **Electrification rate:** We assume 80% direct electrification rate to be achieved in 2050 according to the most ambitious end of the "National Scenarios". Please see in addition the increasing share of hydrogen below under the direct energy fuel mix, which leads to near full electrification (direct use of electricity and indirect electrification through use of hydrogen) of Australia's industry sector (up to about 90%) by 2050. The "High Ambition" case in the National Scenario is also consistent with the Advanced Renewables Scenario based on Teske et al., 2016. The Advanced Renewables Scenario assumes a 100% renewable energy supply by 2050. And hydrogen serves as an additional renewable fuel option, supplementing biomass in industrial processes, whenever direct use of renewable electricity is not applicable.
- **Direct energy fuel mix:** The role of renewable energy sources and hydrogen in achieving zero-carbon industry sector has been emphasised by different studies such as (Teske et al., 2016; CAT 2017; BZE 2018; Kuramochi et al. 2018; Ueckerdt et al. 2019).

Corresponding to the most ambitious end of the *'National' scenarios'*, we assume that the share of coal and oil declines to zero by 2050. Beyond 2030, the share of natural gas also reduces continuously until full replacement by hydrogen and other renewable alternatives achieved in 2050. The share of biomass remains limited respecting the maximum total potential (please see the *"National Scenarios"* for further details)

- **Process emissions intensity:** According to the most ambitious end of the "National Scenarios" with respect to substitution of fossil fuel feedstocks with bioenergy and in particular renewable hydrogen in various industrial processes such as ammonia production and petrochemicals to achieve carbon neutrality in Australia's industry sector, we assume that the process emissions intensity declines from today (91 $MtCO_2e$/US$) to zero by 2050.

- **Overall energy intensity:** According to the "Applying best-in-class levels", we assume that the overall energy intensity in Australia's industry sector reduces from today (0.00363 PJ/million US$) by an average rate of -4.82% from 2020 onwards.

National scenarios

Iron & steel manufacturing industry

Based on the analysis conducted by (Beyond Zero Emissions, 2018), using renewable hydrogen as the reducing agent and natural gas as the fuel source, steel-related emissions can be reduced by up to 90%. Zero-carbon steel can be made by using renewable hydrogen as fuel or by electrifying heat processes. It has been emphasised by (Beyond Zero Emissions, 2018) that Australia has an opportunity to become a pioneering producer of zero carbon steel. The scenario analysis conducted by the Australian-German Energy Transition Hub (Burdon et al., 2019) also identifies renewable hydrogen as a promising alternative to fossil fuels for steel production in Australia. It gives the example of four European steelmakers producing steel through the hydrogen-DRI process.

An earlier scenario analysis conducted by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) is more conservative, not foreseeing replacing the Blast Furnace technology but mainly assuming an increase in use of domestic steel scrap and corresponding increase in steel production by Electric Arc Furnaces (EAF) to 42% by 2050, in line with the IEA business as usual projection of an increase in share of recycled materials in iron and steel production from a third today to slightly over 50 percent by 2050. In addition, (ClimateWorks Australia, Australian National University (ANU), et al., 2014) assumes replacing 50% of coking coal by charcoal made from biomass by 2050, and the use of Carbon Capture and Storage (CCS).

The following indicators has been derived from different literature sources and considered for the implementation of "National Scenarios" in the PROSPECTS scenario evaluation tool:

- **Production method:** According to the scenario analysis by (BZE 2018), foreseeing 100% electrification of Australia's industry sector as well as use of hydrogen as reducing agent for steel making process, we assume that the share of BF-BOF reduces to zero by 2050, while the share of steelmaking via electric arc furnaces (both direct reduction and scrap) increases to 100% by 2050. Additionally, we assume the share of EAF-scrap increases from today (23%) to 42% by 2050 according to (ClimateWorks Australia, Australian National University (ANU), et al., 2014). Correspondingly, in our scenario, the share of BOF/BF reduces from today to 51% (2030); 25% (2040) and 0% (2050). The share of EAF-scrap increases from today (23%) to 30% by 2030, 36% by 2040 and 42% by 2050. The share of EAF-DRI starts increasing from 2020 onwards, reaching to 19% by 2030, 39% by 2040 and 58% by 2050.

- **Direct energy fuel mix:** According to the scenario analysis by (BZE 2018), zero carbon steel is made with renewable hydrogen as reducing agent, use of natural gas or alternatively synthetic methane as fuel for heating which requires no coal. According to this, for the "High ambition" scenario, we assume that the share of fossil fuels in steelmaking process reduces to zero by 2050. This can be realised for instance by applying the Circored technology using renewable hydrogen as reducing agent and use of synthetic fuels (e.g. hydrogen, renewable methane) for provision of heat. Thus, we assume that the share of coal and oil declines to zero by 2050. Beyond 2030, the share of natural gas reduces continuously until full replacement by renewable hydrogen and synthetic fuels achieved in 2050. For the “Low ambition” scenario, we assume that coal will be fully replaced by natural gas in 2050; renewable hydrogen is thus used in the Circored technology as reducing agent, but natural gas is still used for heating. Additionally, the share of biofuels in Australia’s steel industry today is negligible (0%). Therefore, in both the low and high ambition scenario we do not consider an increasing role of biofuels in the steel industry due to potential challenges with regard to interferences with food supply as well as competing application areas such as particular modes of transport with limited electrification potential (heavy duty vehicles, aviation and shipping), other industry sectors and corresponding uncertainties about the sustainable potential of biomass available to steel industry.

Cement manufacturing industry

Currently, the standard cement type is limestone-derived Portland cement, which is quite carbon-intensive process. In Australia, production of Portland cement is responsible for 7.4 million tonnes of emissions, about 1.3% of national emissions (BZE 2017).

The study conducted by (BZE 2017) outlines how Australia can move to a zero-carbon cement industry. One proposed strategy is to develop high blend-cements with reduced clinker content. Portland cement now includes an average of 20-30% of clinker substitutes but this could be increased to 70% based on the analysis conducted by (BZE 2017).

Another proposed strategy is to shift to geopolymer cement, as chemical reactions involved in making geopolymer cement do not generate any CO_2 or other greenhouse gases in contrast to the carbon-intensive process of producing Portland cement from limestone. Thus, geopolymer cement involves zero process-related emissions (accounting for more than 50% of cement-related emissions). By applying zero carbon sources of energy instead of burning fossil fuels and decarbonisation of electricity, direct energy and electricity-related emissions could also be removed and thus zero-carbon cement becomes feasible. Concerning the performance, concrete made with geopolymer cement matches the performance of Portland cement concrete, and meets the requirements of Australian standards (BZE 2017). Additionally, geopolymer cement provides several performance advantages and is thus a better option that could be used instead of Portland cement.

Currently most commercially available geopolymer cement is made from two raw materials: fly ash as by-product of coal-fired plants and slag as by product of iron blast furnaces, whose availability could be restricted in the future if the steel sector and the power sector were to be decarbonised. However, geopolymers can be made with almost any material with a high enough content of aluminosilicates, while silicon and aluminium are the second and third most abundant elements, and so abundant natural sources exist in Australia, making the production of large quantities of geopolymer cement possible.

Finally, shift towards zero-carbon sources of energy plays an important role in achieving zero-carbon cement. As indicated also by other studies (BZE 2018, Ueckerdt et al. 2019), hydrogen could be used as fuel in industry sectors which are hard to electrify, like cement.

The following indicators has been derived from different literature sources and considered for the implementation of “National Scenarios” in the PROSPECTS scenario evaluation tool:

- **Clinker substitution:** Based on the potential to replace clinker by 70% according to the second strategy as outlined in (BZE 2017), in the ”High Ambition” case we assume that the clinker to cement ratio reduces from today (78%) to 30% by 2050, following a s-curve trajectory. For the “Low Ambition” case based on the study conducted by (ClimateWorks Australia, Australian National University (ANU), et al., 2014) we assume that the clinker to cement ratio reduces from today (78%) to 47% by 2050.
- **Process emission intensity:** According to the first strategy as proposed by (BZE 2017) for substitution of carbon-intensive limestone-based Portland cement with geopolymer cement as well as new materials as proposed by (BZE 2018) to realise the shift to low-carbon industry, in the “Higher Ambition” case we assume that the process emissions intensity reduces from today (0.53 $MtCO_2e$ / Mt clinker) to zero by 2050 based on full substitution of Portland cement with geopolymer cement, which involves zero process-

related emissions. For the “Lower Ambition” scenario is assumed that the limestone-based Portland cement will be dominating the cement manufacturing industry also in the future with clinker substitution and the use of renewable energies and zero-carbon synthetic fuels as the two major mitigation measures applied to decarbonise the Australia’s cement industry.

- **Direct energy fuel mix:** Based on the role of renewable hydrogen in achieving zero-carbon cement as emphasised by different studies such as (BZE 2018, Ueckerdt et al. 2019), for the “High ambition” scenario, we assume that the share of fossil fuels in the direct energy fuel mix reduces to zero by 2050. The share of coal and oil declines to zero by 2050. Beyond 2030, the share of natural gas reduces continuously until full replacement by renewable hydrogen and synthetic fuels achieved in 2050. For the “Low ambition” scenario, we assume that coal will be fully replaced by natural gas in 2050; use of renewable hydrogen for provision of industrial heat processes is thus not included in the low ambition case. Additionally, the current share of biofuels in Australia’s cement industry is relatively low (2.5%). Therefore, in both the low and high ambition scenario we do not consider an increasing role of biofuels in the cement industry due to potential challenges with regard to interferences with food supply as well as competing application areas such as particular modes of transport with limited electrification possibilities (heavy duty vehicles, aviation and shipping), other industry sectors and corresponding uncertainties about the sustainable potential of biomass available to cement industry.

Other manufacturing industries

Electrification of Australia’s industry sector, which currently rely on burning fossil fuels, through direct use of cheap renewable electricity provided by abundant renewable sources in Australia can eliminate major part of emissions occurring from industrial heat processes[23]. By switching to electrical heating, it is also possible to double the efficiency of many industrial processes (BZE 2018). This is mainly due to the capability of electrical heating technologies (e.g. industrial heat pumps, electromagnetic heating, electrical resistance, electric arc heating) to deliver heat at the precise temperature needed and not higher, transfer heat directly to material, providing heat at the point of use so minimising distribution losses. Alternatively, an indirect route to electrifying industry can be followed by using synthetic fuels and renewable hydrogen (produced by water electrolysis using renewable electricity) for provision of heat. In addition, renewable hydrogen provides an alternative to fossil fuel feedstocks in various industrial processes such as the production of ammonia and a range of organic chemicals, further eliminating the process-related emissions.

The following indicators has been derived from different literature sources (Ueckerdt et al., 2019; BZE 2018; Teske 2016; CWA 2014) and considered for the implementation of “National Scenarios” in the PROSPECTS scenario evaluation tool:

- **Electrification rate:** For the “High Ambition” case we assume 80% direct electrification rate to be achieved in 2050 according to the “Leadership Scenario” as the most ambitious range of electrification rate of Australia’s industry sector based on (Ueckerdt et al., 2019). This is also in line with the full electrification of Australia’s industry sector (direct use of electricity and indirect electrification through use of hydrogen) according to the study conducted in (BZE 2018)[24]. For the “Low Ambition” case, we consider a moderate electrification rate of 40% based on the “NDC Scenario” from (Ueckerdt et al., 2019). Additionally, in the ‘Advanced Renewables Scenario’ by (Teske et al., 2016), the electricity use doubles by 2050 to replace direct fuel consumption. This scenario foresees an electrification rate (direct and indirect electrification via hydrogen) of 56% in total Australia’s industry sector by 2050. This already lies within the range we considered for the modelling of the high and low ambition end of ‘National Scenarios’.

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[23] Every year in Australia burning fossil fuels for industrial heat processes produces 42 million tonnes of carbon dioxide – 8% of the national total (BZE 2018).

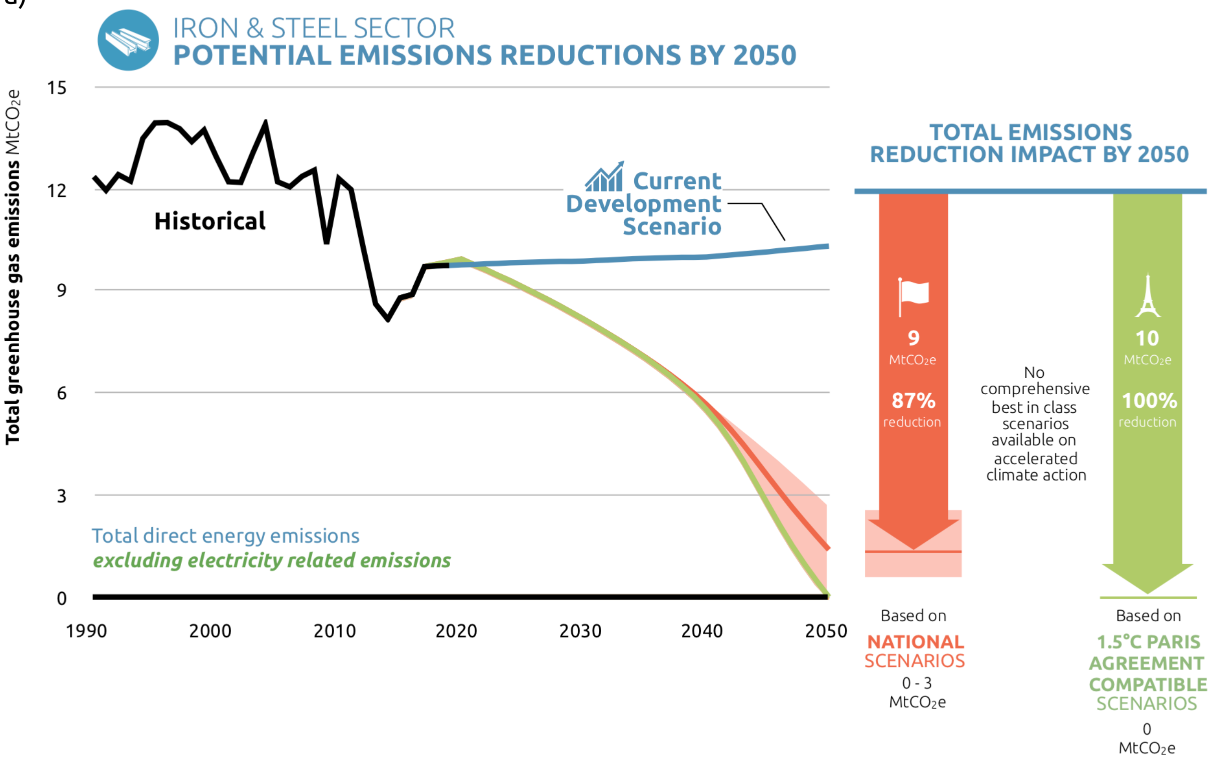
[24] please see in addition the increasing share of hydrogen below under the direct energy fuel mix, which leads to near full electrification of Australia’s industry sector (up to about 90%) by 2050 in our “High Ambition” case.

- **Direct energy fuel mix:** The 'Advanced Renewable Scenario' developed in (Teske at al., 2016) foresees that the supply of energy in Australia's total industry sector could achieve 100% renewables by 2050. The role of renewable hydrogen and synthetic fuels for (indirect) electrification of industrial heat processes to achieve carbon-neutrality in Australia's industry sector has been emphasised in different studies, for instance by (BZE 2018; Teske 2016). Other renewable alternatives include bioenergy and industrial solar thermal. However, the potential of these alternatives is limited. Bioenergy currently provides about 115 PJ of the energy used in Australia's manufacturing sector (IEA 2017). According to the analysis conducted in (BZE 2018), a quarter of Australia's unexploited bioenergy could become available to industry, equal to an additional 112 PJ, i.e. more or less doubling bioenergy use from today. Additionally, solar thermal technologies, has the potential to displace about 22% of fossil fuels currently used in industrial heat processes. Based on these, for the "High ambition" scenario, we assume that the share of fossil fuels reduces to zero by 2050. Beyond 2030, the share of natural gas reduces continuously until full replacement by renewable hydrogen and synthetic fuels achieved in 2050. The share of biomass remains limited respecting the maximum total potential as elaborated above. For the "Low ambition" scenario, we assume that most coal and oil use in other manufacturing could be switched to gas, and that 15 percent of remaining gas use could be shifted to biomass/biogas in manufacturing according to the scenario analysis conducted in (CWA 2014). Renewable hydrogen and synthetic fuels are thus not taken into account in the lower ambition scenario; biomass use peaks at 200 PJ/year, remaining below the maximum sustainable potential available to industry as elaborated above.
- **Process emissions intensity:** According to the decarbonisation strategies as proposed by (BZE 2018) for substitution of fossil fuel feedstocks with bioenergy and in particular renewable hydrogen in various industrial processes such as ammonia production to achieve carbon neutrality in Australia's industry sector, for the "Higher Ambition" case we assume that the process emissions intensity declines from today (91 $MtCO_2e$/US$) to zero by 2050. For the "Low Ambition" case we assume that the process emissions intensity remains constant over time as in the "Reference Scenario".

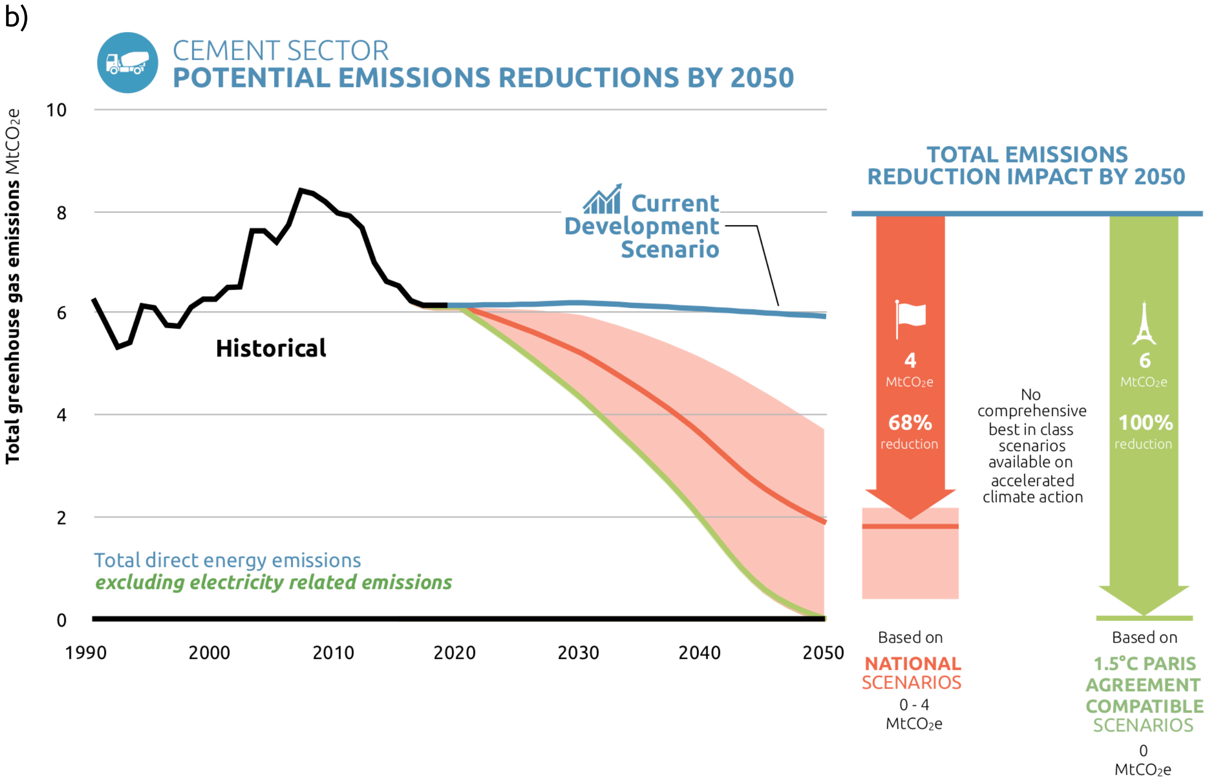
It is worth mentioning that in our scaled climate action scenarios, we do not take into account the Carbon Capture and Storage (CCS) as a viable strategy that can be applied at the large-scale needed for achieving low-carbon industry due to high costs which makes this option a less competitive strategy in the market against integration of renewable energies and zero-carbon synthetic fuels such as renewable hydrogen that could be produced from water electrolysis of cheap excess renewable power. Adding CCS to a new cement plant for instance would double both capital and operating costs, (BZE 2017). Another important barrier to its implementation is the need for availability of local geological formations for storing carbon dioxide. Even with availability of such formation near to the plant, the long-term behaviour and security of the stored carbon dioxide is not well understood and is subject to uncertainty. Leakage during capture and transportation add to the risk and would have to be compensated.

4.3.3.2 Quantification of emission levels with PROSPECTS Australia

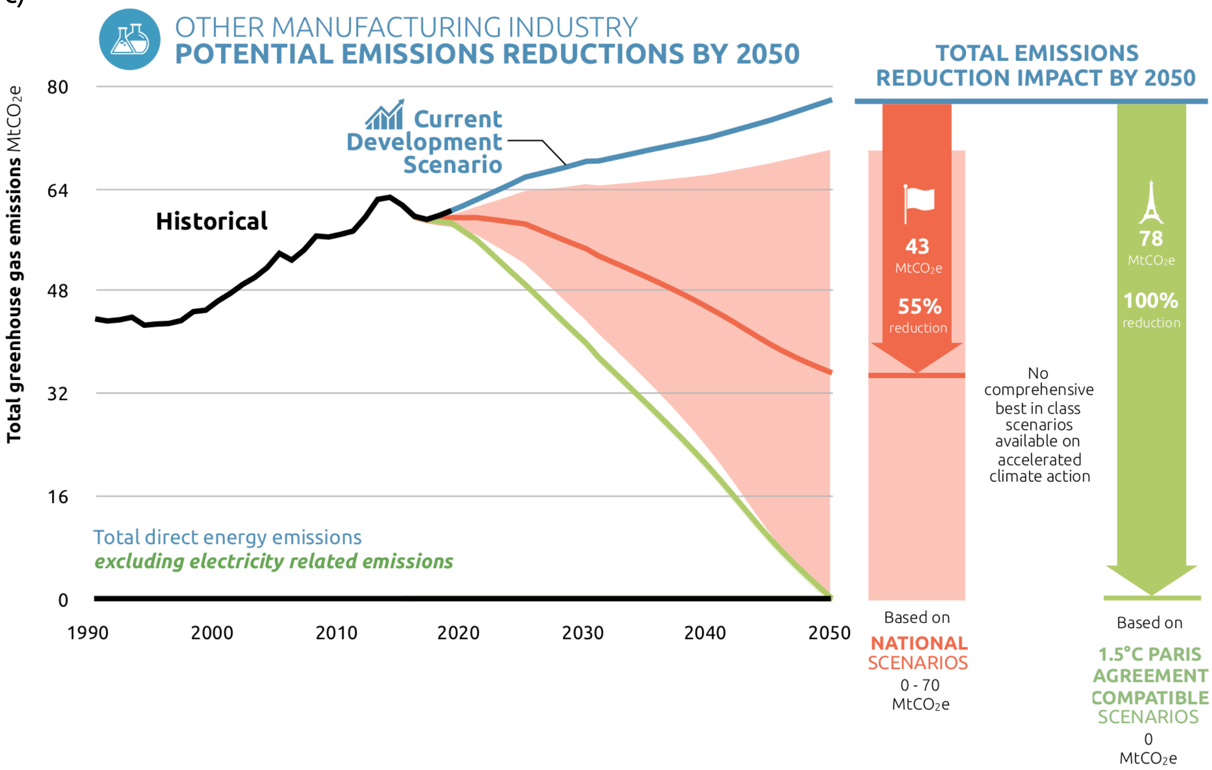
a)



b)



c)



d)

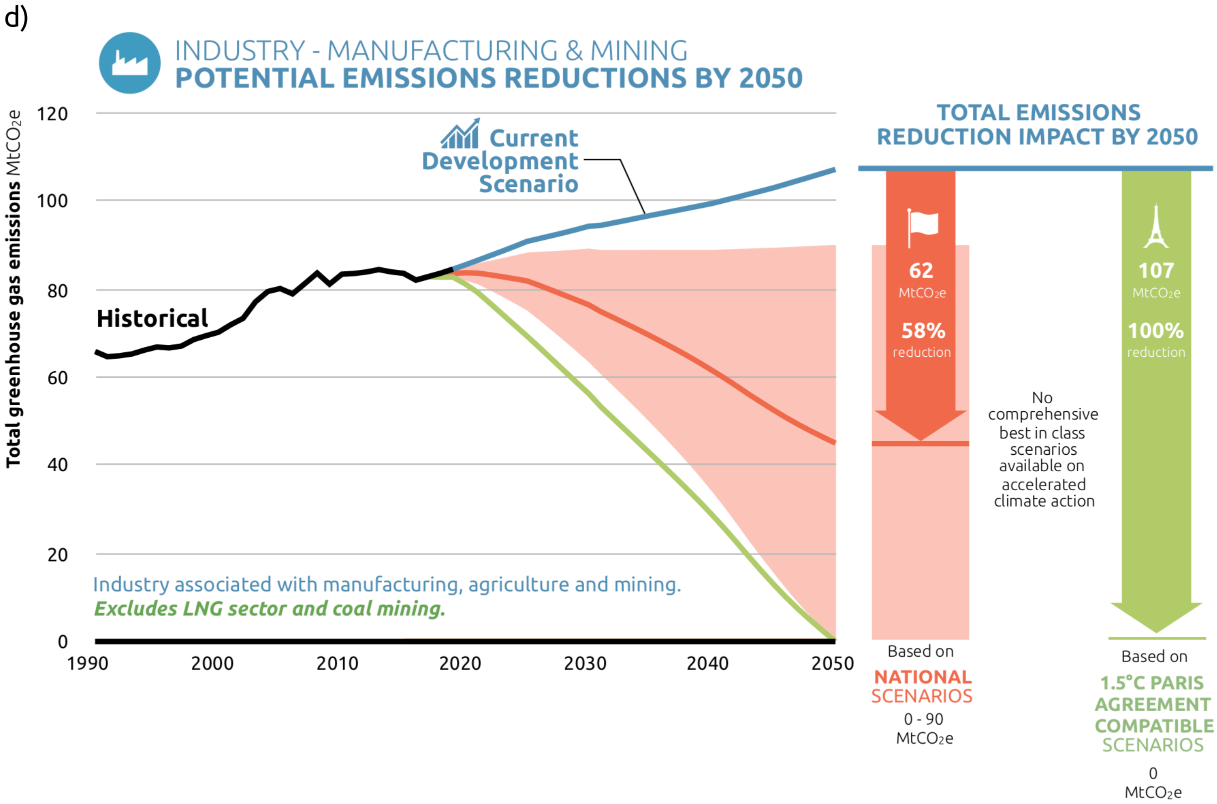


Figure 32 Overview of sectoral emission pathways under Reference scenario projections and different levels of accelerated climate action in Australia's industry sector excluding electricity-related emissions: (a) Iron & Steel (b) Cement (c) Other industry (d) Total industry (Manufacturing, agriculture, mining, without LNG sector and without coal mining).

Figure 32 a) illustrates the emissions trajectories from Australia's iron & steel industry until 2050 for different scenario categories, while enhanced climate action in the steel sector is further combined with decarbonisation of the electricity sector. This reveals how by applying mitigation measures on the demand side such as increasing the share of steel production via electric arc furnace route, phase out of coal followed by gas and other fossil fuels through replacement with hydrogen generated by water electrolysis combined with a simultaneous decarbonisation of the electricity sector, significant reduction of emissions can be achieved by mid-century.

The DEE projections covering the industrial process and product use emissions from metal industry, including iron and Steel and aluminium (excl. electricity-related emissions), show emissions of about 11 $MtCO_2e/a$ in 2030, i.e. 24% below 2005 (Australian Department of the Environment and Energy (DEE)., 2019a). For comparison, the Reference Scenario results in emissions from Australia's iron and steel industry (excluding electricity-related emissions) is about 10 $MtCO_2e/a$[25] in 2030, i.e. 19% below 2005 levels[26].

All scaled-up climate action pathways imply much further emissions reductions in the iron & steel industry far beyond the reference scenario projections:

- The '**1.5°C Paris Agreement compatible'** pathway substantially reduces emissions and leads to the full decarbonisation of the iron & steel industry by 2050. This is mainly driven by the strong increase of steel production via EAF route as well as phasing out fossil fuels replaced by increasing share of renewable-based hydrogen and synthetic fuels.
- The '**National scenarios'** pathway reveals a broader range across the upper and lower ambition end. The high ambition end implies a full decarbonisation of iron & steel sector by mid-century. The upper trajectory reduces emissions to around zero in 2050, i.e. around 10 $MtCO_2e/a$ below reference scenario projections.

The DEE projections covering the industrial process and product use emissions from mineral industry, including cement, clinker and lime industry (excl. electricity-related emissions), show emissions of about 5.4 $MtCO_2/a$ in 2030, i.e. 17% below 2005 (Australian Department of the Environment and Energy (DEE)., 2019a). Similarly, the Reference Scenario results in emissions from Australia's cement industry (excluding electricity-related emissions) is about 6.2 $MtCO_2/a$ in 2030, i.e. 16% below 2005 levels.[27]

All scaled-up climate action pathways imply much further emissions reductions in the cement industry far beyond the reference scenario projections:

- The '**1.5°C Paris Agreement compatible'** pathway substantially reduces emissions and leads to the full decarbonisation of the cement industry by 2050. This is mainly driven by the penetration of geopolymer cement as a replacement to the carbon-intensive process of making Portland cement as well as phasing out fossil fuels replaced by increasing share of renewable-based synthetic fuels such as hydrogen. Increasing the clinker substitution ratio plays an important role to reduce emissions from Portland Cement in the short-term before being replaced by less carbon-intensive alternatives. Reducing the direct energy and electricity intensity are further measures contributing to the green cement industry in line with the Paris Agreement temperature target.
- The '**National scenarios'** pathway reveals a broader range across the upper and lower ambition end. The high ambition end implies a full decarbonisation of cement sector by mid-century. The upper trajectory reduces emissions to net zero in 2050, i.e. 6 $MtCO_2e/a$ below reference scenario projections.

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25 The reported values by (Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a)(Australian Department of the Environment and Energy (DEE)., 2019a) additionally includes the aluminum sector, which is not covered in our calculations for the steel sector.

26 Derived from Category 1A2a+2C-2C3-2C7 in http://ageis.climatechange.gov.au/

27 Category 1A2fi+2A1 from http://ageis.climatechange.gov.au/.

Figure 32 (c) illustrates the emissions trajectories from Australia's other manufacturing industry until 2050 for different scenario categories, combining scaled up climate action in the other sector with decarbonisation of the electricity sector. The Reference Scenario results in emissions from Australia's other manufacturing industry (excluding electricity-related emissions) to reach to 68 $MtCO_2e$/a and 78 $MtCO_2e$/a by 2030 and 2050 respectively, i.e. 26% and 44% above 2005 levels. All scaled-up climate action pathways imply much further emissions reductions in the other manufacturing industries far beyond the reference scenario projections:

- The '**1.5°C Paris Agreement compatible'** pathway substantially reduces emissions and leads to the full decarbonisation of the other industry by 2050. This is mainly driven by the strong electrification as well as phasing out fossil fuels replaced by increasing share of hydrogen and other renewable alternatives.
- The '**National scenarios'** pathway reveals a broader range across the upper and lower ambition end. The high ambition end implies a full decarbonisation of other manufacturing industry sector by mid-century. The upper trajectory reduces emissions to around zero in 2050, i.e. 95 $MtCO_2e$/a below reference scenario projections.

The Green and Gold scenario of the ANO 2019 (Brinsmead et al., 2019) project a slightly above 1% annual improvement in energy efficiency across the agriculture, energy intensive manufacturing and other industries (Brinsmead et al., 2019). Our Paris compatible scenario shows Australia following the example of global forerunners such as the UK and improve the energy intensity in the industry sector quite significantly at an average annual rate between 4% and 5% (Castro-Alvarez et al., 2018).

4.4 Electricity supply

All deeper transformations in demand sectors addressed in the previous subsections have implications for increased electricity supply either through direct electrification (e.g. use of electric vehicles, replace gas heating with heat pumps) or indirect through Power-to-gas/Power-to-liquid fuels technologies, for instance use of hydrogen produced via renewable electrolysis.

Table 23 provides an overview of the analysis results for scaling up climate action in the Australian electricity supply sector. The table's upper graph presents the value ranges for the RES indicator for each of the three scenario categories.

Figure 33 (a) displays emission trajectories for all scenario categories.

Table 23 Outcome overview of analysis on scaling up climate action in Australia's electricity sector shown is the percentage share of Renewable energy in total generation.

Reference Scenario (REF)	National scenarios	Best-in-class scenarios	1.5°C Paris Agreement Compatible scenario
13% by 2015	-	-	
53% by 2030	59-84% by 2030	97% by 2030	
79% by 2040	82-99% by 2040	100% by 2040	
89% by 2050	92-100% by 2050	100% by 2050	
Based on AUSeMOSYS developed by Climate Analytics (Aboumahboub 2020)	*Based on 'Advanced Renewables' Scenario by (Teske et al. 2016) for the High ambition case and 'Fast Change Scenario' by* (AEMO, 2018a) *for the Low ambition case*	*Based on AUSeMOSYS developed by Climate Analytics (Tina Aboumahboub et al., 2020; Tino Aboumahboub, Brecha, Gidden, et al., 2020)*	

Required policy measures for sectoral transformation	**Remaining challenges threatening implementation**
⇨ Promote the uptake of renewable energy, ensuring policy continuity and government support. In particular, introduce renewable	⇨ Policy backtracking such as downgrading the renewable energy target has led to investor uncertainty.

energy targets for beyond 2020 and plan for a 100% renewable energy transition by 2040 taking into account increased demand for electrification of end use sectors and potential export opportunities.

⇨ Phase out coal by 2030, with a strategy to address the 'just transition' from coal mining and electricity generation.

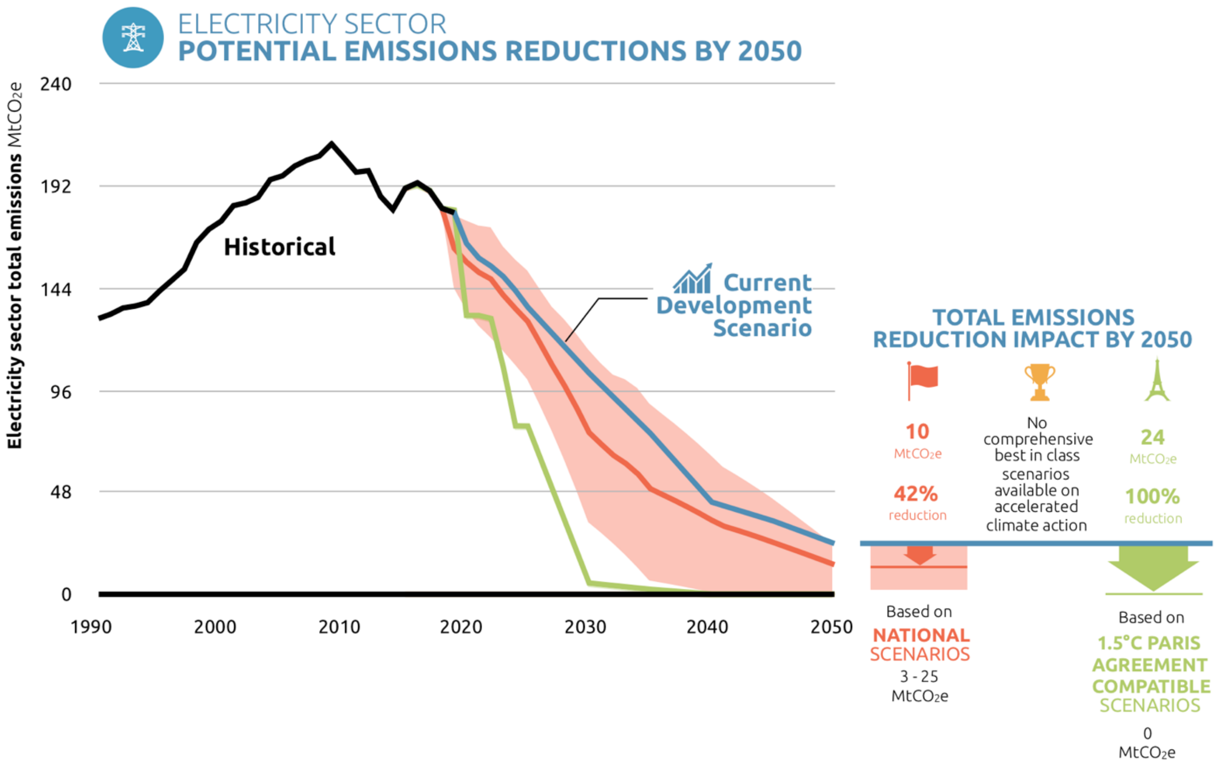
⇨ Grid infrastructure investment for the National Energy Market (NEM) and other energy markets to ensure effective transmission, along with demand management and storage.

⇨ There are misconceptions from politicians and commentators about the ability to address variability of renewables.

⇨ Continuing support and subsidies for fossil fuels creates an unfair advantage for the fossil fuel industry, detrimental to the competing renewable energy industry.

Policy support for coal results in the continuation of outdated polluting coal power stations.

Lack of strategy and targets inhibits planning for improved transmission grids and access, leading to curtailment, connection delays as well as reduced investments.



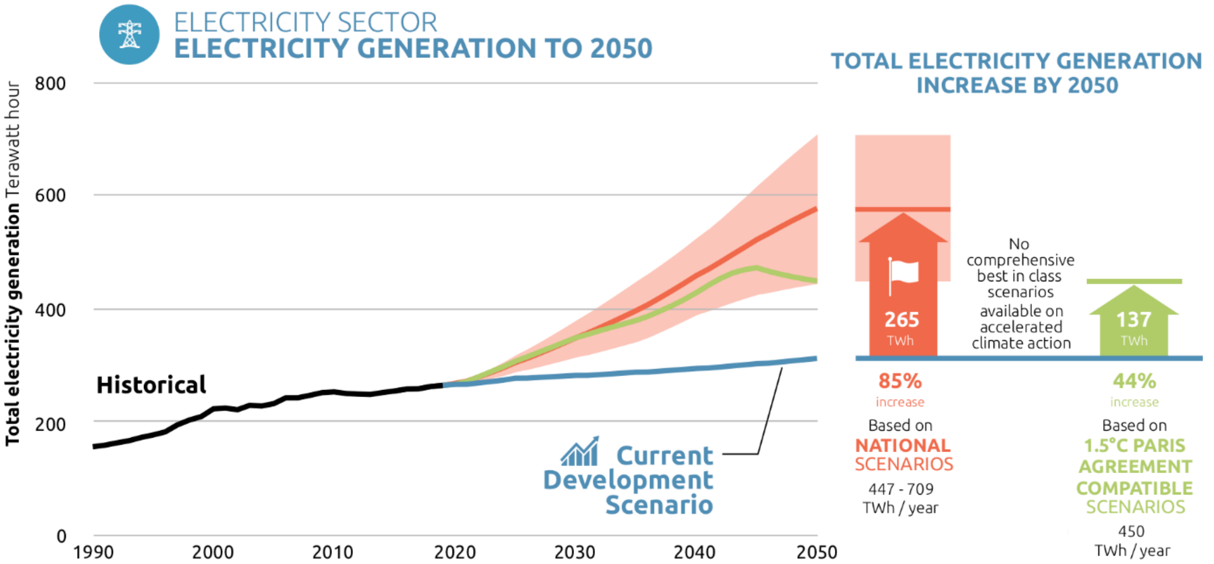


Figure 33 (a) Overview of sectoral emission pathways under reference scenario projections and different levels of accelerated climate action in the Australia's electricity supply. The electricity-related emissions from end-use sectors are included. (b) The projected electricity demand considers accelerated climate action in the Australia's residential buildings, commercial buildings, passenger transport including domestic aviation as well as freight transport and industry sectors.

4.4.1 Context for scaling up climate action in the electricity sector

Saving costs through increasing share in renewables generation

Australia has aging coal fired power stations with many drawing closer to their end of operating life (Burke, Best, & Jotzo, 2018). In Australia, the last power station was built in 2010, 12 power station closed between 2012 and 2017, and there are no new plans for power stations on the horizon (Burke et al., 2018). With a median lifespan of 43 years (Burke et al., 2018), the remaining power stations will need to be replaced in coming decades with other power options.

Increasingly high electricity prices are a politically charged issue in Australia. A report by the Grattan Institute found that misconceptions about renewables on electricity reliability creates hasty reactions by policy makers creating electricity bill rises (Wood, Dundas, & Percival, 2019). Another report by the Climate Change Authority observed that policy uncertainty and changes in policy direction has affected investment, risks to the reliability of energy and increases electricity prices (CCA, 2017b). In fact, the Australian Energy Market Commission reports that electricity prices are set to fall in the near future due to flat demand and the new renewable energy supply added to the grid (AEMC, 2019).

Renewable energy is the lowest cost option for energy in Australia. Studies by the CSIRO and the AEMO (Australian Energy Market Operator) have found that for any further new build option, renewables offers the lowest cost option for electricity generation when including storage as compared to coal power with further reduced cost estimates for wind and solar in a more recent study (Graham, Hayward, Foster, & Havas, 2019; Graham, Hayward, Foster, Story, & Havas, 2018). IRENA finds that in most parts of the world, renewables offers the cheapest source of new generation (IRENA, 2018). The costs of renewables are in decline globally, and renewables are expected to decline in price further, especially solar and wind (IRENA, 2018). Solar PV and wind are close to costing less than the costs of operating *existing* coal fired plants (IRENA, 2018). By 2020, 77% of onshore wind and 83% of utility scale solar PV projects capacity will produce cheaper electricity than any coal, oil or natural gas options (IRENA, 2018).

Government support and subsidies for fossil fuels

A major issue is that government subsidies and support for the fossil fuel industry are creating an unfair playing field for the renewable energy market. The Australian tax-based subsidies supporting fossil fuel industry amount to over $12 billion per year based on estimates from the Australia federal government's budgets (Market Forces, 2019). In addition, there has been numerous projects and funding to advance the so called "clean" coal industry, including The Low Emissions Technologies for Fossil Fuels (LETFF) programs (DIIS, 2019c). Government support and subsidies instead of necessary phase out of coal and the renewable energy transition.

Integration of variable sources of energy

Transitioning from fossil fuels to mainly wind and solar energy creates challenges in balancing electricity supply and demand. However, the Grattan Institute found that despite the misconceptions from politicians and commentators, renewable energy has made the energy system more reliable, and that issues with transporting and distributing electricity generated creates the most outages (Wood et al., 2019). Battery storage technology has been successfully implemented in different locations across Australia, helping to manage the variable sources of energy. For example, the Hornsdale battery in South Australia offers dispatchable renewable power to stabilise the South Australian grid. Other large storage projects include Snowy pumped hydro project, and Tasmania's Battery of the Nation project.

Dispersed electricity generation places pressures on the transmission networks. The transmission networks were designed to connect large generators to demand centres. Installing renewable energy often involves smaller but more numerous generation sites requiring the transmission systems to be updated to increase the capability of the system to ensure flexibility and security of power (Clean Energy Council, 2019a). The Energy Market Operator (AEMO) have provided detailed analysis for an Integrated System Plan (ISP) to improve the National Electricity Market (NEM), which covers the eastern and southern Australian states (Clean Energy Council, 2019a) but a lack of federal strategy leads to a lack of planning towards larger shares of renewable energy .

Job benefits

Renewable energy investment has brought record levels of renewable energy jobs in Australia. In 2018, renewables accounted for over 10,000 jobs in construction, nearly 3000 jobs in operations and maintenance and over 6000 in solar rooftop installation (Clean Energy Council, 2019a). Renewable energy provides more employment then fossil fuel electricity generation in Australia (Clean Energy Council, 2019a). There is also a move to renewables from the business sector, with onsite generation and power purchase agreements (Clean Energy Council, 2019a). The closure of coal fired power plants has sparked discourse on a 'just transition' from coal to renewables in Australia. In Australia, coal power stations are located close to coal fields in rural areas, so the surrounding economies are reliant on the coal industry and there are less prospects for the workers in the local area, once power stations close (Maher, 2017). Furthermore, the relatively high paid workers have implications for the local economy as salary spent creates benefits for other industries (Maher, 2017). The closure of the Hazelwood coal-fired power station in Latrobe Valley, Victoria, created issues as the power station employed 750 workers. The Latrobe Valley Worker Transfer Scheme was created after the closure announcement to minimise the impacts of the closure. The scheme aimed to employ 150 Hazelwood workers by end of March 2019, but had only employed 90 by mid-March (Latrobe Valley Express, 2019). Collie is a regional town in Western Australia with three aging coal power plants and coal mines. The Western Australia Labor Government is consulting coal mining and electricity companies, unions, and community leaders to develop plans to address the just transition for workers in the town of Collie (Department of Treasury, 2019). The national government needs to decide a plan for phasing out aging coal power station fleet closures to minimise the effects on fossil fuel based regional communities.

4.4.2 Scenario analysis for scaling up climate action in the electricity sector

4.4.2.1 Identification of indicator levels

Table 24 presents the value ranges for the RES indicator for each of the three scenario categories. The indicator levels have been directly input into the PROSPECTS Australia scenario evaluation tool to conduct the emission pathway analysis for the Australia's electricity supply sector. The indicator levels for the 'Reference Scenario' as well as 'Paris Agreement' and 'Applying best-in-class levels' are the result of the model-based scenario analysis for the electricity supply taking into account the electricity demand for the end-use sectors analysed in sections 4.1 to 4.3. In addition, a range of indicator levels has been derived from the analysis of existing national scenarios published in the literature.

For the scenario analysis of electricity supply sector, we apply the AUStralian energy MOdelling SYStem (AUSeMOSYS), developed by Climate Analytics based on the current version of the Open Source energy MOdelling SYStem (OSeMOSYS). The AUSeMOSYS model provides a cost-optimized energy system pathway to meet the given demand for electricity (Tina Aboumahboub et al., 2020). For a detailed description of the OSeMOSYS modelling framework and formulations we refer to (Howells et al., 2011).

Each scenario is applying the electricity demand summed over all end-use sectors respecting the additional electrification of buildings, transport and manufacturing industry sectors from the corresponding scenario as taken from the bottom-up assessment of end-use sectors via PROSPECTS AUS scenario evaluation tool as described through sections 4.1 to 4.3.

AUSeMOSYS divides Australia into seven regions corresponding with the states and territories[28], with transmission between regions forming the current National Electricity Market (NEM). Key assumptions used for all the scenario categories relate to technology costs and constraints to growth rates for specific renewable energy technologies. Technology costs are derived from a recent national study based on CSIRO Outlook (Graham et al., 2019). The long-term sustainable potential for electricity from biomass has been estimated by (International Energy Agency, 2018) for Australia and has been set as upper limit in the scenario analysis for all scenario categories.

[28] The Australian Capital Territory (ACT) is integrated into the same region as the state New South Wales (NSW)

A maximum growth rate of 0.2% per year is assumed for hydropower production in Australia in line with former studies taking into account techno-economic potential (Teske et al., 2016; Bahadori et al., 2013). This leads to about 17 TWh/year hydropower production to 2050.

Solar and wind energy are the main renewable resources, with a very high potential for both in Australia. Australia has seen a remarkable boom in investment in wind and utility solar as well as in roof-top solar over the last years, driven by the existing renewable energy target for 2020 (already achieved with approved capacity) as well as state renewable energy targets and legislation and dynamic technology development. Key factors constraining the growth rate are the lack of policy direction for investment certainty and related planning of and investment into and management of the transmission grids as well as storage technologies.

Based on the model outcome for the Current Development Scenario, the annual average capacity addition rate over 2021-2050 for wind is 1.5 GW/year and for solar PV is about 1.4 GW/year, which are fairly in line with the scenarios by (AEMO, 2018a), foreseeing a capacity addition rate in a range of 1.0-2.3 GW/year for solar PV (including 0.6-0.7 GW/year for PV rooftop) and 0.5 GW/year for wind for the NEM region. In the Paris Agreement scenario, the maximum potential of renewable resources is exploited by the model to achieve carbon neutrality as implied by the emission constraint. Based on the model outcome for the PA Scenario, the annual average capacity addition rate over 2021-2050 for wind is 2 GW/year and solar PV is 6.3 GW/year, which are fairly in line with the most ambitious end of the ranges given in the literature, for instance (Ueckerdt et al., 2019).

Neither nuclear energy nor Carbon Capture and Storage (CCS) are considered, given the current ban for nuclear energy and that CCS has not been applied yet at operational/commercial level in the power sector despite longstanding attempts by the Australian Government to support CCS development. It is not considered economically viable in comparison to renewable energy with storage.

Scenario-specific assumptions are discussed in the following sections. A detailed description of assumptions and input parameters as well as scenario-specific constraints are elaborated in the Methodological Annex.

Table 24 Identification of indicator levels for scaling up climate action in the Australia's electricity supply sector. Shown is the share of REN energy in total power generation resulting from the scenarios under the assumptions for the three scenarios category

	Reference Scenario (REF)	National scenarios	Best-in-class scenarios	1.5°C Paris Agreement Compatible scenario
Share of renewables in total electricity generation	13% by 2015	-	-	
	53% by 2030	59-84% by 2030	97% by 2030	
	79% by 2040	82-99% by 2040	100% by 2040	
	89% by 2050	92-100% by 2050	100% by 2050	
References	*Based on AUSeMOSYS developed by Climate Analytics (Aboumahboub 2020)*	*Based on 'Advanced Renewables' Scenario by (Teske et al. 2016) for the High ambition case and 'Fast Change Scenario' by (AEMO, 2018a) for the Low ambition case*	*Based on AUSeMOSYS developed by Climate Analytics (Aboumahboub 2020)*	

1.5°C Paris Agreement compatible scenarios

The 1.5°C compatible scenarios apply emission budget constraints as major driver for ramping up renewables and decarbonisation of Australian electricity sector. We apply an emission budget constraint over 2018-2050 based on the downscaled IEA B2D Scenario for Australia by the SIAMESE model, adjusted based on the broad set of 1.5°C scenarios from regional pathways assessed in the Special Report on Global Warming of 1.5°C by the Intergovernmental panel on Climate Change (IPCC SR 1.5, 2019) (see Box 4.1). AUSeMOSYS provides the cost-optimal power generation capacity and fuel mix, which is compatible with the 1.5°C limit, while taking the additional electricity demand due to electrification of all demand sectors into account.

Box 4.1: 1.5°C compatible CO_2 budget for Australia's electricity emissions

In order to ensure consistency between the Australian emissions pathways and global 1.5°C scenarios, we used the SIAMESE model (Sferra et al., 2019), developed by Climate Analytics to downscale the IEA/ETP B2DS pathway from the OECD region to Australia. The estimated budget by the SIAMESE model for the Australia's electricity sector reaches 2150 $MtCO_2$ over 2018-2050.

Whilst the IEA estimated that the B2DS pathway has a peak global warming of 1.75°C above pre-industrial with a 50% likelihood, both our own analysis and that of the IPCC confirm that it provides useful information on 1.5°C compatible pathways up to at least 2050. We evaluated the IEA pathway applying the same climate model approach to warming levels as was used in the IPCC SR1.5 and earlier IPCC AR5, enabling a comparison of "like with like" with the IPCC 1.5°C compatible pathway set (see Box 2 in CAT Scaling Up EU). In addition to this earlier assessment of the B2DS regarding global warming projections, we now further compare electricity-sector emissions of this scenario for the OECD with the 1.5°C pathways assessed in the Special Report on Global Warming of 1.5°C by the Intergovernmental Panel on Climate Change (IPCC SR 1.5, 2019). These pathways lead to peak warming to at most 1.6°C and subsequently return warming to below 1.5°C by 2100 with at least 50% probability.

The cumulative CO_2 emissions from the electricity sector for OECD in the IEA ETP B2DS scenario over its time horizon (2014-2060) are on the high side compared to the range of the IPCC 1.5 pathways (applying the 25th to 75th percentile range, as is commonly used in IPCC SR1.5, i.e. the range covers half of the pathways, while a quarter of pathways has cumulative emissions below this range, and the final quarter of pathways lie above this range). The lower end of the range of these IPCC SR1.5 pathways achieves cumulative CO_2 emissions roughly 50% below those in IEA ETP B2DS over 2014-2060. Staying on the more ambitious end of the range of CO_2 budgets would minimize the amount of negative emissions needed for Paris Agreement compatibility over the second half of the century.

We also consider a subset of SR1.5 pathways that keep within the sustainability limits for negative emissions (carbon-dioxide removal) options identified in the literature. Fuss et al. (2018) identify a sustainability limit of 0-3.6 $GtCO_2$ (removal)/yr for Agriculture, Forestry and Other Land Use (AFOLU), and 0.1 – 5 $GtCO_2$/yr for Bioenergy with Carbon Capture and Storage (BECCS) in 2050, as also reflected in the IPCC SR1.5. We apply these limits to the average of each of the corresponding pathway values between 2040-2060 to filter out pathways which exceed them. This particular subset of pathways results in a lower-end carbon budget estimation of 30-98% less than the B2DS OECD pathway (25th-10th percentile). Given the large uncertainty for lower-emissions sustainable pathways, we take as a reasonable estimation the 20th percentile, resulting in a 50% reduction from the B2DS electricity sector carbon budget.

On this basis, we assume an ambitious budget for the 1.5°C-compatible scenario of the Australia's electricity sector of 50% of the B2DS-based calculation, resulting in 1100 $MtCO_2e$ over 2018-2050. Note however, that for OECD as a whole, still a fifth to a quarter of the IPCC SR1.5 pathways assessed here have cumulative emissions yet lower than this "high ambition" case.

The sustainable energy system of future is characterized by a very strong sector coupling of the power with the buildings, transport and industry sectors. This can be observed via the **increasing generation of power, increasing by about 30% in 2030, 61% in 2040 and 68% in 2050 as compared to 2020 values**. Conventional fossil sources still account for about 80% of electricity generation in 2017. However, the generation mix changes structurally from 2020 onwards. This is in addition driven by CO_2 emissions constraints requiring a quick ramp up of renewable technologies. Solar PV and wind become economically competitive due to rising fossil fuel prices and significant drop of renewable technology costs over future periods. Additionally, to model the "1.5°C Paris Agreement compatible" scenario, no new fossil power plants are installed beyond 2020. According to the modelled pathway for "1.5°C Paris Agreement compatible" scenario, coal-fired generation phases out by 2030[29] followed by gas-fired generation, phasing out in 2040. The capacity of large hydropower remains nearly flat in Australia over the entire modelled period, accounting for about 2% of total electricity production in 2050, equivalent to about 17 TWh/year electricity, which is in line with former studies taking into account the techno-economic potential of hydroelectricity in Australia (Teske et al., 2016; Bahadori et al., 2013). The contribution of biomass remains limited as of today. The share of other low-carbon energy sources such as nuclear remains zero over the whole modelled horizon. Solar PV (utility scale and roof-top PV) and wind power are thus expected to be the main pillars of future power supply. The modelling results indicate a RES share of **97% by 2030, 100% by 2040, and 100% by 2050** for Australia to be consistent with the 1.5°C target. This implies a fully decarbonised electricity generation by 2040 for the Paris Agreement Compatible Scenarios. Taking into account that overall demand will increase, this translates into an annual average capacity addition rate over 2021-2050 for wind of 2 GW/year and solar PV of 6.3 GW/year, which are fairly in line with the most ambitious end of the ranges given in the literature, for instance (Ueckerdt et al., 2019).

This transition does not allow for an increase in gas for power generation. The share of gas for power generation decreases from about 18% today to 3% by 2030 and is completely phased out by 2040, contrary to statements by the government that more gas will be needed as a transition fuel or partner for renewable energy, and plans of the government to subsidise new gas fired power plants.

National scenarios

Indicator values for the 'National Scenarios' have been inspired based on recently published modelling studies by Australia's research institutions and universities. The RES indicator ranges derived from those studies are **59-84% by 2030, 82-99% by 2040, and 92-100% by 2050.** The range of indicator values have been derived based on the studies described below:

- **Upper bound of RES indicator range**: The upper bound of the indicator range is derived from the "Advanced Renewables Scenario" by Institute of Sustainable Futures (ISF) (Teske et al. 2016). Quantification by (Teske et al. 2016) performs least cost optimization over the time horizon until 2050. The model used by ISF was created by the German Aerospace Agency in cooperation with Greenpeace International. Three scenarios have been developed by the source to show possible pathways for Australia's future energy system. The 'Advanced Renewables' Scenario as the most ambitious pathway achieves a fully renewable-based energy system by 2050. In this scenario, all coal power plants shut down by 2030. Gas-fired generation also phases out by 2040. The 'Advanced Renewables' developed by the source achieves a renewable share of about 84% by 2030, about 99% by 2040 and 100% in 2050.
- **Lower bound of indicator range**: The lower bound of indicator values are based on the 'Fast Change Scenario' by (AEMO, 2018a). This Integrated System Plan (ISP) is a cost-based engineering optimisation plan by the Australian Energy Market Operator (AEMO) that forecasts the overall transmission system requirements for the National Electricity Market (NEM) over the next 20 years. For this ISP, AEMO has used an integrated energy approach utilising state-of-the-art PLEXOS software to optimise electricity supply system that meets Australia's future energy needs at lowest cost. The Fast change scenario considers a future where economic growth is strong, increasing overall discretionary income at a household level, and stronger emission abatement aspirations are economically sustainable. The 'Fast Change Scenario' achieves a renewable share of about 59% by 2030 and 78% by 2040. Assuming similar trend as of 2035-2040, the renewable share further rises to 92% in 2050.

To derive the upper and lower bound of RES indicator range as elaborated above, we considered several studies and scenarios developed by various Australian institutions. The RES-E share derived by other scenarios either stay within the indicator range specified above or stay below the ambition level already achieved by our "Reference Scenario" projections; therefore, not

29 *Based on the threshold of more than 90% reduction from 2010 levels.*

further considered here. Please see a brief overview in Table 25. A range of other scenarios and analyses have pointed to the feasibility of a 100% RE for Australia (or for the main grid, the NEM) by 2030 (Blakers et al., 2017; Gulagi et al. 2017).

Table 25 Overview of renewable electricity supply shares provided by various national studies, including AEMO 2020 Integrated System Plan (ISP) Scenarios for NEM

Institution/ Source	Scenario	2030	2040	2050
Australian Energy Market Operator (AEMO, 2018a)	**Neutral Scenario**	**46%**	**70%**	**N/A**
Australian Energy Market Operator (AEMO, 2018a)	**Slow Change Scenario**	**48%**	**64%**	**N/A**
Australian Energy Market Operator (AEMO, 2018a)	**Fast Change Scenario**	**58%**	**78%**	**N/A**
Australian Energy Market Operator (AEMO 2020)	**Central Scenario**	**49%**	**74%**	**N/A**
Australian Energy Market Operator (AEMO 2020)	**High DER Scenario**	**53%**	**75%**	**N/A**
Australian Energy Market Operator (AEMO 2020)	**Step Change Scenario**	**63%**	**94%**	**N/A**
Australian Energy Market Operator (AEMO 2020)	**Fast Change Scenario**	**49%**	**80%**	**N/A**
Australian Energy Market Operator (AEMO 2020)	**Slow Change Scenario**	**47%**	**48%**	**N/A**
Bloomberg New Energy Finance 2018	**New Energy Outlook Scenario**	**45%**	**79%**	**92%**
ClimateWorks Australia (ClimateWorks Australia, 2020a)	**2°C Pathways**	**70-74%**		**100%**
ClimateWorks Australia (ClimateWorks Australia, 2020a)	**1.5°C Pathways**	**79%**		**100%**
CSIRO Energy and CSIRO Futures (CSIRO, 2017)	**P1: Energy productivity plus**	**43%**	**49%**	**51%**
CSIRO Energy and CSIRO Futures (CSIRO, 2017)	**P2: Variable Renewable Energy**	**62%**	**75%**	**92%**
CSIRO Energy and CSIRO Futures (CSIRO, 2017)	**P3: Dispatchable power**	**49%**	**56%**	**57%**
CSIRO Energy and CSIRO Futures (CSIRO, 2017)	**P4: All in**	**43%**	**65%**	**77%**
Department of Industry and Science 2015	**Alternative Policy Scenario**	**57%**	**64%**	**67%**

ETH 2019 (Ueckerdt et al. 2019)	**Status quo scenario**	**40-50%**	**74%**	**93%**
ETH 2019 (Ueckerdt et al. 2019)	**NDC scenario**	**57-62%**	**79%**	**96%**
ETH 2019 (Ueckerdt et al. 2019)	**Leadership scenario**	**90-92%**	**97%**	**100%**
Institute for Sustainable Futures (ISF) (Teske et al. 2016)	**Reference Scenario**	**23%**	**20%**	**17%**
Institute for Sustainable Futures (ISF) (Teske et al. 2016)	**Renewables Scenario**	**68%**	**94%**	**99%**
Institute for Sustainable Futures (ISF) (Teske et al. 2016)	**Advanced Renewables Scenario**	**84%**	**99%**	**100%**
Reedman et al. 2018(Reedman, Graham, Kanudia, & Qiu, 2018)	**2-degree scenario- Unconstrained**	**78%**	**82%**	**82%**
Reedman et al. 2018(Reedman et al., 2018)	**2-degree scenario – High Dispatch**	**51%**	**51%**	**51%**
Reedman et al. 2018(Reedman et al., 2018)	**Beyond 2-degree scenario- Unconstrained**	**68%**	**80%**	**75%**
Reedman et al. 2018(Reedman et al., 2018)	**Beyond 2-degree scenario- High Dispatch**	**57%**	**64%**	**67%**

The Australian National Outlook (ANO) 2019 report launched in 2019 by (Brinsmead et al., 2019) with the goal of investigating how Australia would look like in 2060 from the social, economic and environmental perspectives, models three scenarios for the energy system of Australia viz., Slow Decline scenario, Thriving Australia scenario and Green and Gold scenario.

The Slow Decline scenario is characterized by Australia drifting and underachieving emissions reduction potential with settings similar to those existing today. The Thriving Australia scenario is a more ambitious scenario than Slow Decline scenario in terms of climate goals and is characterized by relatively enhanced technology adoption across the Australian industries but a fractious global context. The Green and Gold scenario is the most ambitious scenario of all in terms of climate action and decarbonization goals, and is set under a more cooperative global context (Brinsmead et al., 2019).

Each of the scenarios modelled by (Brinsmead et al., 2019) project a large-scale transition to renewables in the electricity generation mix in the future with a consistent decline in the share of coal and gas. While the Slow Decline and Thriving Australia scenarios reach 90% share of renewables in electricity generation mix in 2051, the most ambitious Green and Gold scenario reach 90% share of renewables in electricity generation mix in 2038. This still lags in terms of speed of renewables uptake in electricity generation mix in a 1.5 °C Paris Agreement compatible scenario, the share of renewables reach 90% much earlier, around 2030 and 100% in 2040 with a complete phase-out of fossil fuel-based plants.

2020 Integrated System Plan (ISP) Scenarios

The **2020 Integrated System Plan (ISP)** is an actionable roadmap for eastern Australia's power system. It is a set of plans to optimise net market benefits while delivering low-cost, secure and reliable energy through a complex and broad range of plausible energy futures. The ISP was developed using cost-benefit analysis, least-regret scenario modelling, detailed engineering analysis and several sensitivity tests. The scope of the ISP is the whole of the National Electricity Market (NEM) power system with a planning horizon of next two decades, to 2040. The development of the latest ISP involved several stages of consultation and feedback with industry, academia, government, developers and consumer representatives. The 2020 ISP presents five scenarios to reflect different degrees of energy transition in the NEM (Australian Electricity Market Operator, 2020).

The **Central Scenario** determines the future energy system driven by the current market forces under the current federal and state government policies. The Central Scenario incorporates policies such as the NEM's share of the Federal Government objective of reducing emissions by atleast 26% below 2005 levels by 2030.

Renewable Energy (RE) targets of Victoria and Queensland (both 50% renewables share in electricity generation by 2030), and that of Tasmania (100% renewable electricity by 2022), the New South Wales Electricity Strategy[1], the Snowy 2.0 energy storage project, and all current state and federal policies impacting Distributed Energy Resources (DER) and energy efficiency policies. In the Central Scenario, the renewables share reach 49% and 74% by 2030 and 2040 respectively in electricity generation in the NEM region. Electricity generation in the NEM region reaches 206 TWh by 2022, 213 TWh by 2030 and 239 TWh by 2040 (Australian Electricity Market Operator, 2020).

The **High Distributed Energy Resource (DER) scenario** is characterized by a more rapid, consumer-led transition, as consumers take control of their energy costs with easy-to-use interactive technologies, falling costs of distributed energy resources and EVs. In this scenario, the renewable energy share in electricity generation reaches 53% and 75% by 2030 and 2040 respectively in this scenario. Electricity generation in the NEM region reaches 206 TWh, 215 TWh and 244 TWh by 2022, 2030 and 2040 respectively, similar to the central scenario. It is to be noted that there is the highest uptake of storage technologies in this scenario (Australian Electricity Market Operator, 2020).

The **Step Change scenario** is the most ambitious scenario in the ISP in which both consumer-led and technology-led transitions occur in the midst of the aggressive global decarbonisation and strong infrastructure commitments. Relative to the central scenario, the step change scenario assumes higher population and economic growth, increased technology innovation and DER uptake, greater EV uptake, and much stronger role of energy management solutions and energy efficiency measures.

In the Step Change Scenario, the renewables share in the electricity generation in the NEM reach 37% by 2022, 63% by 2030 and 94% by 2040 respectively (Australian Electricity Market Operator, 2020). This is, however, still less ambitious than the Advanced Renewables Scenarios based on (Teske et al. 2016), which is used as the National Scenario 1 in our scenario analysis, where the renewables share reach 84% by 2030 and 99% by 2040 in the electricity generation mix respectively. (Australian Electricity Market Operator, 2020) states that in the Step Change Scenario, EVs would account for approximately 12% of underlying NEM power-point consumption by 2040. However, there is no electrification targets for other end-use sectors like industry and buildings.

In the Step Change scenario, the electricity generation reaches 210 TWh by 2022, 223 TWh by 2030 and 255 TWh by 2040 respectively (Australian Electricity Market Operator, 2020). This scenario projects an increase in electricity demand of 6% between 2022 and 2030, and 14% between 2030 and 2040. In the Paris Agreement compatible scenario used in our assessment however, the increase in electrification rate across all end-use sectors drives the electricity demand to increase substantially by 31% between 2020 and 2030 and 23% between 2030 and 2040.

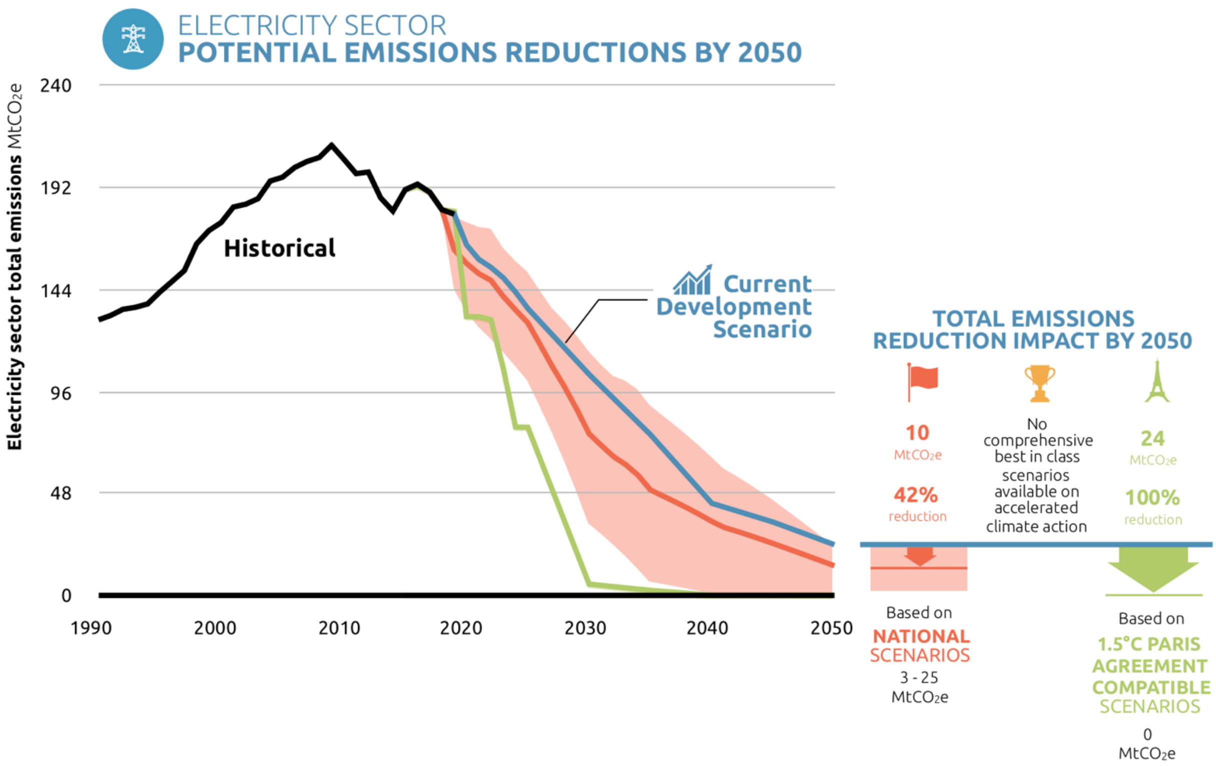
(Australian Electricity Market Operator, 2020) also provides the projections of gas-powered generators (GPG) under various scenarios. The existing Combined Cycle Gas Turbine (CCGT) and Open Cycle Gas Turbine (OCGT) generators are forecast to play critically complementary roles when significant coal-based generation retires in the 2030s. The electricity generation by GPG varies significantly every year in their future projections, which depends on variability of renewable based generation (wind, solar and hydro), as well as constraints on gas supplies and uncertainties in future gas prices. However, the electricity generation from GPG is not well aligned with the broader decarbonization objectives in state, national and global level. The Paris Agreement compatible scenario in our assessment foresees a steady decline in the share of gas in electricity generation mix in Australia from about 19% today to 3% in 2030 and eventually being phased out in 2040. It is envisioned that the alternative options such as storage and strong sector coupling between the electricity and various end-use sectors offers the flexibility required in the power system in the Paris Agreement compatible scenario.

The **Fast Change Scenario** reflects a technology-led transition particularly at grid scale. In this scenario, the advancements in large-scale technology improvements and targeted policy support reduce the economic barriers of the energy transition. Relative to the Central Scenario, the Fast Change Scenario reflects faster adoption of decarbonised investments, technology innovation and increased DER uptake, greater EV uptake and stronger role for energy storage solutions. In this scenario, renewables share reaches 49% by 2030 and 80% by 2040 with electricity generation projected to reach 216 TWh by 2030 and 243 TWh by 2040 respectively (Australian Electricity Market Operator, 2020).

The **Slow Change Scenario** reflects a slow-down in the energy transition, which is characterized by slower progress in technology, reduced technology costs, low population growth, and low political and consumer motivation to make the upfront investment that is needed for significant emissions reductions. Thus, this is the least ambitious scenario of all in terms of decarbonisation goals. The renewables share only reaches 47% by 2030 and 48% by 2040 respectively. The electricity generation projections reach 196 TWh by 2022, 178 TWh by 2030 and 192 TWh by 2040 respectively (Australian Electricity Market Operator, 2020)

4.4.2.2 Quantification of emission levels

(a)



(b)

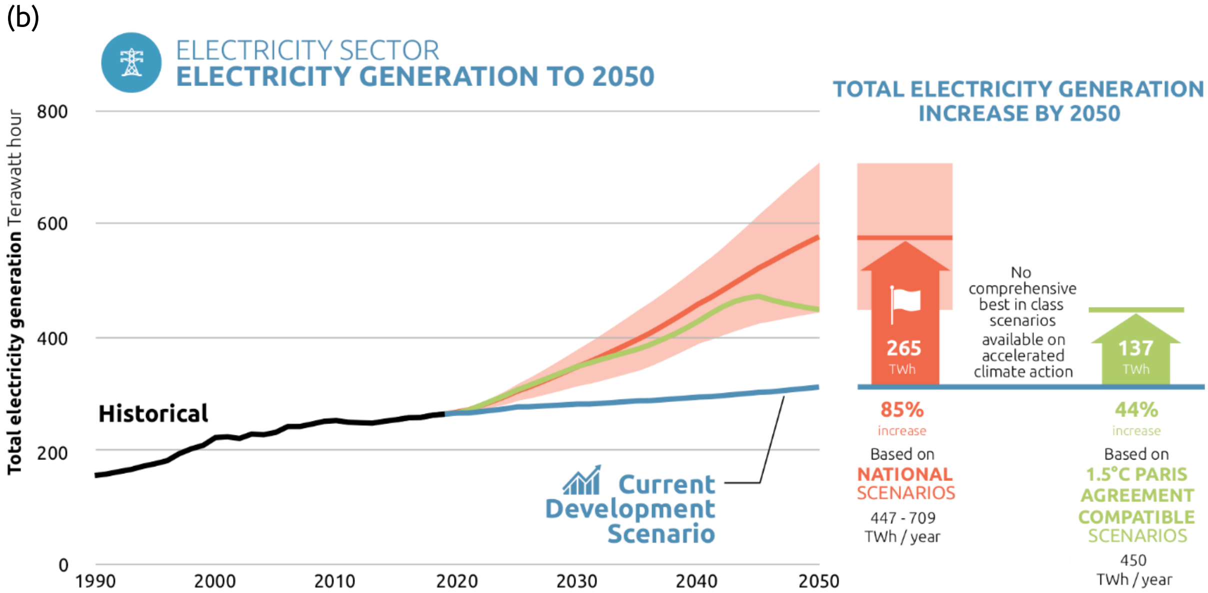


Figure 34 (a) Overview of sectoral emission pathways under reference scenario projections and different levels of accelerated climate action in the Australia's electricity supply. (b) The projected electricity demand considers accelerated climate action in the Australia's end-use sectors corresponding to the same scenario categories as described in sections 4.1-4.3, which leads to higher electricity generation (right).

Figure 34 shows the emissions trajectories from electricity generation until 2050 for different scenario categories. Under the reference scenario projections, the emissions in 2050 are 82% lower than 1990 levels and 87% lower as compared to 2005 values. All resulting pathways based on enhanced climate action in the Australia's electricity sector lead to emissions lower than reference scenario projections by 2050. The pathways vary in the level of emissions reached by 2050 and the pace of reduction:

- The **'1.5°C Paris Agreement compatible'** pathway imply an immediate and drastic reduction of emissions from electricity generation and lead to a full decarbonisation of

Australia's electricity sector by 2040 under the higher ambition level. This is mainly driven by a quick ramp-up of renewable electricity generation and early phase out of fossil fuel power generation. The emissions reduce by an average annual rate of -23% p.a. between 2020 and 2030 followed by -15% p.a. pace of reduction over 2030-2050. For comparison, the recent 1.5°C compatible pathways from the SR1.5 scenario database (IPCC SR15, 2018) identify a reduction rate of -1% p.a. to -6% p.a. for CO_2 emissions from electricity supply for the OECD region over 2010-2030 and a rate of -3% p.a. to -17% p.a. over 2030-2050. In our Paris Agreement compatible pathway, the renewable energy based generation increases by an average annual rate of 12% p.a. between 2020 and 2030 and 2% p.a. between 2030 and 2040. The average wind and solar PV capacity addition is approximately 8.3 GW per year between 2020 and 2050.

- The **'National scenarios'** pathway reveals a broad range across the upper and lower ambition trajectory. The upper ambition end (corresponding with the Teske et al scenario) implies an immediate and quick reduction of emissions mainly driven by an ambitious ramp up of renewable power and early phase out of coal power. The upper ambition end implies a fast reduction of emissions, while leading to a complete decarbonisation of the Australia's electricity sector by 2045. The lower end of ambition (corresponding to the AEMO fast transition pathway) positions slightly below the reference scenario projections until 2040. Over the short to medium-term horizon, due to strong electrification of demand sectors and non-sufficient decarbonisation of electricity supply sector as reflected by the lower ambition end of the 'National scenarios', the emissions from this scenario stays slightly below the Reference Scenario projections prior to 2040. This further emphasises the importance of electrification of end-use sectors in parallel to decarbonisation of power sector as complementary measures towards an emission-free sustainable energy system of future. The lower end of ambition leads to an emission reduction of about 80% rel. to 1990 levels in 2050.

4.4.2.3 Quantification of employment impacts for different scenarios

Employment is higher in a Paris Agreement compatible scenario

The quantification of employment impacts for selected electricity supply sector scenarios between 2021 and 2030 shows that the Current Development Scenario (CDS) supports the fewest jobs. Under the CDS, approximately 17,000 people on average per year are directly employed in the development of new capacity for power generation and the operation and maintenance (O&M) of total capacity (existing and new capacity) over the period between 2021 and 2030. We estimate that the investments would stimulate a further 51,000 indirect and induced jobs on average per year. In addition, over 8,000 jobs related to batteries (distributed and utility scale) and pumped hydro storage (PHS) could be expected in the CDS (see Figure 35).

Paris Agreement consistent scenarios with accelerated transition to renewable energy have higher employment impacts. Applying the same assumptions for local shares as for the CDS, the estimated number of direct jobs in electricity generation in the PA1.5 Scenario is 31,000 on average per year between 2021 and 2030. We estimate that the investments would stimulate a further 71,000 indirect and induced jobs in electricity generation on average per year for this scenario. These consider the indirect impact of electricity supply investments through the supply chain — for example the production of cement for concrete foundation of wind turbines — as well as induced economic impacts driven by the spending of wages throughout the economy. The higher storage needs due to the higher share in renewable energy could moreover result in more than doubling the number of direct jobs related to storage, mostly batteries (approximately 20,000) (see Figure 35).

Assuming efforts to increase Australian manufacturing of solar and wind and local sourcing of all related services further increases job prospects. By increasing the share of Australian manufacturing in solar technology parts to 25% (from currently assumed to be very low shares of around 2% for modules and inverters for PV utility and 4% for modules and inverters for PV roof) and for wind to 50% (from currently assumed to be around 10% for turbines, 5% for blades and 24% for towers) as well as increasing the local share for transport, project planning and finance, this can be increased to almost 62,000 direct (electricity generation and storage) and 90,000 indirect and induced jobs.[30] An accelerated transition to renewable energy in line with the Paris Agreement can create a total of 46,000 additional jobs compared to the Current Development Scenario, increasing to a total of 76,000 for higher shared of local manufacturing and services.

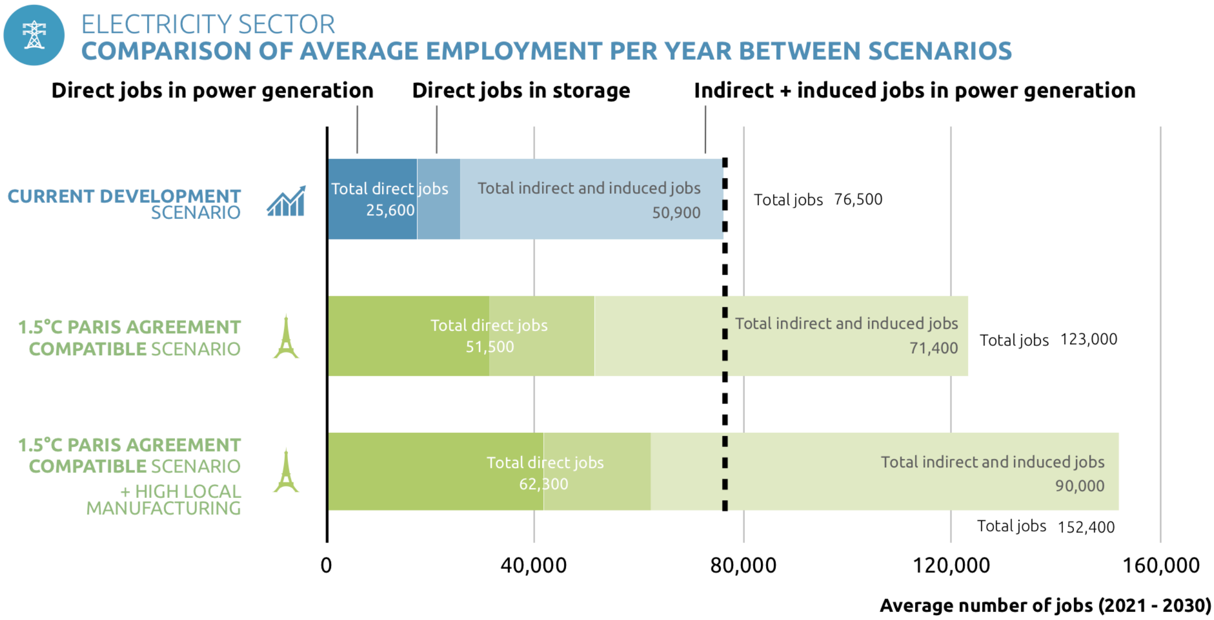


Figure 35: Average direct employment per year between 2021–2030 and average total employment per year between 2021–2030 in Australia for different electricity generation scenarios. Employment impacts related to power generation are estimated with the Economic Impact Model for Electricity Supply (EIM-ES)[31]. Direct jobs related to storage have been approximated based on employment factors from the literature (Ram et al., 2020; Rutovitz et al., 2020) *using approximated storage capacity needs. No indirect jobs related to storage have been estimated. Due to a thinner existing empirical basis with regard to storage, the presented numbers for storage are only indicative. Direct jobs include jobs in manufacturing, construction and installation and operation and maintenance. Indirect jobs are jobs further down the supply chain and induced jobs are created by spending of wages throughout the economy. A scenario variant of the PA scenario has been added to demonstrate the relevance of local sourcing for local jobs. This PA variant is based on the same emission pathway and technology mix as the Paris Agreement compatible Scenario, but it assumes higher shares for local manufacturing of technology components and services being provided within Australia for wind and solar. More information can be found in the methodological annex.*

[30] Note that information on actual local shares is scarce and is subject to measurement error, especially as added capacities vary between years. These numbers have been derived based on the literature and newspaper articles on reporting on Australian industry in manufacturing of PV and wind technology parts. For this Paris Agreement compatible scenario variant, we assume that all operation and maintenance and other services (e.g. finance, civil works, installation, project planning and transport) are also local jobs. In the default assumptions, these are assumed to be between 70% and 100%. See methodological annex for a comparison of local share assumptions across scenarios).

[31] The general EIM-ES tool including a documentation of the tool is available here https://newclimate.org/2018/11/30/eim-es-economic-impact-model-for-electricity-supply/.

Transitioning to 100% Renewable Energy can support the development of jobs with future

Fossil-based jobs also do not have a promising future in the Current Development Scenario. The number of jobs related to fossil-based power generation (mainly from domestic coal mining and coal power generation) steadily decreases in the CDS. In the Paris Agreement Scenario, jobs in wind and solar contribute the large majority of jobs already early in the 2020'ies due to high added capacities for these and resulting jobs in manufacturing and construction and installation, even if local share assumptions are chosen rather conservatively.

Jobs related to storage could potentially provide large job opportunities. Job estimates related to distributed batteries and utility scale batteries as well as pumped hydro storage (PHS) indicate that the potential for job generation related to storage needs could be substantial. While the provided estimates need to be taken with some caution[32], our estimates suggest that even in the Current Development Scenario, jobs related to storage could contribute a substantial share, but the average number of jobs increases substantially (more than double) in the Paris Agreement compatible scenario with accelerated transition to renewable energy and related storage needs.

Reaping the opportunities of the energy transition means thinking ahead with regard to skills and training of the workforce. These findings show the higher overall employment potential of accelerated climate action for the electricity generation sector. They likewise highlight the need to avoid investing in skills and jobs in fossil-fuelled technologies which are incompatible with the Paris Agreement and will very likely not provide long-term employment prospects. Managing the transition well will therefore require reducing incentives to train new workers for the fossil-sector and instead invest in building up skills and capacities in local manufacturing of RE-technology parts and training the workforce to fully provide RE related services locally.

[32] Storage related jobs are estimated based on approximated storage capacity needs derived from literature and expert feedback (see methodological annex) as well as applying storage-specific employment factors from the literature (Ram et al., 2020; Rutovitz et al., 2020). However, empirical evidence related to storage is still scarce. This makes the derivation of (future) employment factors challenging as also highlighted in the study commissioned by the Australian Clean Energy Council (Rutovitz et al, 2020). Thus, estimated employment factors in the literature with regard to storage differ between studies. To be more conservative, we therefore applied a lower employment factor from Ram et al. (2020) for Operation and Maintenance jobs for utility scale battery. See methodological annex for more information. Likewise, the quantification of future storage capacity needs is challenging and would require an energy system model with very high temporal resolution beyond the temporal resolution of AUSMOSYS. Our assumptions on storage needs are detailed in the methodological annex.

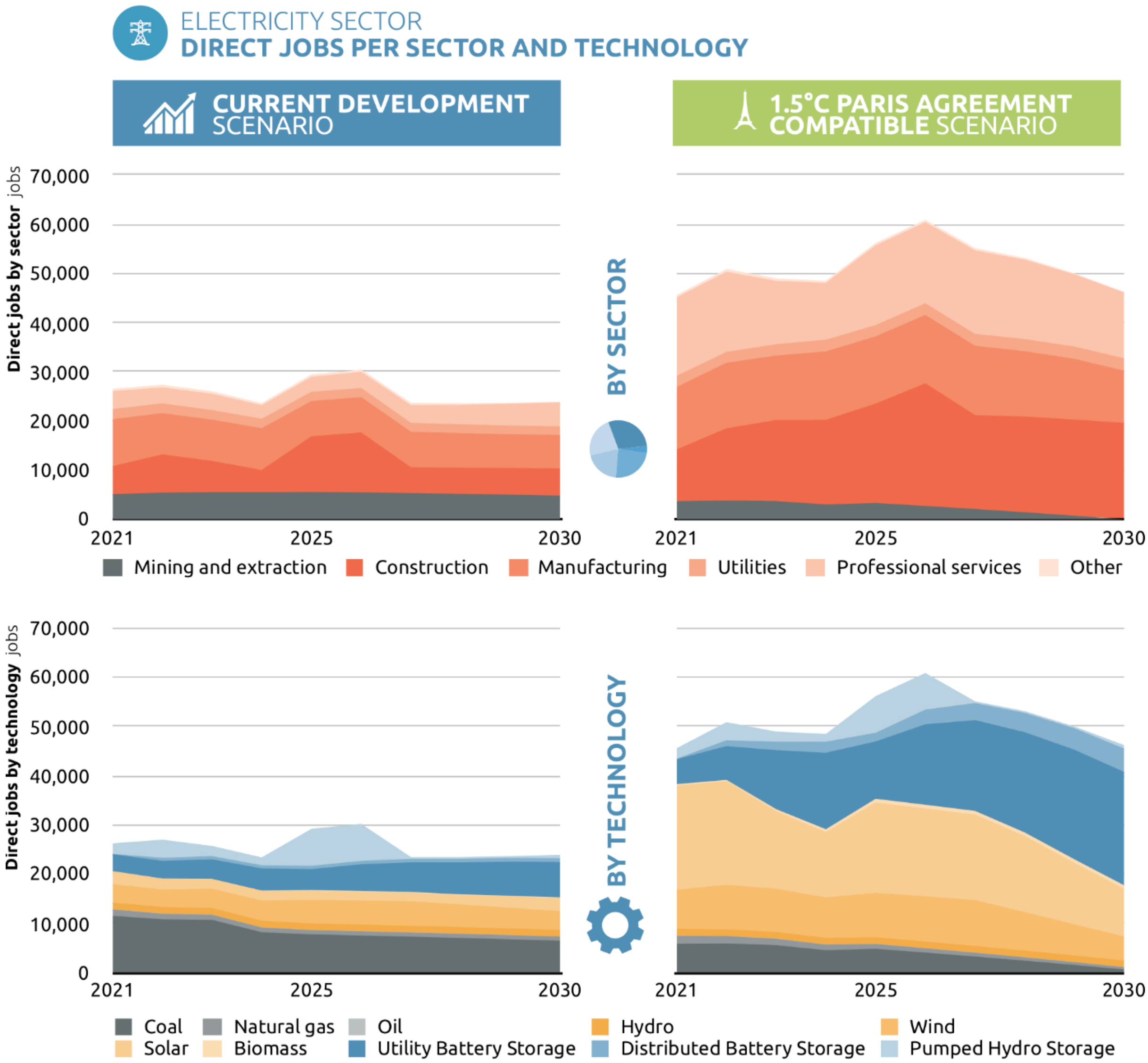


Figure 36: Direct jobs per employment sector' and 'Direct jobs per generation technology' between 2021-2030 for the Current Development Scenario (CDS) (graphs on left) and the 1.5°C Paris Agreement compatible scenario (same assumptions on local shares, graphs on right) for the Australian electricity supply sector Direct employment estimates reflect energy supply sector investments linked to planning, construction, manufacturing of component parts, operation (including fuel supply such as oil and gas production, where relevant) and maintenance of power plants. Note employment impacts for mining and extraction only relate to the fuels used in the Australian electricity supply sector and do not include jobs supported to supply other sectors or the export market. Employment impacts related to power generation are estimated with the Economic Impact Model for Electricity Supply (EIM-ES)[33], jobs related to storage are approximated based on employment factors from the literature (Ram et al., 2020; Rutovitz et al., 2020), both based on Input from AUSMOSYS (see methodological annex). Note that the optimization period in AUSMOSYS starts in 2017 with the model suggesting that it would have been optimal to install substantial capacities for wind and solar already in the years before 2021 not shown in this figure, which have however not been installed to this extent in reality. As a consequence, the job impact especially for the Paris Agreement compatible pathway can be considered to even underestimate the job potential in renewable energy for the period shown.

[33] The general EIM-ES tool including a documentation of the tool is available here https://newclimate.org/2018/11/30/eim-es-economic-impact-model-for-electricity-supply/.

Domestic investments and employment impacts

The Paris Agreement compatible scenario assuming higher local shares stimulates the highest local investments in Australia and also supports the highest number of jobs per unit of investment. For this scenario we estimate that over 415 million AUD of local investments for the period 2021 to 2030, with about 47 million AUD locally invested per MWh of electricity generation (not including investments for storage). In the Paris Agreement scenario assuming the more conservative local shares for manufacturing and services also used in the Current Development Scenario, the total local investments are lower (with about 348 million AUD) compared to the high-local-shares Paris Agreement Scenario, as with lower local shares for solar and wind less of the investment remains within Australia, but are higher than in the Current Development Scenario (with about 282 million AUD) as wind and solar capacities are expanded substantially in the PA scenarios. Both Paris Agreement Scenarios support more jobs per unit of local investment compared to the Current Development Scenario, with the PA scenario with higher local shares showing higher jobs per local investment than the PA scenario with lower local shares. The Paris Agreement scenario with the higher local shares has higher investments per electricity output remaining within Australia and therefore shows less electricity generation per US dollar invested locally. For the Paris Agreement scenario with conservative local shares for solar and wind we find more electricity generation per local investment compared to the Current Development Scenario.

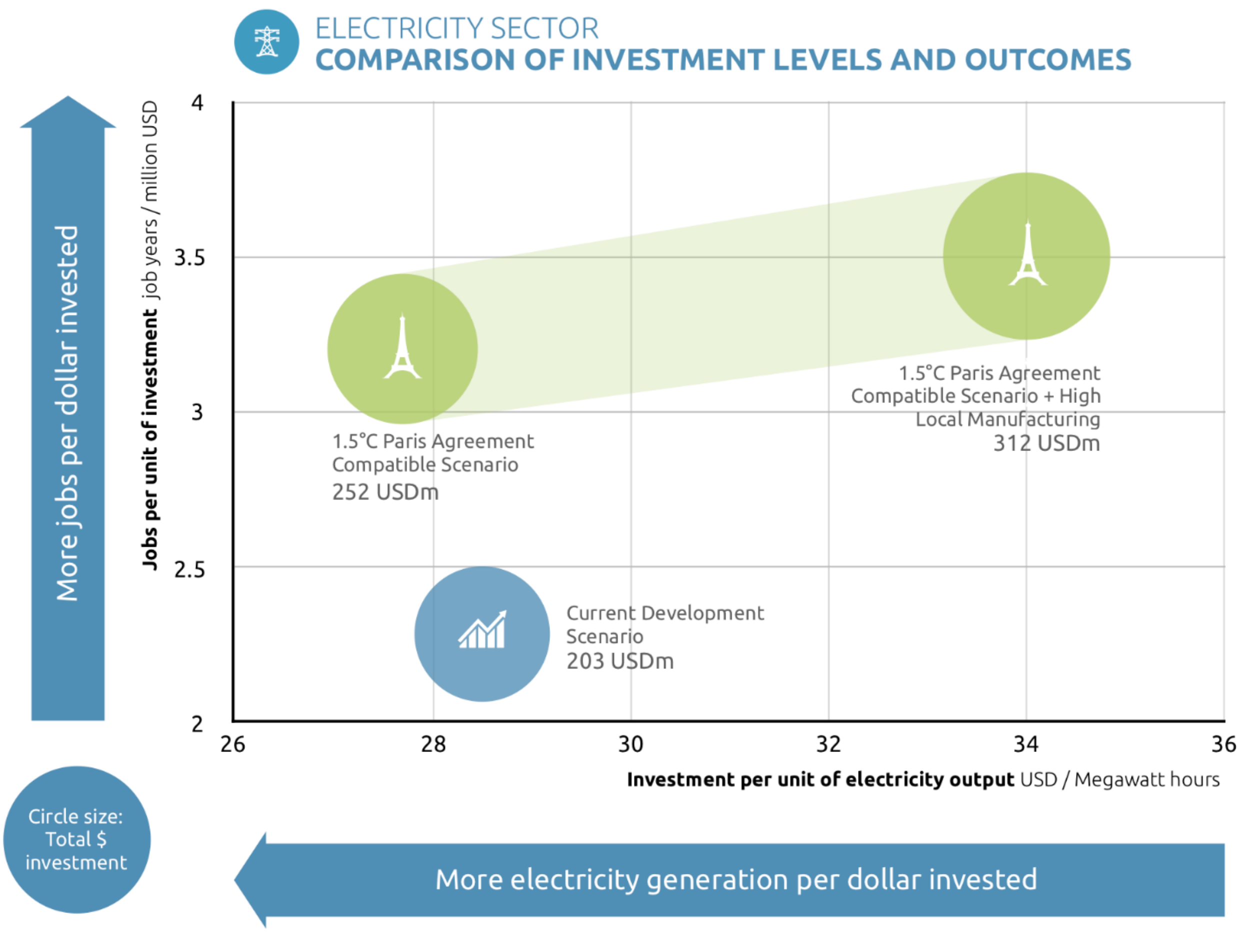


Figure 37: Average job generation per unit of investment (in job years per million USD) and average investment per unit of electricity generation (in USD per MWh) in the Australian electricity supply sector for selected electricity generation scenarios between 2021–2030. Note the figures reported here relate exclusively to investments in Australia and do not reflect the overall cost of scenarios, which also include investments on imported products and services. Employment impacts are estimated with the Economic Impact Model for Electricity Supply (EIM-ES)[34] and do not contain storage related jobs or investments into storage capacities.

[34] The general EIM-ES tool including a documentation of the tool is available here https://newclimate.org/2018/11/30/eim-es-economic-impact-model-for-electricity-supply/.

4.5 Fossil fuels sector

4.5.1 Liquefied Natural Gas (LNG) export industry

Western Australia is a major LNG exporter, positioning geographically near to the large gas consumers in Asia Pacific region (including China, Japan, South Korea, and Taiwan). When these are combined with LNG projects in Queensland and the Northern Territory (NT), Australia contributed to around one-fifth of total global LNG capacity in 2018 (AEMO 2016; AEMO 2017;AEMO 2018b; AEMO 2019). In 2019, Australia overtook Qatar to become the largest exporter of LNG in the world (Oil & Gas Today, 2020). The future trend of LNG export volumes thus could have a major effect on Australia's emissions. Renewable electrification of LNG Processing need to play a key role in phasing out emissions from the LNG processing industry in Australia.

Australia's LNG export volumes are forecast to increase from 62 million tonnes in 2017–18 to 82 million tonnes in 2019–20; the export volumes are forecasted to 81 million tonnes by 2023 (DIIS 2019). Here, we project the LNG export volumes under the "Reference Scenario" to reach to 87 million tonnes by 2025, rise further to 97 million tonnes by 2030, and assume the export volumes to remain constant beyond 2030.

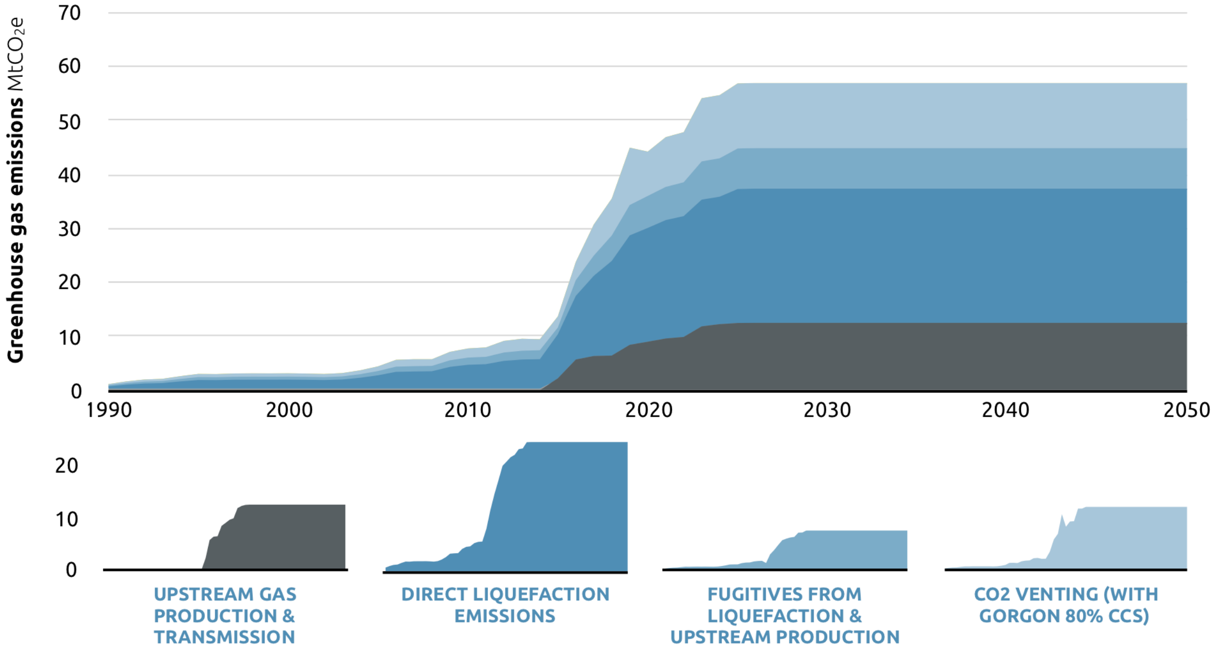
For the '1.5°C Paris Agreement compatible' scenario, we assume that LNG export volumes would decline continuously from 2030 onwards, and eventually be phased out by 2050. This has been inspired according to the declining trend of Asian gas demand in the IEA ETP B2D scenario as well as 1.5 °C compatible pathways from IAMs (IPCC SR 1.5)(Climate Analytics, 2019b; IPCC, 2018a).

Remaining cumulative emissions from LNG processing need to be reduced substantially, even assuming a reduction in demand, and the basic options are to ensure reservoir CO_2 is captured and stored rather than releasing it into the atmosphere, and introducing renewable energy in the LNG manufacturing process. CO_2 in the natural gas reservoir has to be captured from the gas stream in any event to produce LNG, and its storage and transport to an appropriate geological storage reservoir should be well within the means of the industry to achieve. The broad approaches assumed here is that the level of CCS planned for the Gorgon plant of 80% from 2019 is phased in to all LNG plants in Western Australia from around 2023 consistent with a report focusing on mitigation options in Western Australia (Climate Analytics, 2019b). In addition, we assume phasing in of renewable energy so that by 2030 50% of natural gas uses in LNG manufacturing are replaced by renewable energy and 90% by 2035 and ultimately 100% by 2050.

With all these options applied, emissions increase from the LNG sector can be limited to 633% increase by 2030 (as compared to 2005), reduced to only 14% higher value by 2040 as compared to 2005 and to zero in 2050.

Additional electricity demand required for LNG processing is taken into account in the analysis of the electricity supply sector with AUSeMOSYS (see section 4.4).

LNG SECTOR
CURRENT DEVELOPMENT SCENARIO EMISSIONS T0 2050



LNG SECTOR
1.5°C PARIS AGREEMENT COMPATIBLE SCENARIO EMISSIONS T0 2050

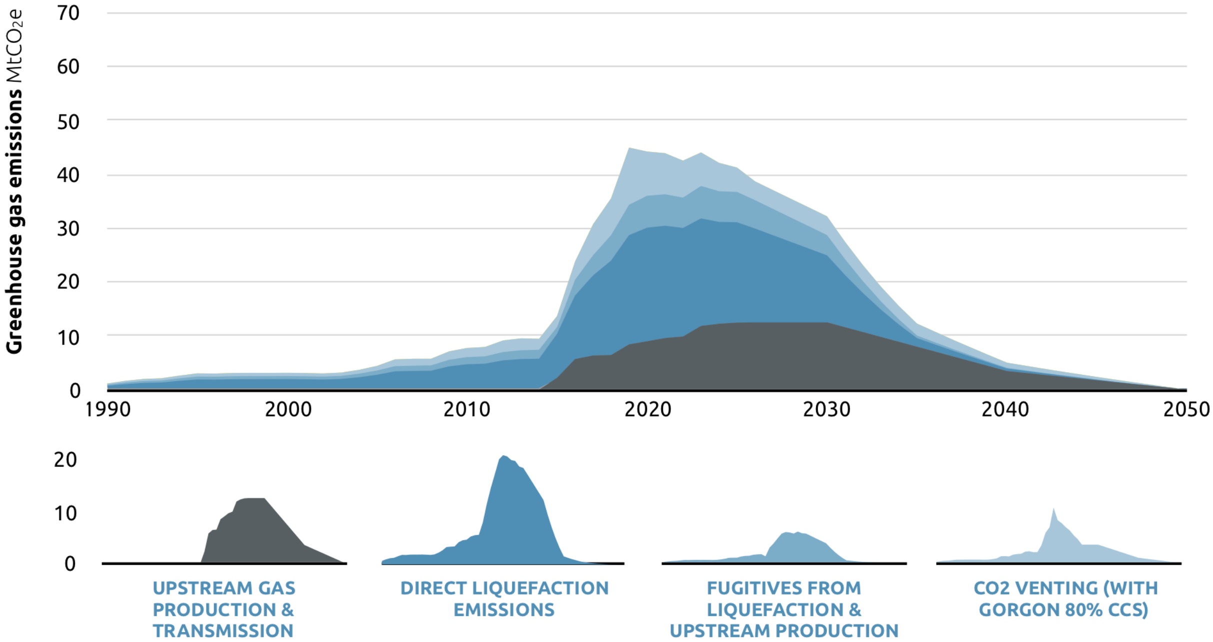


Figure 38: Overview of sectoral emission pathways under reference scenario projections and 1.5 °C Paris Agreement compatible in the Australia's LNG processing sector.

Required policy measures for sectoral transformation	Remaining challenges threatening implementation
➾ Develop new markets for green hydrogen to enable a transition away from exporting LNG in line with expected decrease of demand in Asia in a world implementing the Paris Agreement. ➾ Ensure reservoir CO_2 is captured and stored, and renewable energy is phased in for processing ➾ This can be achieved either through adequate carbon pricing, or through binding regulatory requirements on the LNG industry to meet or exceed Paris Agreement pathway consistent greenhouse gas intensity benchmarks for existing and planned facilities ➾ Moratorium on future LNG projects not consistent with a global Paris Agreement pathway.	➾ Industry-government patronage networks allows industry to operate business-as-usual practises and creates preferential treatment such as exemptions and approvals at the expense of the taxpayer, the environment and emissions levels. ➾ Tax subsidies for the fossil fuel sector does not create an environment to encourage innovation but sets a course for business-as-usual, without implementation of transformational mitigation measures and without preparing the sector for a global transition away from fossil fuels. ➾ Lack of development of a long-term strategy and pathway across all sectors in line with the Paris Agreement leads to neglecting the need to address decarbonisation of the LNG sector and reap benefits building on Australia's advantages through transitioning to exporting green energy carriers. ➾ The Current Hydrogen strategy could be used to prop up the fossil fuel and LNG sector

Oil and gas extraction (excluding LNG)
According to the Australian Energy Statistics 2019, the total indigenous production of oil and gas in Australia amounted to approximately 5377 PJ in 2017. In the last decade, Australia observed a steady decline in the production of oil (crude oil, condensate and LPG). On the other hand, the natural gas production has grown steadily in Australia. Pertaining to the growth in LNG sector in Australia, there has been a significant rise in natural gas extraction from 2016 onwards. However, in this section, we assess the emissions pathways for oil and gas extraction excluding the LNG sector.

In the short run, the natural gas production in Australia is forecast to grow driven mainly by increase in LNG export volumes. Excluding the gas extraction for LNG sector, there is relatively low investment in oil and other gas sector (Department of the Environment and Energy (DEE)., 2019). Therefore, it is assumed that the domestic gas use would peak around 2025 and decline gradually to reach 900 PJ in 2050. Similarly, the oil production is also projected to decline over the projection period.

We further assume that the electricity demand in the extraction industry is mainly fulfilled by the onsite fossil fuel-based generation which is dominated by gas. And the direct energy fuel mix remains rather unchanged under the Reference Scenario projections as mainly provided by gas according to the last energy update by (Department of the Environment and Energy (DEE)., 2019).

The 1.5 °C compatible world envisions a shift from the use of fossil fuels like coal and gas and a complete phase-out by 2050. For example, the applications like heating, cooking, lighting and appliances are almost completely electrified in the buildings sector. In the industry sector, applications are either electrified or run by green hydrogen or biofuels. Similarly, in the transport sector, the electric vehicles dominate the fleet while the fuel mix is mainly composed of synthetic fuels. Therefore, we assume that the oil and gas extraction is reduced continuously from 2020 onwards in a Paris Agreement consistent pathway to reach zero by 2050.

Studies suggest that the electrification of the extraction industry is not only favorable on a commercial level but also necessary for the climate (ABB, 2014). Electrification of oil and gas industry could drive dramatic impact in the high-tech production facilities for more efficient operations in the new era[35].

Figure 39 illustrates the emissions trajectories from Australia's oil and gas extraction until 2050 for the Reference and Paris Agreement scenarios, while enhanced climate action is further combined with decarbonisation of the electricity sector. The Reference Scenario results in

[35] Please see https://www.hartenergy.com/opinions/electrification-new-era-oil-gas-industry-122683

emissions from Australia's oil and gas extraction decline slightly from today to about 3.3 $MtCO_2e$/a in 2050. The '1.5°C Paris Agreement compatible' pathway substantially reduces emissions and leads to the full decarbonisation of the oil and gas extraction industry by 2050.

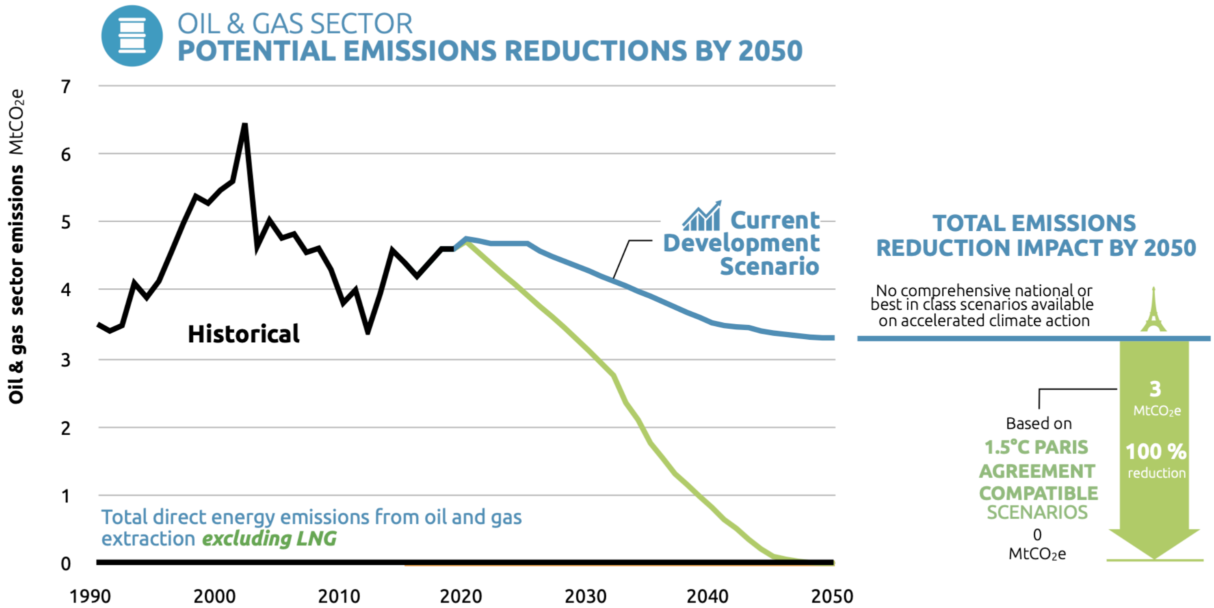


Figure 39: Overview of sectoral emission pathways under Reference scenario projections and different levels of accelerated climate action in Australia's oil and gas extraction

4.5.2 Coal mining

One major mitigation strategy for the mining companies is the use of decarbonised renewable electricity from the grid instead of onsite fossil-fuel based generation. Further complementary strategies are to increase efficiency as well as electrification of energy end uses that have been so far powered by fossil fuels.

Electrification of coal mining activities opens the way for sector coupling and use of renewable electricity in mining industry. Electric mining technology is mature enough that the dream of an all-electric mine is becoming a reality at Goldcorp's Borden Lake gold mine in Ontario, Canada (Kirk and Lund, 2018).

Mining companies are expected to have an emission intensity target that should decline by about 87% by 2050 from 2010 levels (Kirk and Lund, 2018). This results in the same absolute energy-related emissions reductions percentage being applied to all companies within the sector and thus guarantees that, should each company meet this target, the sector would stay within its 2°C carbon budget. Towards meeting the 1.5 °C target of the Paris Agreement implies more aggressive reduction of emissions is needed from the mining industry. Several mining companies across the world have ambitious emission reduction targets. For instance, the BHP mining company aims to achieve net-zero operational GHG emissions in the second half of this century (Kirk and Lund, 2018).

According to the (Department of the Environment and Energy (DEE)., 2019), the amount of coal production in Australia in 2017 amounted to approximately 12617 PJ. Most of the coal production in Australia is black coal whose share is steadily increasing in the recent years as opposed to brown coal which has seen decline in the production in the recent years. According to (Department of the Environment and Energy (DEE)., 2019), the share of metallurgical coal and thermal coal in black coal exports is about 40% and 60% respectively and is projected to remain so until 2024. The same source also forecasts black coal export to peak around 2022 after which it'd observe a relatively small decline until 2024.

Under the ‚Reference Scenario' projections, we make the projections for brown coal and black coal production in Australia based on (Department of the Environment and Energy (DEE)., 2019). In this scenario, the brown coal production in Australia declines at -1.53%, -0.13% and -0.83% between 2020-2025, 2035-2030 and 2030-2050 respectively. However, the black coal production is projected to increase at 0.23%, 0.75% and 0.49% over the same projection period respectively. We further assume that the electricity demand is mainly provided by onsite fossil fuel-based generation (mainly diesel). The direct energy fuel mix remains rather unchanged under the Reference Scenario projections as mainly provided by diesel according to the last energy update by (DEE, 2019b).

In a 1.5 °C compatible world, the share of conventional steel manufacturing route via reduction of iron ore with coke in blast furnace-basic oxygen furnaces (BF-BOF) reaches to zero by 2050, while coal-fired electricity generation phases out by 2030-2035. Currently, a major share of the coal production is exported. In 2017, about 84% of the total coal production was exported which is primarily black coal (Department of the Environment and Energy (DEE)., 2019). We assume that this is also reduced based on Paris Agreement benchmark scenarios. These are considered as main factors affecting the Australia's coal production volumes under the Paris Agreement compatible Scenarios. On this basis, we assume that Australia's coal production volumes decline continuously from 2020 onwards with a complete phase out of coal production in 2050.

In a PA compatible scenario, it is assumed that the mining companies would increasingly shift towards use of decarbonised electricity from the grid instead of onsite fossil-based generation. The proportion of grid electricity to onsite generation increases from near 0% today to 100% by 2050. Additionally, according to the international best practices for all-electric mines, we assume that electrification rates in Australia's coal mines increases continuously to reach 100% by 2050 following a s-curve trajectory.

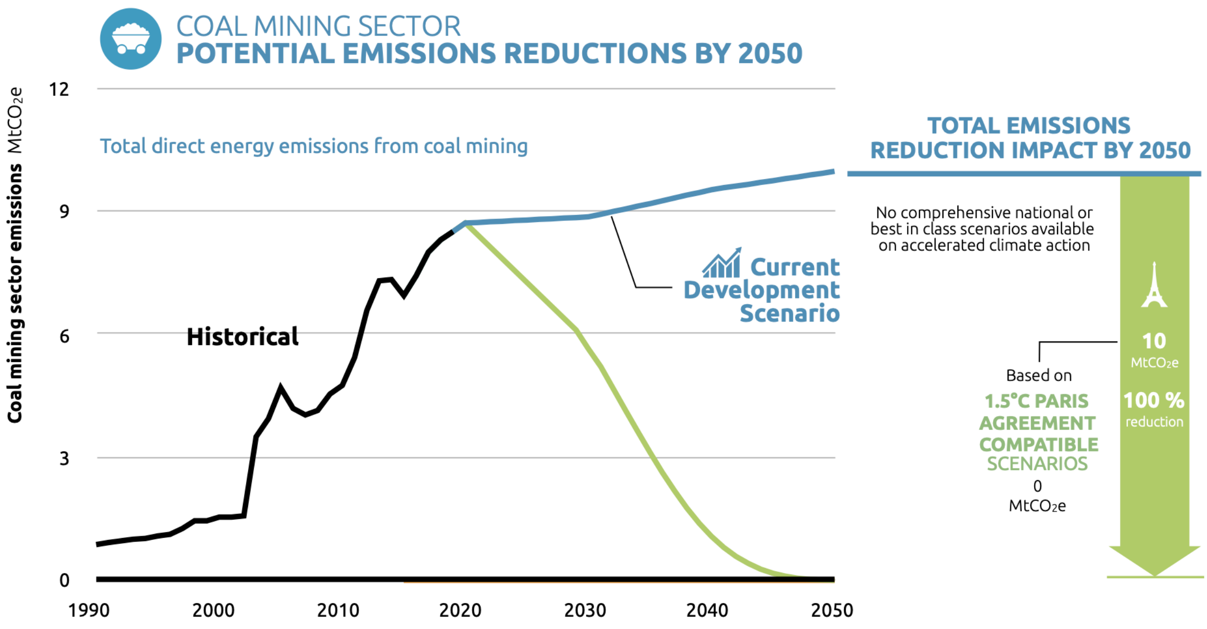


Figure 40: Overview of sectoral emission pathways under Reference scenario projections and accelerated climate action in Australia's coal mining

Figure 40 illustrates the emissions trajectories from Australia's coal mining until 2050 for the Reference and Paris Agreement scenario, while enhanced climate action is further combined with decarbonisation of the electricity sector. The Reference Scenario results in emissions from Australia's coal mining industry rising to about 12 $MtCO_2e/a$ in 2050. The '1.5°C Paris Agreement compatible' pathway substantially reduces emissions and leads to the full decarbonisation of the coal mining industry by 2050. This is mainly driven by the strong electrification of the mining sector and use of decarbonised electricity from grid as a replacement to fossil fuel-based onsite generation.

4.5.3 Petroleum refining

The Reference Scenario projections of Australia's refinery production are based on the forecasts provided by (DIIS 2019). According to the source the refinery production is expected to variate with a compound average annual growth of -0.6% between 2018 and 2024. We apply the same trend to derive the refinery production projections until 2050. We further assume that the electricity demand is mainly provided by onsite fossil fuel-based generation (mainly diesel). It is assumed that the direct energy fuel mix remains rather unchanged under the Reference Scenario projections as mainly provided by oil according to the last energy update by (DEE, 2019b).

For every barrel of crude oil, local refineries produce a range of petroleum products including petrol, diesel, jet fuel, fuel oil, LPG, and other products and chemical feedstocks. In a 1.5 °C compatible world, the passenger vehicle fleet becomes fully electric by 2050 and zero-emission freight trucks and trains dominate the freight transport vehicle fleet; thus, the share of petrol and diesel in the transport declines to zero. Additionally, zero carbon fuels such as biofuels and renewable-based synthetic fuels would replace jet fuel used in aeroplanes. Also, the share of fuel oil and other fossil fuels in the power sector significantly reduces. Based on the significant reduction for petroleum products across various sectors expected under the 1.5 °C compatible scenario pathways, we assume that Australia's refinery production declines continuously from 2020 onwards to reach zero in 2050. Additionally, we assume that the proportion of grid electricity to onsite generation increases from near 0% today to 100% by 2050. We also assume that the refinery industries are completely electrified following a s-curve trajectory.

In petroleum refining sector, steam is mainly used for process heating while electricity is used for machine driven systems. Thus, increased electrification of heating, rotating equipment and machineries in the petroleum refinery could lead to reduction in the conventional fuel use in the sector and as a result, lower emissions (Kreijkes et al., 2018).

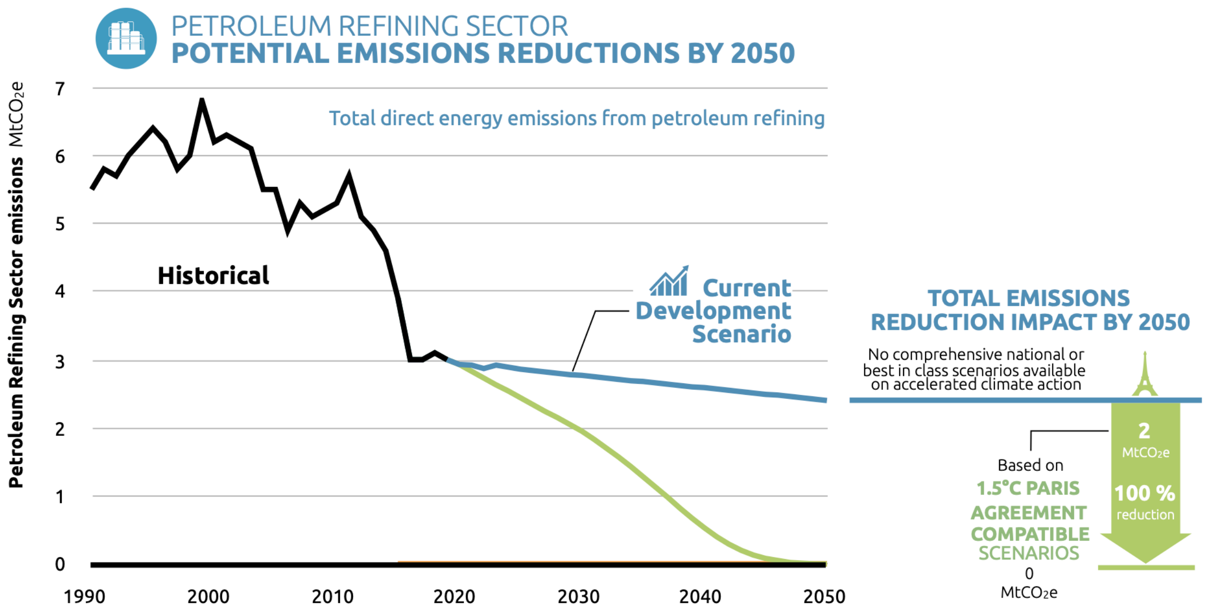


Figure 41: Overview of sectoral emission pathways under Reference scenario projections and different levels of accelerated climate action in Australia's petroleum refining

Figure 41 illustrates the emissions trajectories from Australia's petroleum refining sector until 2050 for the Reference and Paris Agreement scenarios, while enhanced climate action is further combined with decarbonisation of the electricity sector. The Reference Scenario results in emissions from Australia's petroleum refining activities slightly decline from today to about 2.5 $MtCO_2e/a$ in 2050. The '1.5°C Paris Agreement compatible' pathway substantially reduces emissions and leads to the full decarbonisation of the petroleum refining sector by 2050.

4.5.4 Fugitive emissions

In this section, the fugitive emissions coming from coal, oil and domestic gas are assessed (fugitive emissions from natural gas used for export are covered in the section on LNG). In the case of coal, the fugitive emissions come from black coal only. Therefore, historical data of the production of black coal is based on (Department of the Environment and Energy (DEE)., 2019). The historical fugitive emissions from coal and the projections in black coal production are based on 2030 (Australian Department of the Environment and Energy (DEE)., 2019a). The black coal production is projected to increase at 0.23%, 0.75% and 0.49% between 2020-2025, 2025-2030 and 2030-2050 respectively. The average fugitive emissions intensity ($MtCO_2e/PJ$) based on recent five years is used to calculate the fugitive emissions from coal production over the projection period. In the reference scenario, the fugitive emissions from coal increase from about 24 $MtCO_2e$ in 2019 to 28 $MtCO_2e$ in 2050 i.e. 8% above 2005 levels. In the Paris Agreement scenario, the coal production is projected to decline continuously from 2020 onwards and reach zero by 2050. Hence, the fugitive emissions from coal production would also become zero in a 1.5 °C compatible world.

In the case of gas, the fugitive emissions from LNG sector are assessed separately in section 4.5.1. The fugitive emissions from domestic gas in Australia comes from natural gas use in Australia except the gas used in LNG production. In the reference scenario, the gas consumption in different sectors in Australia (excluding LNG) rise from about 1140 PJ in 2019, peak around 2025/26 and decline to reach about 900 PJ in 2050 (Department of the Environment and Energy (DEE)., 2019). The average fugitive emissions intensity ($MtCO_2e/PJ$) based on recent five years is applied to estimate the fugitive emissions from domestic gas over the projection period. In the reference scenario, the fugitive emissions from domestic gas change from 16.3 $MtCO_2e$ in 2019 to 11.7 $MtCO_2e$ in 2050 which is 22% above 2005 levels (Australian Department of the Environment and Energy (DEE)., 2019a).

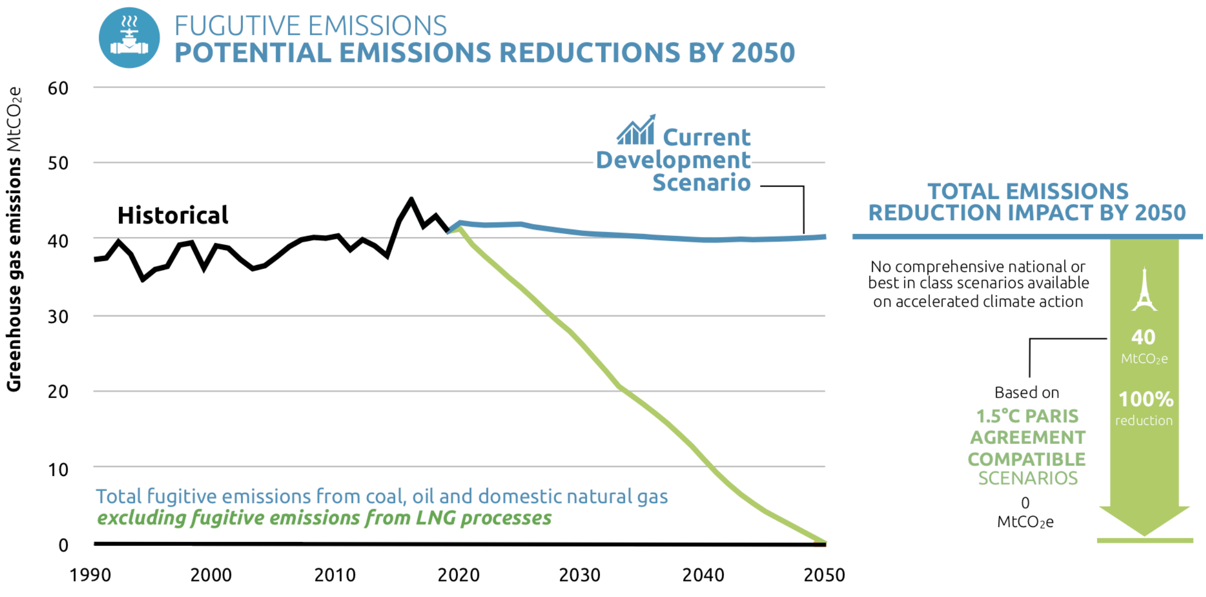


Figure 42 : Overview of sectoral emission pathways under reference scenario projections and 1.5 °C Paris Agreement compatible from coal, oil and domestic gas fugitives. Source: own calculations, Assumptions see text.

In the recent years, there is a declining trend in the production of crude oil, condensate and LPG in Australia as well as declining investment in the oil sector (Department of the Environment and Energy (DEE)., 2019). The share of fugitive emissions from oil production in 2019 was 0.8 $MtCO_2e$, which is very small as compared to the fugitive emissions from other fuels levels (Australian Department of the Environment and Energy (DEE)., 2019a).

In the reference scenario, it is assumed that the oil production would peak around 2020 and continue in the recent declining trend until 2050. In this scenario, the fugitive emissions from oil would reach 0.22 $MtCO_2e$. In a 1.5 °C compatible world, the fugitive emissions from oil would reach zero due to the complete phase out of fossil fuel and replacement by zero carbon fuels.

4.6 Non-energy emissions from agriculture and waste sector

To assess the historic as well as projections of emissions from the agriculture sector under the Reference scenario, we apply the PROSPECTS Australia Scenario evaluation tool. The non-energy related emissions from agriculture cover emissions from enteric fermentation, manure management, manure applied to soils and left on pasture, rice cultivation, and other land-related emissions from synthetic fertilizers, crop residues and cultivation of organic soils. Thus, here we do not cover the energy-related emissions from electricity use or fuel combustion from operating equipment, which are included in the energy-related emissions covered in overall industries. The bulk of agriculture greenhouse gas emissions we cover in this part are methane and nitrous oxide.

To derive the projections of non-energy emissions from the Agriculture sector for the "Paris Agreement Compatible Scenarios", we applied the growth rate of non-CO_2 emissions from the agriculture sector for the OECD region over 2016-2050 based on the 1.5°C pathways assessed in the Special Report on Global Warming of 1.5°C by the Intergovernmental panel on Climate Change (IPCC SR 1.5, 2019). The subset of scenarios excludes those that exceed the sustainability limits for carbon-dioxide removal options identified in the SR 1.5 and the underlying literature[36]. The ambition level of the "Paris Agreement Compatible scenarios" is derived based on the selected set of scenarios from (IPCC SR 1.5, 2019), projecting an annual average rate of -1% p.a. over 2016-2050.

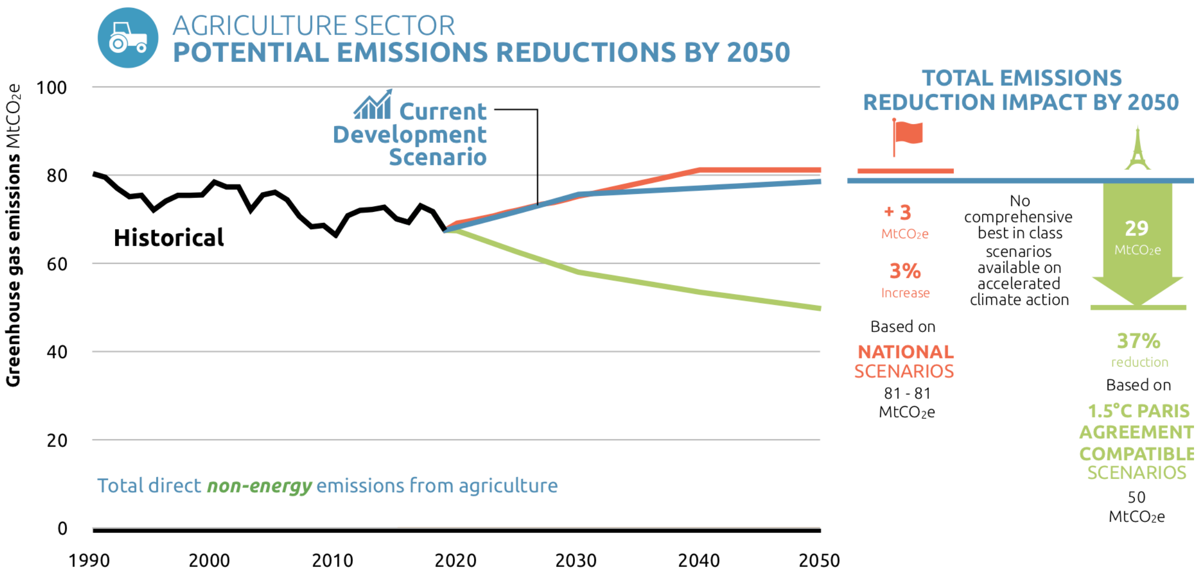


Figure 43: Overview of non-energy emission pathways under reference scenario projections, Paris Agreement Compatible pathways, and a scenario based on published national scenarios in the Australia's agriculture sector

Figure 43 shows the non-energy emissions trajectories from Australia's agriculture sector until 2050 for different scenario categories. Under the reference scenario projections, the emissions in 2050 are 3% higher as compared to 2005 values. The DEE projections covering the emissions from enteric fermentation, manure management, rice cultivation, agricultural soils and field burning of agricultural residues show emissions increasing to about 74 $MtCO_2e$/a in 2030 (Australian Department of the Environment and Energy (DEE)., 2019a). For comparison, the Reference Scenario results in non-energy emissions from Australia's agriculture sector (excluding direct energy and electricity-related emissions) increasing from 70 $MtCO_2e$/a in 2015 to 76 $MtCO_2e$/a [37] emissions in 2030.

[36] Fuss et al. (2018) identify a sustainability limit of 0-3.6 $GtCO_2$ (removal)/yr for Agriculture, Forestry and Other Land Use (AFOLU), and 0.1 – 5 $GtCO_2$/yr for Bioenergy with Carbon Capture and Storage (BECCS) in 2050. We apply these limits to the average of the corresponding pathway values between 2040-2060 to filter out pathways which exceed them.

[37] This is higher than the reported values by DEE due to the fact that reported values by PROSPECTS include three subcategories related to manure emissions: (1) Manure applied to soils (2) Manure left on pasture (3) Manure management from the FAOSTAT data. The reported values by (Department of the Environment and Energy, 2018)(Department of the Environment and Energy, 2018)(Department of the Environment and Energy, 2018)(Department of the Environment and Energy, 2018)(Department of the Environment and Energy, 2018)(Department of the Environment and Energy,

The '1.5°C Paris Agreement compatible' pathways imply an immediate and drastic reduction of non-energy emissions from agriculture sector. Based on annualized reductions for the OECD region, the "Paris Agreement Compatible Scenarios" project an approximately 35% reduction of emissions relative to 2005 levels by 2050, respectively. In the underlying scenarios, key mitigation options are enhanced agricultural management (e.g. manure management, improved livestock feeding practices, and more efficient fertiliser use), as well as demand side measures such as dietary shifts to healthier, more sustainable, low-meat diets and measures to reduce food waste. The underlying scenarios do not, however, offer a complete assessment of mitigation options and do not generally cover e.g. large-scale replacement of meat by plant-based proteins and cultured meat, novel technologies such as methanogen inhibitors and vaccines, nor synthetic and biological nitrification inhibitors (see IPCC SR 1.5, 2019). Finally, the reliance of some pathways on significant amounts of bioenergy after mid-century (see IPCC SR 1.5, 2019, Sections 2.3.3 and 2.4.2) coupled to a substantial use of nitrogen fertilizer also makes reducing N_2O emissions harder.

There are no national scenarios published that lead to reductions in emissions from agriculture that do not include carbon sinks from the LULUCF sector. The Deep Decarbonisation Pathway Scenario (Climate Works 2014) leads to an increase in emissions by 2050 by 20%. A recently published study (FABLE, 2019) also assumes agriculture emissions to stay at a level of 80 Mt CO_2eq in 2050. This is reflected in the NS shown in the graph. Meyer (2020) found that net zero or negative emissions from the agricultural sector are possible within the next 10 years, but the sector scenarios included agriculture related deforestation/land use change and energy and fossil fuel emissions from agricultural production. (This scenario was not included as a national scenario in the above graph due to the differing sector assumptions such as the inclusion of LULUCF and energy related emissions). Achieving negative emissions poses a huge challenge, but Meyer (2020) outlines the possibility through mitigation methods currently available, research and development investment, and also through incentives for options that are not currently commercially feasible. Challenges preventing adoption for emissions mitigation in the agriculture sector are related to installing new infrastructure and new farm techniques, the expertise and costs with reporting and verification of carbon credits, and knowledge gaps (Meyer 2020).

Emissions from waste are primarily due to the release of landfill gas from anaerobic decomposition of waste material in landfills as well as due to waste-water treatment. These would mainly include methane and nitrous oxide emissions. We apply the PROSPECTS Australia scenario evaluation tool to evaluate the historic emissions as well as Reference Scenario projections for the emissions from the waste sector. The waste sector module in PROSPECTS tool distinguishes between the emissions from municipal solid waste as major contributor, whose emissions is calculated based on IPCC approach, and a smaller share of emissions due to wastewater treatment.

2018)(Department of the Environment and Energy, 2018)(Department of the Environment and Energy, 2018) includes the manure management category but does not include the "manure applied to soil/left on pasture" category.

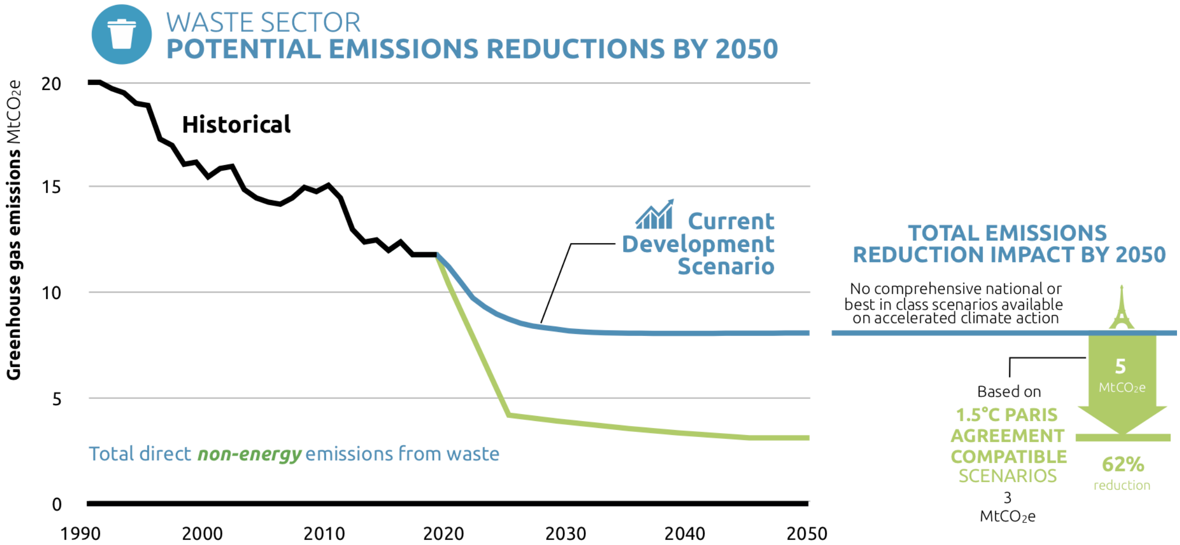


Figure 44: Overview of emission pathways under reference scenario projections and Paris Agreement compatible Pathways in the Australia's waste sector

Figure 44 shows the trajectories of total emissions from Australia's waste sector until 2050 for different scenario categories. Under the reference scenario projections, the emissions in 2050 are by 44% lower as compared to 2005 values. The DEE projections covering the emissions from municipal solid waste as well as domestic and commercial waste water in Australia show emissions reach to 10.7 $MtCO_2e$ in 2030, a decline of 25% from 2005 levels (Australian Department of the Environment and Energy (DEE)., 2019a). For comparison, the Reference Scenario in our assessment projects Australia's waste sector emissions declining from 12 $MtCO_2e/a$ in 2015 to 8.2 $MtCO_2e/a$ emissions in 2030 (32% reduction).

To derive the projections of emissions from waste sector for the "Paris Agreement Compatible Scenarios", we applied annualized growth rates for the OECD region over 2016-2050 based on the regional pathways assessed in the Special Report on Global Warming of 1.5°C by the Intergovernmental panel on Climate Change (IPCC SR 1.5, 2019). Under the '1.5°C Paris Agreement compatible' pathway, the emissions from waste sector shows an immediate and drastic reduction, declining to approximately 73% in 2030 as compared to 2005 levels and about 3 $MtCO_2e/a$ in 2050. Note however that the range of models and scenarios that provide emissions for the waste sector is very small and is based here essentially on a single model. Nonetheless, very deep reductions in such scenarios are to be expected as mitigation in the waste sector are highly cost effective and could even return a net profit (IPCC SR 1.5, section 4.3.6).

4.7 A Pathway for Australia to net zero emissions

Meeting the Paris Agreement's long-term temperature goal (LTTG) of holding warming well below 2° and limiting warming to 1.5°C above preindustrial is the focus of this report.

In the Australian policy context the fact that this goal is a replacement of and strengthening of the hold warming below 2°C goal agreed in Cancun 2010 is sometimes overlooked. Pathways compatible that 'hold warming below 2°C achieve this goal with a likely (>66%) probability and peak 21st century warming no lower than 1.7-1.8°C above pre-industrial (Wachsmuth, Schaeffer, and Hare 2018).

The IPCC Special Report on 1.5℃ (IPCC SR1.5) (IPCC 2018a) Summary for Policy makers (IPCC 2018b) identifies 1.5°C compatible pathways as those with no or limited overshoot of the 1.5°C warming level. All of these pathways limit warming below 1.5°C by the end of the century (median 1.3°C warming by 2100), with a 50% or greater probability. Low-overshoot pathways limit warming well below 1.5°C by the end of the century (around 1.3°C warming by 2100) after a brief and limited overshoot of peak warming below 1.6°C around the 2060s. No-overshoot pathways limit peak global warming to 1.5°C throughout the 21st century with 50% or greater probability without exceeding 1.5°C warming. There were no technically and economically feasible pathways reviewed in the IPCC SR1.5 that hold warming throughout the 21st century below 1.5°C with a likely probability (66% or greater).

To meet the Paris Agreement's 1.5°C warming limit IPCC SR1.5 finds that a massive increase in effort is required to peak global GHG emissions as soon as possible, reduce all greenhouse gas emissions, including CO_2 emissions to 45% below 2010 levels by 2030 and to reach net-zero emissions around 2050 for CO_2 emissions and net zero GHG emissions globally by around 2070.

4.7.1 Global Carbon Budget estimates: limitations and uncertainties

Australia's cumulative CO_2 and GHG emissions from this study fit within a range of different perspectives on the carbon and greenhouse gas budgets consistent with limiting warming to 1.5°C. Carbon budgets for warming limits have a very large uncertainty and because of the need for negative CO_2 emissions[38] can be confusing and hard to interpret.

Carbon budgets are subject to very large uncertainties, including first and foremost from non-CO_2 GHG gases. In addition, this kind of budget obscure some key features of the technically and economically feasible pathways of energy system transformation that could meet the 1.5°C warming limit in practice. The CO_2 emissions from 1.5°C compatible scenarios can exceed the carbon budgets identified in IPCC SR1.5 above by 2050, and any excess will have to be compensated for by negative CO_2 emissions post 2050. Part of the reason for this is due to historically high emissions which need to be compensated with negative CO_2 emissions. In addition, ongoing non-CO_2 GHG emissions from hard to abate sectors including agriculture also need to be compensated, so there likely to be a need for negative CO_2 emissions for this purpose.

Two broad perspectives are used here as a cross check on Australia's cumulative emissions.
The IPCC SR1.5 has estimated the remaining carbon that can be emitted for different levels of warming along with uncertainties such as non-CO_2 greenhouse gas scenarios, climate response and sensitivity uncertainties, and geophysical feedbacks (See Table 2.2, (Rogelj et al. 2018). The remaining carbon budget from 2018 before reaching 2.0 °C warming with a likely (66% chance) was estimated as 1,120 $GtCO_2$, and to limit warming to 1.5 °C warming with a 50% probability 580 $GtCO_2$, and with a 67% probability 420 $GtCO_2$ (Rogelj et al. 2018). After accounting for an estimated 100 $GtCO_2$ of carbon release from geophysical feedbacks the remaining budget to limit the warming to below 1.5 °C (50% chance) would reduce to 480 $GtCO_2$ and 320 $GtCO_2$ with a 67% probability (IPCC 2018a).

The IPCC SR1.5 (IPCC 2018a) estimated the remaining cumulative carbon (carbon budget) that can be emitted for different levels of warming along with uncertainties such as non-CO_2 greenhouse gas scenarios, climate response and sensitivity uncertainties, and geophysical feedbacks (See Table 2.2 (J Rogelj et al. 2018)). After accounting for an estimated 100 $GtCO_2$ of carbon release from geophysical feedbacks the remaining budget to limit the warming to below 1.5 °C (50% chance) would reduce to 480 $GtCO_2$ and to 320 $GtCO_2$ with a 67% probability (IPCC 2018a). Recently the EU Horizon 2020 research project provided an update of the remaining carbon budget from 1.1.2020 (CONSTRAIN 2019). The reduction in the remaining carbon budgets in the recent CONSTRAIN estimates are due approximately 84 $GtCO_2$ emitted from fossil and land-use change sources in 2018 and 2019 (Friedlingstein et al. 2019) (Table 26).

38 To achieve zero emissions there is a need to compensate for remaining emissions using carbon dioxide removal options (CDR), including either large-scale afforestation and reforestation, bioenergy with carbon capture and storage (BECCs) or other options such as direct air capture (DAC). In our analysis, we have not analysed the deployment options for carbon dioxide removal, via BECCs or DAC. We have focused on analyses of options for emission reductions across all sectors with the aim to minimise the reliance on CDR options in the period to 2050. This will also have the benefit of minimising, but not eliminating, the need for CDR options post 2050, a timeframe not considered in this report

In designing a Paris Agreement compatible emissions pathway and budget emissions of non-CO_2 greenhouse gases also need to be accounted for. Carbon budgets are subject to very large uncertainties, including first and foremost from non-CO_2 gases. These uncertainties are of the range of -400 $GtCO_2$ to +250 $GtCO_2$ per evaluated component (J Rogelj et al. 2018; Joeri Rogelj et al. 2019). Furthermore, irreducible uncertainties linked to assessments of the human-induced warming to date amount to +/- 180 Gt CO_2 (or 5 years of present-day CO_2 emissions) (Tokarska et al. 2020). Also critical to defining the carbon budget is the probability with which a given temperature level/limit is to be achieved. Two probability levels often referred to in scientific assessments are 50% probability and a likely probability (a 66% or greater chance of limiting warming to the chosen level).

Table 26: 1.5°C Global carbon budget estimates – $GtCO_2$

1.5°C above 1850-1900	**IPCC SR1.5** ***without*** earth system feedbacks	**IPCC SR1.5** ***with*** earth system feedbacks	**CONSTRAIN** ***without*** earth system feedbacks	**CONSTRAIN** ***with*** earth system feedbacks [39]
	From 1.1.2018	From 1.1.2018	from 1.1.2020	from 1.1.2020
50%	580	480	495	395
>66 %	420	320	335	235

From the very large uncertainties described here it can be seen that carbon budgets at best only provide an orientation around whether or not a given temperature limit can be met, and in addition obscure some key features of the technically and economically feasible pathways which are required to meet those limits in practice.

If Australia's share of this were equivalent to its current contribution to global CO_2 emissions of 0.9% its budget would be 2.9-4.3 $GtCO_2$. As this budget corresponds to the time at which 1.5°C is reached this corresponds to the period 218-2050 and can be compared with the cumulative Australian total CO_2 emissions from this study of around 2.8 $GtCO_2$ for the same period. It should be noted that the cumulative fossil fuel and industry CO_2 emissions from this study until 2050 are around 5 $GtCO_2$.

Whilst on the surface the cumulative Australian CO_2 emissions would appear to be consistent with the 1.5°C carbon budget above the picture is more complex due to the ongoing emissions of non-CO_2 GHGs, and the related need for negative CO_2 emissions.

Another way to derive an appropriate greenhouse gas and carbon budget for Australia is to look at the cumulative GHG and CO_2 emissions from 1.5°C compatible scenarios using integrated assessment models (IAM) assessed in the IPCC SR1.5. The full range of emissions including air pollutants are assessed using reduced complexity climate models to produce probabilistic assessment of the global warming consequences to evaluate how these pathways meet the climate goals. This is the way the IPCC SR1.5 evaluated these pathways for 1.5°C compatibility.

The 1.5°C compatible scenarios using integrated assessment models (IAM) assessed in the IPCC SR1.5. have cumulative emissions GHG emissions from 2018 until 2100 of 830 $GtCO_2e$ (see Table 27Table 27). The cumulative total GHG emissions in 1.5°C scenarios from 2018 until 2050 are 860 $GtCO_2e$ and afterwards 2051-2100 net negative emissions of -30 $GtCO_2e$. If Australia's share of this were equivalent its current contribution to global CO_2 emissions its budget would be around 7.7 $GtCO_2e$ to 2050 and about 7.5 $GtCO_2e$ for the full century (2018-2100). Australia's cumulative GHG emissions from this study from 2018-2050 are around 6.4 $GtCO_2e$ (7.8 $GtCO_2e$ before counting land sector carbon storage estimated here at 1.5 $GtCO_2e$). See Table 30 for an overview of these results.

These pathways also show for total CO_2 cumulative emissions from 2018 until 2050 are 560 $GtCO_2$ and from 2051-2100 cumulative emissions CO_2 emissions are negative at around -360

39 Data are rounded to the nearest 5 Gt CO2 (CONSTRAIN report, 2019).

$GtCO_2$, with the total CO_2 cumulative emissions from 2018 until 2100 being 200 $GtCO_2$ Total CO_2 includes emissions from land use as well as fossil fuels. If Australia's share of this were equivalent to its current contribution to global CO_2 emissions of 0.9% its budget would be around 5 $GtCO_2$ to 2050 and about 1.8 $GtCO_2$ for the full century (2018-2100), implying a need for negative CO_2 emissions at scale to compensate post 2050. The cumulative Australian CO_2 emissions from this study from 2018-2050 are around 2.8 $GtCO_2$, which implies a need for ongoing negative CO_2 emissions post 2050.

Considering only Fossil Fuel and Industry CO_2 emissions, cumulative emissions from 2018 until 2050 is 540 $GtCO_2$ and afterwards (2051-2100) cumulative emissions CO_2 emissions from the energy sector are negative at around -190 $GtCO_2$. This is quite close to the total CO_2 budget above for 2018-2050 as these scenarios generally assume the land sector is close to balance in this period as deforestation is reduced and carbon storage on land is ramped. Post 2050 these budgets diverge as carbon storage on land increases (negative CO_2 emissions) so that the total negative emissions are around 360 $GtCO_2$ with about 190 $GtCO_2$ from measures to take CO_2 from the atmosphere using the energy system, and the remainder in the land sector.

If Australia's share of the fossil fuel and industry CO_2 emissions budget were equivalent to its current contribution to global CO_2 emissions its budget would be around 4.9 $GtCO_2$ to 2050 and about 3.2 $GtCO_2$ for the full century (2018-2100), also implying a need for negative CO_2 emissions at scale post 2050. The cumulative Australian fossil fuel and industry CO_2 emissions from this study until 2050 are around 5 $GtCO_2$, implying a need to be negative CO_2 emissions of order to 2$GtCO_2$ post 2050 to compensate for high historical emissions and for remaining emissions that cannot be reduced to zero.

Table 27 Median estimates of scenario carbon budgets in each time period for low and no-overshoot 1.5C pathways (rounded to the nearest 5Gt).

Emissions	2018-2050	2051-2100	2018-2100	Zero emissions
Total GHGs ($GtCO_2e$)	860	-30	830	2070
	[800 - 930] [40]	[-90-70]	[800 - 910]	[2060-2075]
Total CO_2 ($GtCO_2$)	560	-360	200	2050
	[500 - 610]	[-450 - -270]	[100 - 310]	[2050-2055]
Fossil Fuel & Industry CO_2 ($GtCO_2$)	540	-190	350	2060
	[500 - 600]	[-340 - -30]	[200 - 520]	[2050-2065]

This analysis shows that in general the 1.5°C compatible pathways assessed in the IPCC SR1.5 rely significantly on negative CO_2 emissions to limit warming to 1.5°C or below. In general, this is because of the large volume of non-CO_2 greenhouse gas emissions that continue to be emitted in these scenarios because they are hard to reduce or eliminate. Consequently, in part a significant volume of negative CO_2 emissions omitted to compensate for this in the latter half of the century, which is a further complication in interpreting carbon budgets. Scenarios that limit the use of negative emissions are characterised by even stronger near-term emission reductions, for example a reduction of global coal deployment by 2030 by about 80% relative to 2010 (Pathway P1, IPCC SR1.5) and almost complete phase out of all fossil fuels including oil and gas by 2050.

In summary the amount of negative emissions ultimately required is linked to near-term emission reduction actions. Higher emissions than should otherwise be the case for a 1.5°C pathway would entail obligations for the future deployment of negative emissions to compensate. The amount of land sector carbon storage assumed in some studies is high and may be infeasible or can raise concerns from a sustainability perspective. Such obligations can be derived from present (inadequate) mitigation commitments under the Paris Agreement (Fyson et al. 2020). Australia

[40] All calculations here are listed with <median> [<25th percentile> - <75th percentile>]

has about 17 tonnes of CO_2 per capita one of the highest per capita emission rates in the world (Monica et al. 2019).

What this means for policy is that all efforts need to be taken to minimise the need for negative CO_2 emissions, and this means reducing the cumulative emissions by 2050 as much as possible. Apart from economic costs this is another reason why the substantial emission reductions by 2030 are critical, and hence why the pathway to zero emissions is very important for ultimately achieving the Paris Agreement's long-term temperature goal.

4.7.2 Australian carbon budget estimates

There are range of different approaches to go from a global budget to a national budget. Meinshausen and colleagues (Meinshausen, Robiou du Pont, and Talberg 2018) summarised a range of different approaches which are reproduced in Table 28 below. Here we take the full range of approaches shown here to provide an illustrative range of budgets for Australia reflecting different approaches to sharing global mitigation effort from 0.59% to 1.27% of a global budget.

As this work is focusing on domestic action, and does not include an assessment of the contribution Australia to emission reductions abroad, we also show an approach that is more linked to cost effective global emission reduction pathways. For example DIW (Deutsches Institut für Wirtschaftsforschung (DIW). 2018), has shown that allocating CO_2 emissions based on current emissions is close to an optimal allocation by a central planner with perfect foresight, corresponding to the least-cost global emission reduction pathways perspective. Australia's share of CO_2 emissions in 2018 this was about 0.9% accounting for all sources (fossil fuel, cement, and land use change)[41]. This has been gradually decreasing over the last decade from 1.23% in 2009.

In addition a commonly used reference point for the allocation of a carbon budget to Australia is the work of Climate Change Authority from 2014 , as cited by (Meinshausen, Robiou du Pont, and Talberg 2018),of 0.97% for a 2°C global goal. Given the growth of global emissions since that time and Australia's declining relative share of emissions and that this is not for a 1.5°C global goal it may not be an ideal indicator reference point, however it remains in common use.

Table 28 Fair share approaches for Australia's share of the global carbon budget (Meinshausen, Robiou du Pont, and Talberg 2018)

Allocation type	Global scenarios with 67% chance of staying below 2°C	Global scenarios with 50% chance of returning to 1.5°C in 2100
Garnaut (2008) method of modified contraction and convergence (as adopted by the CCA)	0.97% (assumed)	not known
Equal per capita convergence	0.73%	0.78%
Equal cumulative per capita	0.68%	0.62%
Capability	0.52%	0.59%
Greenhouse Development Rights	1.19%	0.98%
Constant emissions ratio	1.27%	1.27%

41 Global data from Global Carbon Project (2019) Carbon Budget and Trends 2019. [www.globalcarbonproject.org/carbonbudget] (Friedlingstein et al. 2019) and national data from https://ageis.climatechange.gov.au/

Table 29 shows the carbon budget for Australia across different time spans (2018-2050 and 2018- 2100) in terms of total greenhouse gas emissions, CO_2 from all sources and CO_2 from fossil fuel and industry sources for the full range of fair share approaches. This table shows that the full century GHG budget share for Australia is in the range of 4.9 to 10.9 $GtCO_2e$, and if a budget were based on Australia's present share of CO_2 emissions it would be around 7,5 $GtCO_2e$ for the period to 2018- 2100. The GHG budget to 2050 is slightly higher 5.1 to 10.9 $GtCO_2e$.

In this study the total cumulative GHG emissions to 2050 are estimated at about 7.7 $GtCO_2$ before consideration of land use change emissions and/or removals. If the net land sector sequestration projected in the Australian Governments 2019 projections were achieved and maintained at 2030 levels to 2050 the total cumulative GHG emissions to 2050 would be about 7.3 $GtCO_2$. As will be discussed in the next section however GHG emissions would still not be zero by 2050.

For fossil fuel and industry CO_2, based on the median of the 1.5°C compatible IAM scenario set for the period 2018 to 2050 the budget is in the range of 3.2 to 6.9 $GtCO_2$, with the share based on Australia's present share of CO_2 emissions would be around 4.9 $GtCO_2$. For the entire century the budget would be substantially lower, in the range 2.1 to 4.4 $GtCO_2$ for the period to 2018-2100. This means that there will very likely be need for negative CO_2 emissions post 2050 at scale to bring the carbon budget back into balance. With a fossil fuel and industry budget based upon Australia's present share of total CO_2 emissions globally negative emissions needs would be around would be around 1.7 $GtCO_2$ to 2100. This is indication of the scale of negative emissions Australia may need to invest in to contribute its share to global efforts to limit warming to 1.5°C.

In this study the total cumulative fossil fuel and industry CO_2 emissions to 2050 are estimated at about 4.9 $GtCO_2$. A summary of the results is provided in *Table* 30.

Table 29 Total carbon and GHG budget for Australia from 2018

	Lower end	Total CO_2 share	Climate change Authority (2014)	Higher end
Australian share of global emissions budget	0.59%	0.90%	0.97%	1.27%
Total GHG 2018-2050 (IAM median)	5.1	7.7	8.3	10.9
Total GHG 2018-2100 (IAM median)	4.9	7.5	8.1	10.5
Total CO_2 2018-2050 (IAM median)	3.3	5.0	5.4	7.1
Total CO_2 2018-2100 (IAM median)	1.2	1.8	1.9	2.5
Total CO_2 based on IPCC SR1.5 carbon budget 2018-2100	1.9-2.8	2.9-4.3	3.1-4.7	4.1-6.1
Total fossil fuel and industry CO_2 2018-2050 (IAM median)	3.2	4.9	5.2	6.9
Total fossil fuel and industry CO_2 2018-2100 (IAM median)	2.1	3.2	3.4	4.4

Notes: The IAM median emissions budgets are calculated from Table 27 and are the estimated cumulative emissions from the set of scenarios classified as 1.5°C compatible in the IPCC SR1.5. For comparison the carbon budgets estimates based on the IPCC SR1.5 as shown in Table 26 are included here (see discussion above) – the low end of these ranges are for 67% probability and the high end for 50% probability budgets respectively for 1.5°C

Table 30 Australia's cumulative CO_2 and greenhouse gas emissions for 1.5°C scenario compared to carbon budget estimates

Australia emissions	Scenario emissions 2018-2050	IAM Budget 2018-2050	IAM Budget 2018-2100
Total GHG emissions $GtCO_2e$	6.4	7.7 [6.2–8.5]	7.5 [6.3–8.2]
Fossil fuel and industry CO_2 emissions $GtCO_2$	5.0	4.9 [4.4–5.6]	3.3 [1.7–4.7]
Total CO_2 emissions $GtCO_2$	2.8	5.0 [4.3–5.5]	1.8 [0.9–2.9]
		IPCC SR1.5 budget 2.9–4.3	

Notes: Australia's share of carbon budget assumed here is 0.9%. IAM median budgets are shown and range is [25th – 75th percentile]. The IPCC SR1.5 range is from a 67% (lower budget) to a 50% likelihood (lower carbon budget). It is located in the period to 2050 as the budget is calculate to the point at which the temperature limit is reached and CO_2 emissions reach zero at this time.

4.7.3 Reaching net zero emissions in Australia

As shown in Table 27 above globally GHG emissions need to reach zero by around 2070, and fossil fuel and industry CO_2 emissions by around 2060, with total CO_2 emissions reaching zero about 2050. The earlier global greenhouse gas emissions and CO_2 emissions peak the sooner warming halt and the lower will be the need for negative emissions in the latter half of the century. These considerations have led to global calls for greenhouse gas emissions to reach net zero emissions by 2050.

When determining its long-term strategy by mid-century, Australia needs to act quickly on a fast decarbonisation of the power sector and recognise this sectors role in decarbonising end use sectors, including industry and transport. It will need to define sectoral targets and roadmaps, and implement more ambitious and stringent policies across all sectors to initiate and steer these sectoral transformations, given long lead times for infrastructure in industry, transport, and buildings.

Emissions from agriculture and waste cannot be reduced to zero, and some of the processes - especially in heavy industry, aviation and shipping - will likely need a bit longer to decarbonise than other sectors. In overall greenhouse gas terms the 1.5°C scenario for Australia developed here, with all options considered, gets to a 90% reduction in emissions (excluding LULUCF) by 2050, with about 50 $MtCO_2e$ per year remaining. Figure 45 provides and overview and summary of the sectoral results from this study.

In this study Australian fossil fuel and industry CO_2 emissions reach zero around 2050, and total CO_2 emissions a little earlier depending upon the assumed storage of carbon in the land sector.

Net zero GHG emissions by 2050 cannot be achieved even with this ambitious strategy unless there is a significant increase in the amount of CO_2 stored in the land sector. Net-zero greenhouse gas emissions would not occur until the 2070s, at the earliest assuming that there are slow reductions in the non-CO_2 emissions from hard to abate sectors.

Achievement of net-zero GHG emissions needs a significant increase in the storage of carbon in Australia in the land sector. This study has not examined the potential for negative emission technology deployment and the timeframe to 2050.

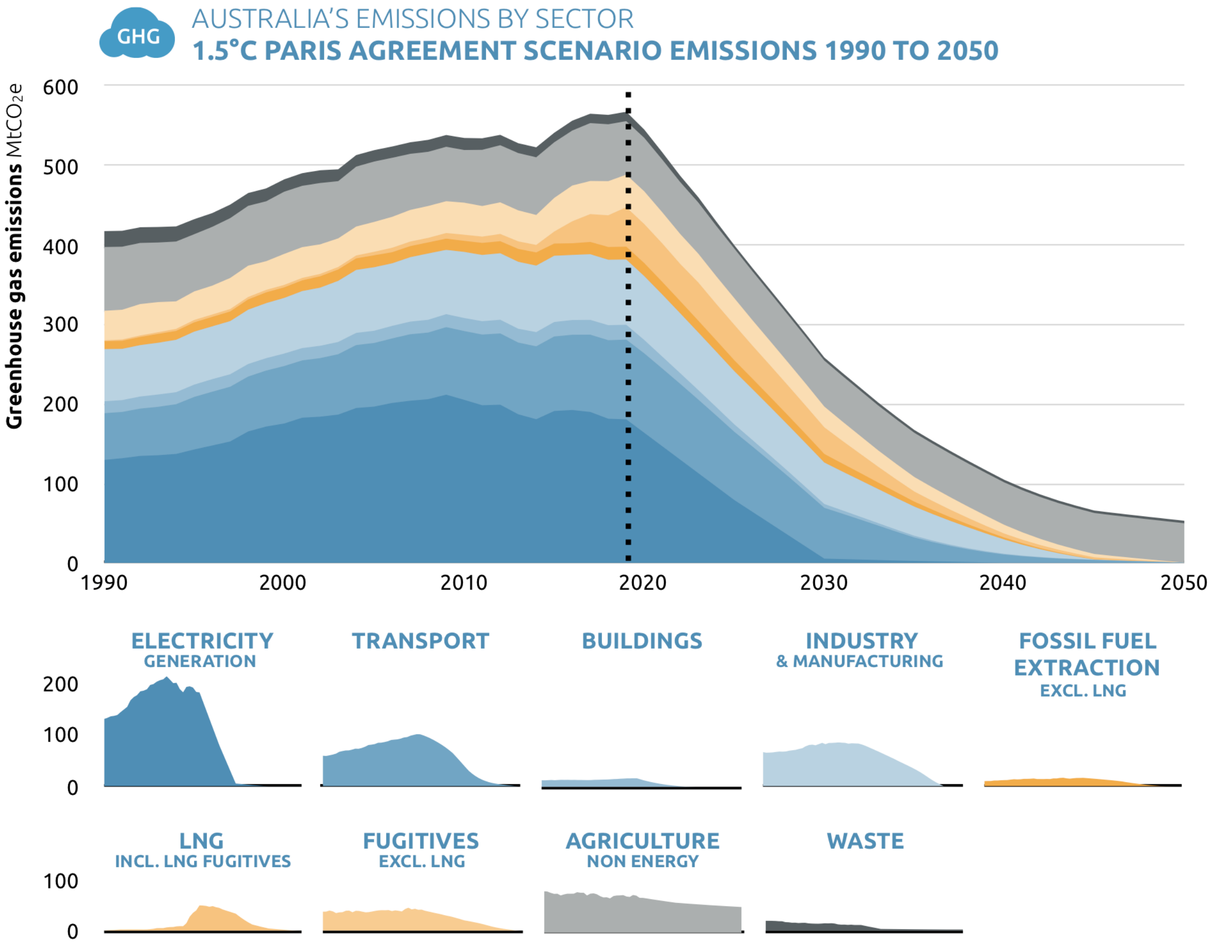


Figure 45 Australia's Paris Agreement-compatible greenhouse gas emissions pathway (not including LULUC) for all of the sectors analysed in this study.

A number of projections indicate that the recent land sector sink will reduce gradually over the next decade without substantial incentives to maintain and increase it. With the government's 2019 land-use change and forestry projections to 2030 extrapolated until 2050 GHG emissions of 93% from 2005 levels may be achievable by 2050.

A CSIRO assessment of potential for land sector carbon sequestration by Bryan et al (2015) indicated substantial potential for additional storage of carbon from a variety of different activities in agricultural land in Australia. A number of conclusions are relevant.

Firstly, policies that focus on carbon storage alone do not generate significant benefits for biodiversity, and policies that favour environment and biodiversity values will result in lower levels of carbon storage.

Secondly, even with large incentives, the inertia in agricultural systems and in the terrestrial biosphere means that there will be low amounts of additional carbon storage by 2030.

Thirdly there is a significant trade-off between a focus on carbon uptake and water values, with a high focus on carbon reducing available water significantly.

These factors indicate a significant research need to evaluate trade-offs and ensure that a focus on carbon storage does not lead to unintended consequences for the agricultural economy, biodiversity water and other environmental values.

There are a significant number of scenarios in Australia that rely very heavily on very large land sector carbon storage in order to reach climate goals or to reach zero GHG emissions significantly earlier than 2050.

It is widely acknowledged that there is some significant scope or land sector storage of carbon.

In this scenario we assume that land clearance emissions stop by 2030 and the net carbon uptake in the forestry sector projected for 2030 continues until 2050. This produces a sink of around 50 megatons per annum in 2050. With this GHG emissions reach net zero by 2050 (Figure 46 and Figure 47Figure 11). This would reduce total GHG emissions including LULUCF by 66% below 2005 (Table 32). The assumption here of essentially halting land clearance emissions, reducing emissions from agricultural and maintaining the forest sink at the levels projected for 2030 is in our view already quite ambitious given the land-use pressures in Australia, as well as the projected effects of climate change on our landscape and natural ecosystems.

Factoring out the non-CO_2 emissions from the land use change and forestry sector, this would have Australia's net-CO_2 emissions reach zero by about 2038, with net negative CO_2 emissions prevailing thereafter (see Figure 12 for land use scenarios). If the rate of carbon storage projected for forests by 2030 can be doubled by 2040 net-CO2 emissions would reach zero a few years earlier by about 2035, and net zero GHG emissions would be achieved about ten years earlier in 2040 compared to 2050 to the case rate of carbon storage projected for forests is maintained at 2030 levels (See Table 31).

Table 31 Sensitivity of cumulative emissions and time of zero GHG and CO_2 emissions to land sector assumptions

Cumulative emissions 2018 to 2050	Land Sector - Govt projections to 2030 extended to 2050	Central scenario End net deforestation by 2030	End net deforestation by 2030, double forest carbon storage by 2040
Total GHG (excluding LULUCF) $GtCO_2e$	7.7	7.7	7.7
GHG Land sector $GtCO_2e$	(0.4)	(1.4)	(2.3)
Total GHG $GtCO_2e$	7.3	6.3	5.5
Year of zero emissions	ca 2070 on trend	2050	2040
Fossil Fuel and Industry CO_2 $GtCO_2$	4.9	4.9	4.9
Year of zero emissions	2055 on trend	2055 on trend	2055 on trend
Total CO_2 $GtCO_2$	3.8	2.7	1.9
Year of zero emissions	2041	2037	2035

The analysis here does not assume offsets between land sector carbon sequestration and greenhouse gas emissions from any other sector. This study also takes into account limits to how much we can rely on increasing carbon removal, as well as inertia in the land sector that limits the available update by 2030, and important trade-offs between a focus on carbon uptake and biodiversity and water values. Policies that focus on carbon storage alone do not generate significant benefits for biodiversity, and policies that favour environment and biodiversity values will result in lower levels of carbon storage. There is a significant trade-off between a focus on carbon uptake and water values, with a high focus on carbon reducing available water significantly.

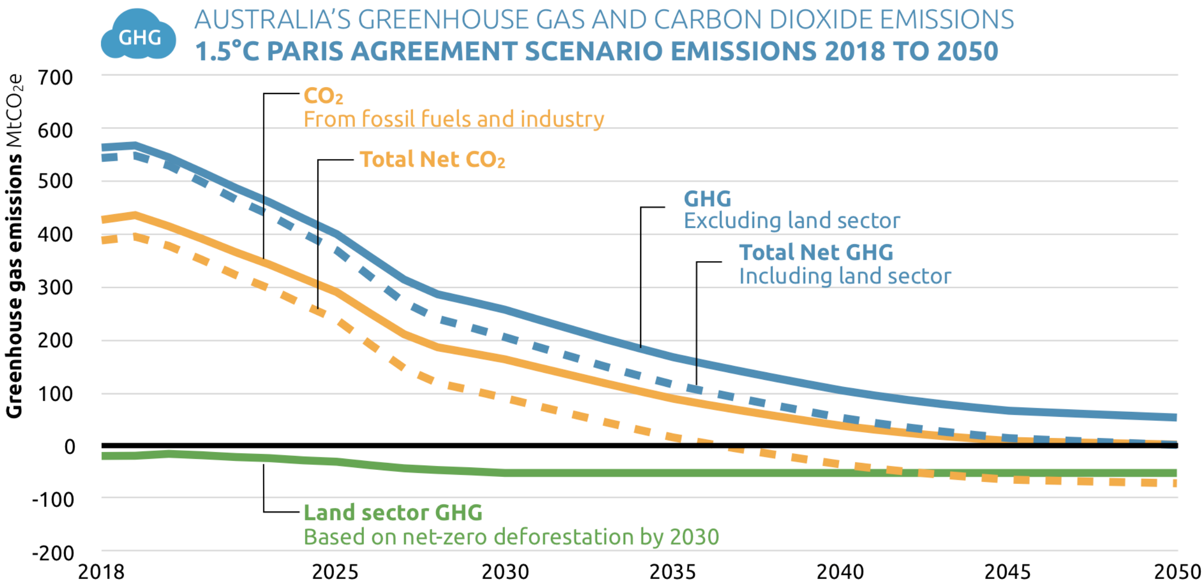


Figure 46 Net greenhouse gas and CO2 emissions pathway for Australia to reach net zero by 2050.

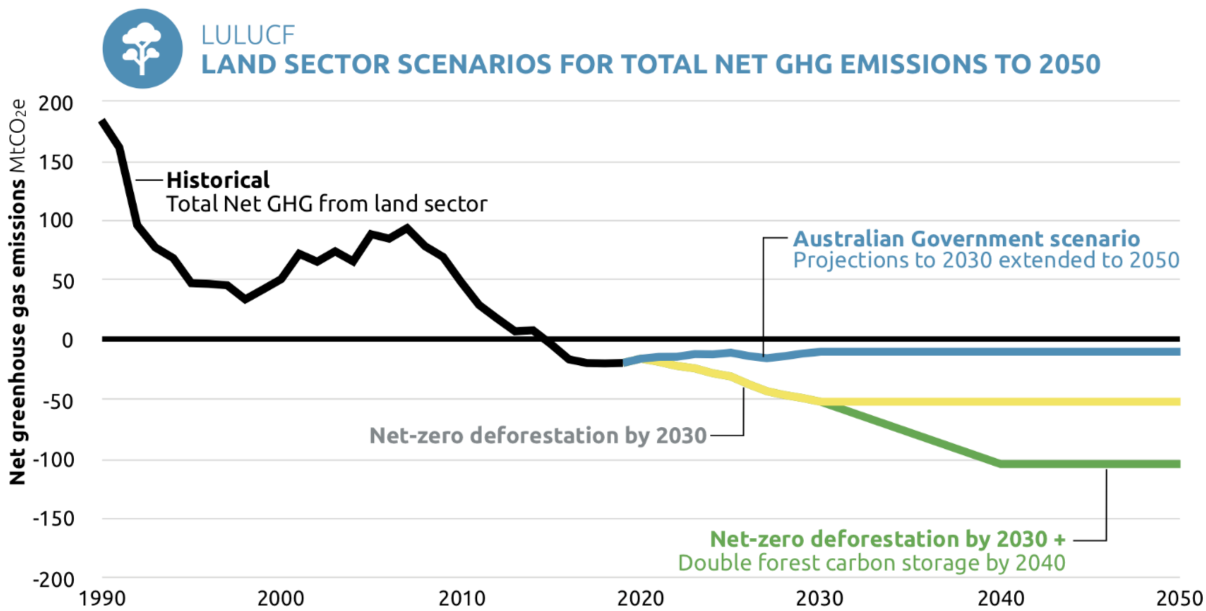


Figure 47 Land use emissions and removals scenarios used in this study.

Table 32 Sectoral emissions and overall reductions in 2030, 2040, 2050 as compared to 2005 for a Paris Agreement consistent pathway as outlined in this study.

Sector	**2005 Baseline**	**2019 value**	**2030 reduction** compared to 2005 baseline	**2040 reduction** compared to 2005 baseline	**2050 reduction** compared to 2005 baseline
Electricity generation	197	180	-97%	-100%	-100%
Buildings	15	19	-69%	-94%	-100%
Transport	80	100	-20%	-87%	-100%
Manufacturing and mining Industry	80	82	-35%	-78%	-100%
Agriculture (non-energy)	76	67	-24%	-30%	-35%
Waste (non-energy)	14	12	-73%	-77%	-78%
Coal mining, Petroleum refining, Oil and Gas extraction (excluding LNG)	15	16	-28%	-84%	-100%
LNG (including fugitive emissions)	4	50	+664%	+14%	-100%
Fugitives from coal, oil and domestic gas	38	41	-31%	-71%	-100%
Total excluding LULUCF	**520**	**567**	**258 (-50%)**	**105 (-80%)**	**53 (-93%)**
LULUCF	**90**	**-19**	**-53**	**-53**	**-53**
Total including LULUCF	**608**	**549**	**105 (-66%)**	**53 (-91%)**	**0 (-100%)**

Note: Totals may not add due to rounding errors

Box - Australian National Outlook 2019 Scenarios

All the three scenarios of the ANO 2019 report rely on carbon sequestration for net emissions reduction in Australia. The Slow Decline scenario and Thriving Australia scenario present 28 $MtCO_2e$ and 33 $MtCO_2e$ of emissions reduction in Australia in 2060 respectively due to sequestration by landscape. Under the Green and Gold scenario, Australia is portrayed to reach net zero emissions in 2050, however, due to heavy reliance on emissions sequestration driven by high incentives. In 2060, 700 $MtCO_2e$ of emissions are sequestered through forest management in Australia to reach a net negative emissions position of -399 $MtCO_2e$ (Brinsmead et al., 2019).

4.8 Combined cross-sectoral analysis

Accelerated climate action in line with the Paris compatible scenarios in all sectors would allow Australia to achieve an enhanced NDC target to reduce emissions by 66% by 2030 compared to 2005 (50% excluding LULUCF).

Building on its extraordinary renewable energy resources as well as essential mineral resources and high skills, Australia can become a regional and international frontrunner in successfully transitioning its energy supply and demand sectors. This will benefit sustainable employment generation, reduce levels of dangerous air pollution, water demand, socially just housing, and new manufacturing value chains and export opportunities based on zero emissions energy carriers including renewable electricity offshore, green hydrogen and energy intensive products such as green steel.

Our findings emphasise that Australia will need to undertake additional mitigation actions in all other remaining non-energy sectors, in particular agriculture and waste, as well as decrease deforestation and sustain a carbon sink in the Land use sector to align its economy-wide emissions pathway with the Paris Agreement's temperature limit and achieve net zero emissions by 2050.

A strategy towards net zero emissions needs to take into account the different starting points, trends and mitigation potential in different sectors (*Table* 32). Some sectors, such as agriculture, cannot reduce emissions to zero, and others, such as electricity generation, can be rapidly decarbonised. All energy-related emissions can be reduced to zero by 2050, thus minimising the need to rely on carbon dioxide removal of remaining emissions.

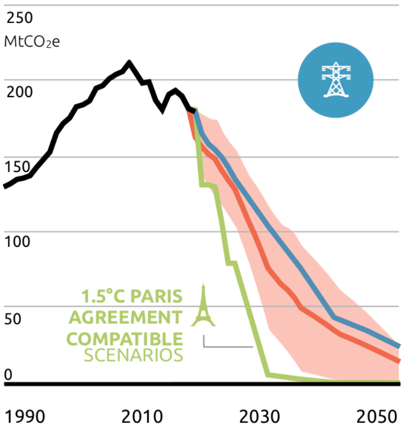
The path to get to net zero emissions matters both in terms of the cumulative emissions and their impact on temperature, as well as in terms of the technical and economic transition pathways and policy implications for the near future. This is why targets for 2030 matter: unless governments have believable pathways backed by policies to reduce emission levels, and energy transformations consistent with achieving zero emissions by 2030, then 2050 promises of net zero emissions lack any real credibility.

Sectoral strategies and policies, such as those outlined above, need to be embedded in an overall strategy, ideally with climate legislation to ensure a transparent and effective process to reach consistent overall and sectoral midterm targets.

In summary our analysis shows that Australia can reduce overall GHG emissions excluding LULUCF by 90% below 2005 levels by 2050 and that net-zero GHG emissions including LULUCF can be achieved in 2050 provided the LULUCF sector is a sink of -53 $MtCO_2e$ or greater by 2050 or if other carbon dioxide removal options not analysed in this study are introduced.

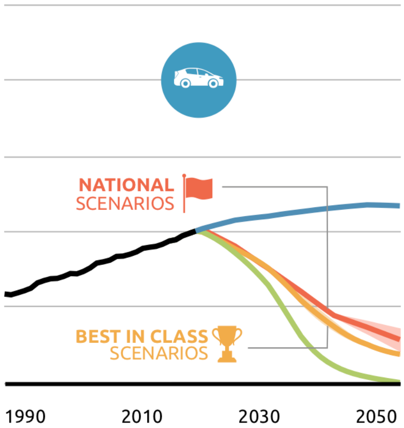
SCALING UP CLIMATE ACTION IN AUSTRALIA
POTENTIAL EMISSIONS REDUCTIONS IN FOCUS AREAS BY 2050

ELECTRICITY SUPPLY



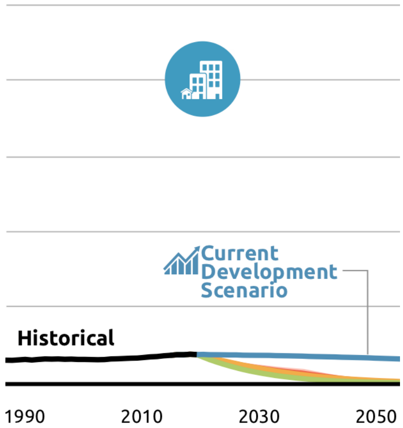
- Policy continuity and targets to support accelerated uptake of renewable energy.
- Phase out coal from power generation by 2030, with a strategy to ensure a just transition from coal mining and electricity generation.
- Grid infrastructure investment and energy market reforms to support uptake of demand management and storage at all scales (household to industrial).

TRANSPORT



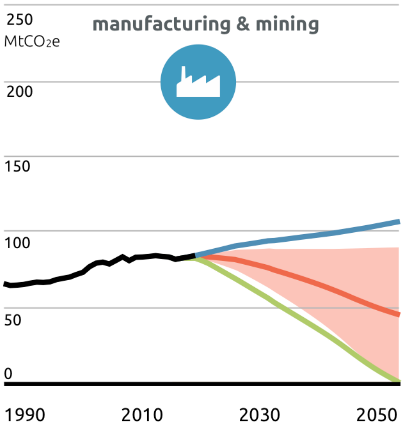
- Set ambitious greenhouse gas emission standards (at least as ambitious as the EU) both for passenger and heavy transport.
- Announce ban on sales of internal combustion cars and LDVs by 2035.
- Programmes to transition the truck fleet to renewable energy sources.
- Concerted initiatives with industry to decarbonise aviation and maritime shipping and develop market for carbon free fuels including bio jet fuel, and P2L technologies.

BUILDINGS



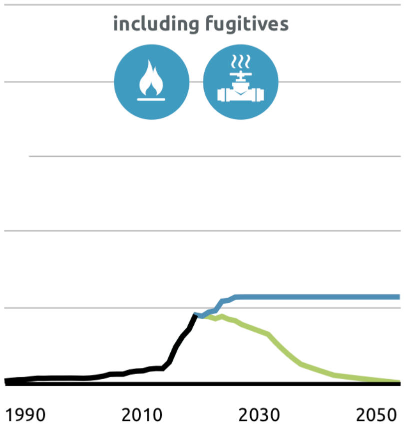
- Commit to national zero carbon ready building code and ensure compliance.
- Progressive requirements and incentives for buildings to include renewables and storage with EV re-charging capabilities.
- Increase awareness and information about energy efficiency benefits, ensure transparency through disclosure schemes, and introduce incentives.
- Energy rating requirements on property transfer and sale.
- Ban fossil fuels for heating from 2030 onwards.

INDUSTRY



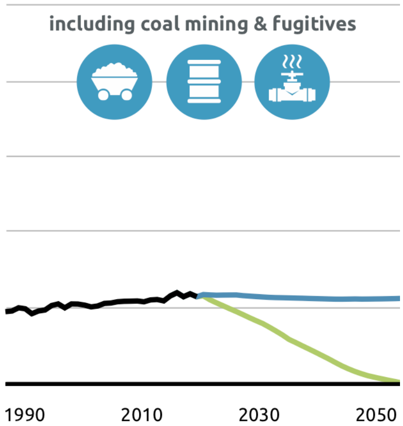
- Replace the ineffective safeguard mechanism with an effective carbon pricing system
- Implement best practice policies such as incentives for Energy management, mandatory energy audits.
- Programmes and incentives for zero carbon mining and metal production
- Establish a defined Paris-compatible decarbonisation pathway and strategy, and targeted sectoral R&D
- Hydrogen strategy needs to focus on renewable hydrogen

LNG



- Carbon pricing or regulation to ensure electrification and phasing in of renewable energy.
- Mandatory capture and storage of reservoir CO_2.
- Mandatory reduction targets and independent MRV for fugitive emissions
- Approval process for LNG projects takes into account consistency with a global Paris Agreement pathway.
- Development of transition strategy for LNG industry to renewable hydrogen
- Develop new markets for green hydrogen for a transition away from exporting LNG.

OTHER FOSSIL FUELS



- Effective carbon pricing system
- Regulation to ensure electrification and phasing in of renewable energy.
- Monitoring and regulation for mitigation measures to reduce fugitive emissions.
- Work towards international Agreement for a moratorium for new fossil fuel extraction projects.
- Federal support for a planned regional just transition process with participation of all relevant stakeholders for regions affected by transition.

Figure 48: Overview of emissions levels under different scenarios for different sectors, and policy recommendations.

An important conclusion from these findings is that it is beneficial for Australia to considerably ratchet up its 2030 target to be consistent with the Paris Agreement. Increased climate action will achieve a wide range of benefits, while they can build on already ongoing activities.

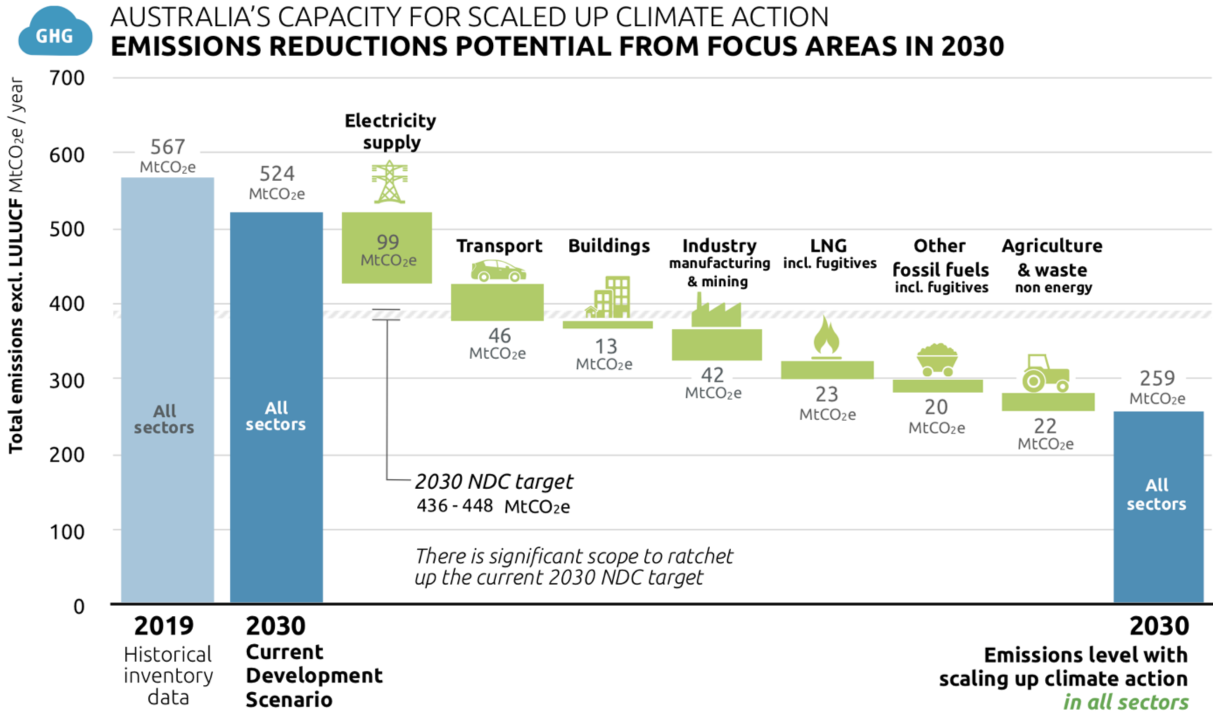


Figure 49: Overview of total emission levels (excl. LULUCF) under historical inventory data in 2014 (left bar), under a Current Development Scenario in 2030 (middle bar), and most ambitious levels of accelerated climate action by 2030 in the electricity supply, the residential buildings sector, and land-based passenger and freight transport (right bar). All electricity-related emission reductions from the residential buildings and transport sectors are allocated as emissions reductions under these two end-use sectors.

Our analysis also shows that these energy related sectors can be fully decarbonised by 2050.

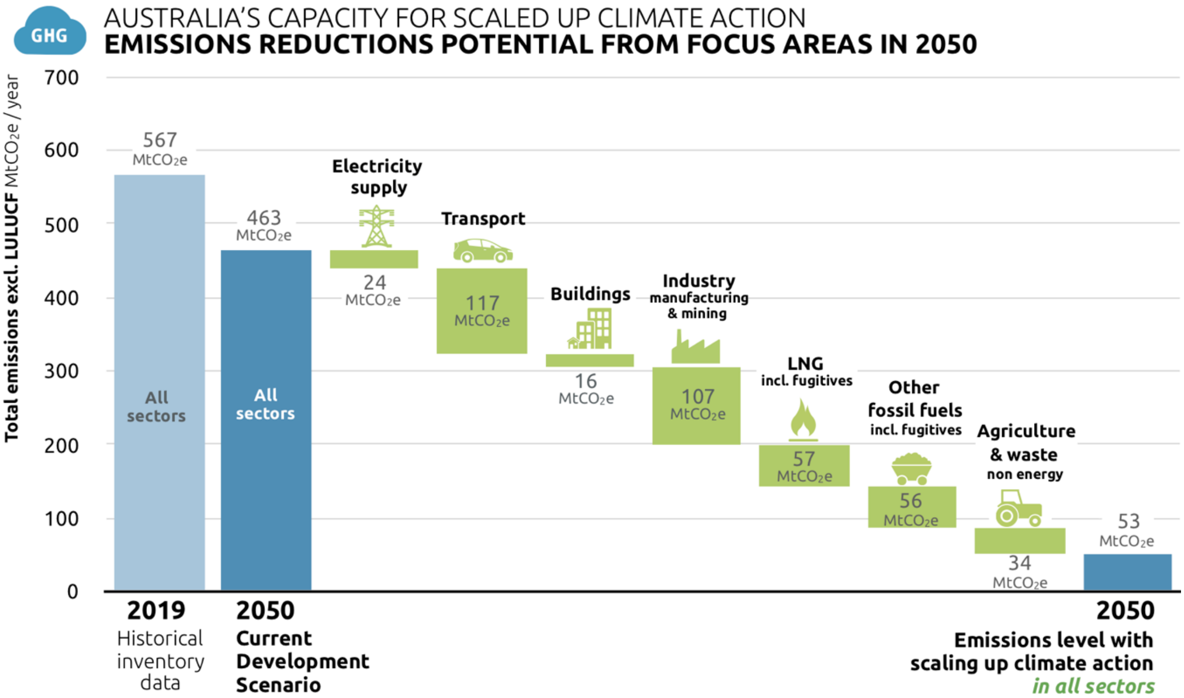


Figure 50: Overview of total emission levels (excl. LULUCF) under historical inventory data in 2014 (left bar), under a Current Development Scenario in 2050 (middle bar), and most ambitious levels of accelerated climate action by 2050 in the electricity supply, the residential buildings sector, and land-based passenger and freight transport (right bar). All electricity-related emission reductions from the residential buildings and transport sectors are allocated as emissions reductions under these two end-use sectors.

If it does so, Australia can become a regional and international frontrunner in successfully transitioning its energy supply and demand sectors, while benefiting from a wide range of socio-economic benefits such as sustainable employment generation, reduced levels of dangerous air pollution, and socially just housing.

Our findings emphasise that Australia will still need to undertake additional mitigation actions in all other remaining sectors to align its economy-wide emissions pathway with the Paris Agreement's temperature limit, particularly in the agriculture and forestry sectors but also the waste sector.

5 Conclusion

- The analysis presents that upscaled mitigation actions in electricity generation, residential and commercial buildings, passenger and freight transport including domestic aviation, manufacturing industries, agriculture and waste sectors in Australia can exceed Australia's current emissions reduction targets of 26% below 2005 levels for 2030 to achieve 50% emissions reduction below 2005 levels for 2030 excluding LULUCF, and decarbonise energy related sectors by mid-century, in line with a global Paris Agreement compatible pathway. Further actions in rest of the sectors would be required to ensure economy-wide Paris Agreement compatible developments.

- The report identifies utilization of the renewable energy resources, electrification of end-use sectors, improvement in energy efficiency measures, and implementation of other low carbon technology options such as green hydrogen in steel and heavy industries as the key levers for the decarbonization of the Australian energy system.

Electricity generation

- Ambitious policy making is imperative for a Paris Agreement-compatible and more ambitious scenarios in the focus areas of the report. In the context of electricity sector, all the analysed scenarios foresee a continuous decline in the share of fossil fuels (coal and gas being the main fuels) in Australia's electricity generation mix. The Paris Agreement compatible scenario envisions no new fossil fuel-based plants installations from today and a fully decarbonized electricity supply by 2040 itself.

- With the very high technical potential available and projected economic competitiveness, wind and solar are expected to become the main pillars of future power supply in Australia in our scenario analyses. This is also supported by the recent studies conducted by (Australian Electricity Market Operator, 2020) and (Graham et al., 2019).

- Any form of government support or tax-based subsidies to support the fossil-fuel based generation and infrastructure is non-aligned with the greater emissions reduction ambitions in all the scenarios analysed and thus, it would lead to stranded assets. Therefore, the Australian Government need to seriously consider consolidating their climate policies in order to avoid stranded assets and ensuing negative economic impacts in the future.
- The sustainable energy system of the future is characterized by a strong sector coupling between electricity sector with buildings, transport and industry sectors. This can be observed by substantial increase in electricity demand in Paris Agreement compatible scenarios by approximately 1.7 times in 2050 as compared to the 2019 levels.

Buildings

- Building is a sector which is relatively easier to electrify as compared to other sectors. Steady increase in the direct electrification of space and water heating, cooking and other applications is the main approach that leads to emissions reduction from the building sector.
- Paris Agreement-compatibility requires the renovation rate of both residential and commercial building sector to increase significantly—ideally to 5% annually—with the energy demand per square meter decreasing by 75% to 100%.
- Besides direct electrification, the use of fossil fuels for space heating or other purposes needs to be replaced by renewable energy sources as the means to achieve zero emissions from the sector.

Transport

- In the context of passenger transport, the benchmark for Paris Agreement compatibility for Australia is to increase its share of electric vehicles (or other emissions-free vehicles) in new sales from below 1% today to 100% by 2035.
- Australia needs to apply stringent standards on CO_2 emissions intensity of new vehicles. Further, the country needs to take inspiration from frontrunner countries such as Czech Republic and Austria in order to have a major modal shift from private to public transport.
- In the Paris Agreement compatible pathway, the freight trucks and trains also need to be zero emission vehicles by 2050. This should be driven by a consistent improvement in emission intensity starting from today and a major increase in the share of trains for freight transport. Moreover, Australia needs to stride towards electrification of its freight transportation fleet by taking inspiration from countries such as Japan and Switzerland, which have 90% and 100% electrification rate in freight trains respectively .
- In a 1.5 °C compatible world, the aviation sector is decarbonized by replacing the jet fuels in the fuel mix with zero emission fuels such as biofuels or synthetic fuels or even hydrogen. In our scenario, we assume full decarbonisation of the aviation sector by 2050, which in the real-world context might require negative CO_2 emissions through Carbon Dioxide Removal technologies to compensate for remaining fossil fuel use if decarbonisation is not achieved by 2050.

Industry

- In order to create a greenhouse gas neutral steel sector in Australia, the use of coke in the blast furnaces needs to be reduced continuously and eventually phased out by 2050. This in turn would be replaced by using green hydrogen as a reducing agent to reduce iron ore in the iron making process. Material efficiency and recycling of scrap steel are some crucial measures in decarbonizing this energy intensive sector. In a Paris Agreement compatible scenario, the share of BF-BOF route in steel production would decline continuously complemented by the increase in the share of EAF-scrap and EAF-DRI routes. In the fuel mix, coal, oil and gas are completely supplanted by green hydrogen and synthetic fuels by 2050.
- Cement industry is another major energy intensive sector in the context of Australia. In a Paris Agreement compatible pathway, the clinker to cement ratio reduces steadily from 78% today to reach 30% by 2050. In order to abate the process emissions, the substitutes for clinker in the cement manufacturing and the alternatives for Portland cement such as Geopolymer cement need to be promoted in the construction sector.
- Currently, Australia is ranked as one of the worst performing developed countries in terms of energy efficiency in the industry sector. The energy intensity in the industry sector needs to improve at a rate between 4% and 5% annually in a Paris Agreement compatible world. The electrification rate in both the light and heavy industry sector in Australia needs to reach up to 80% by 2050. Zero carbon fuels such as biofuels or green hydrogen need to be deployed in the industrial processes, which are hard to electrify such as high temperature processes.

Fossil Fuels Sector

- In 2019, Australia overtook Qatar to become the largest exporter of LNG in the world. The use of gas in the LNG sector value chain and the related fugitive emissions have driven the drastic rise in GHG emissions in Australia in the recent years. Renewable electrification of LNG processing and capturing and storage of carbon dioxide from natural gas reservoirs are the measures to reduce emissions from LNG sector in the short and medium run. However, in our Paris Agreement consistent pathway, the LNG export volume should start declining continuously from 2030 onwards and reach zero by 2050. This, in turn, needs to be replaced by alternative fuels like green hydrogen as an energy carrier.

- In a 1.5 °C compatible world, the processes in end-use sectors like buildings, transport and industry are decarbonised either through the use of zero carbon fuels or via electrification. In this context, the production of black coal, crude oil, condensate and LPG, as well as the use of domestic gas start declining from today and reach zero by 2050 in Australia. Thus, the eventual phase-out of fossil fuels use is central to reach zero emissions from the fossil fuels industry including the fugitive emissions.
- During the transition phase, the increase in the electrification of processes in extraction, mining and refinery industry and use of renewable electricity rather than on-site fossil fuel-based generation in parallel could set the pace towards achieving the goals of the Paris Agreement.

Agriculture and Waste

- As the nature of the sector is, the non-energy emissions from agriculture and waste sector couldn't be reduced by 100% in any scenario. However, in a 1.5 °C compatible pathway, the non-energy emissions could be reduced by up to 35% in agriculture sector and nearly 80% in waste sector in Australia by 2050. This requires drastic and immediate action in both the sectors.
- In the PA compatible scenario, key mitigation options identified in the agriculture sector are enhanced agricultural management (e.g. manure management, improved livestock feeding practices, and more efficient fertiliser use), as well as demand side measures such as dietary shifts to healthier, more sustainable, low-meat diets and measures to reduce food waste.
- In the context of waste sector, deeper emissions reduction is possible as it has been found that the mitigation options in this sector are highly cost effective and could even result in net profits.

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The Climate Action Tracker (CAT) is an independent scientific analysis produced by three research organisations tracking climate action since 2009. We track progress towards the globally agreed aim of holding warming well below 2°C, and pursuing efforts to limit warming to 1.5°C.

The Consortium

NewClimate Institute is a non-profit institute established in 2014. NewClimate Institute supports research and implementation of action against climate change around the globe, covering the topics international climate negotiations, tracking climate action, climate and development, climate finance and carbon market mechanisms. NewClimate Institute aims at connecting up-to-date research with the real world decision making processes.

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Climate Analytics is a non-profit climate science and policy institute based in Berlin, Germany with offices in New York, USA, Lomé, Togo and Perth, Australia, which brings together interdisciplinary expertise in the scientific and policy aspects of climate change. Climate Analytics aims to synthesise and advance scientific knowledge in the area of climate, and by linking scientific and policy analysis provide state-of-the-art solutions to global and national climate change policy challenges.

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