A 1.5°C COMPATIBLE CARBON BUDGET FOR WESTERN AUSTRALIA

WA's role in implementing the Paris Agreement and capturing opportunities in a decarbonising global economy

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Cover photo: Darkydoors
Ningaloo Reef and Cape Range national park, a World Heritage area near Exmouth, Western Australia.

EXECUTIVE SUMMARY

This study analyses what actions Western Australia needs to take to play its role in global and national efforts to limit warming to 1.5°C.

Western Australia is on the frontline of climate impacts and has a vital interest in the world, and Australia as a whole, taking sufficient action fast enough to keep global warming within the Paris Agreement's 1.5°C temperature limit to protect its unique and iconic ecosystems, coastal and agricultural regions, and the health and well-being of its population.

WA's iconic ecosystems and World Heritage sites such as Ningaloo are threatened by warming above 1.5°C and are already showing substantial damage with global mean warming of 1°C. Marine heatwaves are already damaging fisheries and causing massive seagrass loss at Shark Bay.

Declining rainfall and rising temperatures in the southwest are placing escalating pressure on agriculture, water resources and there are early indications of agricultural productivity failing to keep up due to the impacts of a warming and drying climate. These changes are also threating WA's unique biodiversity-rich land ecosystems.

Sea level rise is causing escalating problems on the coast, with accelerating beach erosion and retreat threatening infrastructure, homes and lifestyles and are the first signs of the consequences of the accelerating global sea level rise now being observed in many towns and coastal parts of Western Australia. As the Intergovernmental Panel on Climate Change (IPCC) Special Report on 1.5°C (IPCC SR15) has established, every increment of global warming will rapidly escalate damages, impacts and risks. WA's coral reefs, such as at Ningaloo, face losses of 70-90% with 1.5°C of warming, and virtually complete losses of more than 99% with 2°C of global mean warming above pre-industrial levels.

This study aims to provides key Paris Agreement compatible carbon budget benchmarks and greenhouse gas reduction pathways for Western Australia consistent with the state playing its role in global efforts to limit warming to 1.5°C. The results include state wide emission reduction goals needed for 2030, options for WA to meet its aspirational net zero greenhouse gas (GHG) emissions goal for 2050, and the broad policy changes needed to meet this budget.

WA and the National context

The Australian national reduction target for 2030 of a 26-28% reduction compared to 2005 emission levels is inadequate. National reductions in the range of 44-61% by 2030 are needed to be consistent with the level of action Australia needs to take in global efforts to limit warming to 1.5°C and to meet the Paris Agreement's long-term temperature goal. These emission reductions are needed by 2030 to put the country on a cost-efficient pathway to achieve zero net GHG emissions by around 2050.

The 1.5°C compatible state level greenhouse gas target for Western Australia estimated in this report is a reduction of 49% by 2030 (from 2005 levels). Whilst this is within the Paris Agreement compatible national emissions reductions range for Australia as whole it should be noted that the reductions by 2030 for Western Australia are likely to be slightly less than the total national reductions that Australia will need to achieve, due to the particularly energy intensive character of the Western Australian economy, and in particular its very large liquified natural gas (LNG) sector.

In the national context, when Australia begins to deal seriously with the question of national emission reductions, it cannot be assumed that the other states will accept Western Australia doing less than them. We have not examined these issues in this report, but it is clear that policymakers in Western Australia need to be cognisant of the relative levels of action between the states. The experience with the European Union has shown that each state will have its own set of arguments on what is a fair and economically effective division of mitigation responsibilities.

Although, in August 2019, Western Australia adopted an 'aspirational goal' of achieving net zero GHG emissions by 2050, as of yet it does not have any targets for renewable energy nor does it have a specific 2030 reduction target. Western Australia and New South Wales are now the only states or territories without a renewable energy target. Several other states are moving ahead with more ambitious action and there are appears to be little or no coordination between the states on this, and it cannot be assumed that these states are contemplating Western Australia taking a lesser share of the emissions reduction burden than themselves.

Western Australia has unique opportunities to develop its own vision and strategy and reap the benefits of being a global leader in implementing the Paris Agreement. It is highly independent from the federal level, with its own independent energy system, as well as prime renewable energy and mineral resources. It is therefore well-placed to demonstrate its independence from the failings on climate action at federal level.

WA has the opportunity to develop new added-value manufacturing industries and create employment opportunities while moving away from being an exporter of carbon to becoming an exporter of zero emission energy carriers (green hydrogen, ammonia, or electricity) and products, in particular to neighbouring South East Asian countries. It also has unique challenges, with the physical scale of the LNG industry, and the extensive and deep links this industry has with the political parties and government of Western Australia raise important public policy issues in relation to long-term public interest and climate governance in the state. Nevertheless, the abundance of capacity, renewable energy resources and links to important Asian markets mean that there is a transition strategy open to the state to explore, which would allow it to decarbonise the LNG industry and transform into a major exporter of renewable energy, either directly via electricity or through green hydrogen exports.

A significant part of the study focuses on a Paris Agreement compatible carbon budget for the energy and industry sectors in Western Australia as the largest source of greenhouse gas emissions in the state is carbon dioxide emitted from fossil fuel combustion and use. Globally, carbon dioxide (CO_2) is the main driver of human induced climate change and ocean acidification, and CO_2 from fossil fuels is the largest source, accounting for about 66% of total GHG emissions globally.

In Western Australia, energy and industry emissions are the largest source of greenhouse gases, with CO_2 and methane (CH_4) emissions from fossil fuel use for energy and industry accounting for 89% of total GHG emissions from the state (excluding LULUCF). The most rapidly growing source of greenhouse gases in Western Australia is the LNG sector, with a more than threefold increase (318%) since 2005, with the sector doubling in size over the last five years and set to increase by nearly 50% by the late 2020s.

We know from the IPCC Special Report on 1.5°C (SR15) that to meet the 1.5°C limit in the Paris Agreement, CO_2 emissions from all sources need to peak around 2020, fall by 45% by 2030 compared to 2010 levels, and reach net zero around 2060. This report also shows that the energy transformations required to achieve this are technically and economically feasible and can have large sustainable development benefits. To develop a carbon budget for Western Australia, we draw upon the modelling framework that gives these global results and apply it within the West Australian context so that the

CO_2 emissions budget as well as the energy system transformation dynamics are consistent with the global results.

Carbon budget for Western Australia energy and industry sectors: Key conclusions

The carbon budget for Western Australia's fossil fuel CO_2 emissions for the period 2018-2050 is estimated at around 950 $MtCO_2$. This is about 0.17% of the remaining global carbon budget. **If Western Australia maintains its current emissions rate, it would consume this budget within 12 years**.

With the right policies and modern technologies, Western Australia can spread this budget over the next 30 years, so that it achieves zero CO_2 emissions by 2050, but the pathway to stay within this budget is critical: CO_2 emission reductions of about 37% by 2030, 81% by 2040 (all compared to 2005) and zero emissions by 2050 are needed.

Delays in reducing emissions will imply faster reductions later to stay within the carbon budget, implying higher costs and disruption, and a risk of locking in further fossil fuel infrastructure.

Carbon budgets (emission pathways) for each sector and for all energy/industry emissions are shown below in Table 1 (Figure 1) as well as necessary reductions pathway 2030 and 2040 compared to 2005, so that all sectors reduce emissions to zero by or before 2050.

Table 1: Paris Agreement compatible energy and industry carbon budget for Western Australia 2018-2050 by sector and total, with sectoral and total reductions by 2030 and 2040. Source for historical data: AGEIS (2019). LNG sector emissions include emissions from venting/fugitive emissions (own estimate). Note that the increase in emissions in the LNG sector by 170% in 2030 compares to an increase of 630% in the reference (business as usual) case. Electricity generation reaches zero before 2040, all other sectors by 2050.

Sector	Paris Agreement compatible carbon budget 2018-2050 $MtCO_2$	Remaining years at 2017 emissions rates	2005 Baseline $MtCO_2$	Share of current emissions (2017)	2030 reduction (compared to 2005 baseline) CO_2 only	2040 reduction (compared to 2005 baseline) CO_2 only
Electricity generation	160	6	17.5	31%	-95%	--100%
Transport	207	15	8.8	18%	-16%	-54%
Industry: LNG Sector	208	16	3.6	17%	+170%	-73%
Fugitive emissions (excl. LNG)	25	6	1.6	5%	-55%	-90%
Industry: other	328	15	18.1	28%	-30%	-77%
Buildings	22	12	1.2	2%	-41%	-70%
Total energy/industry emissions	**949**	**12**	**50.8**	**100%**	**-37%**	**-81%**
Total energy/industry excluding LNG sector	**716**	**11**	**45.6**	**79%**	**-53%**	**-79%**

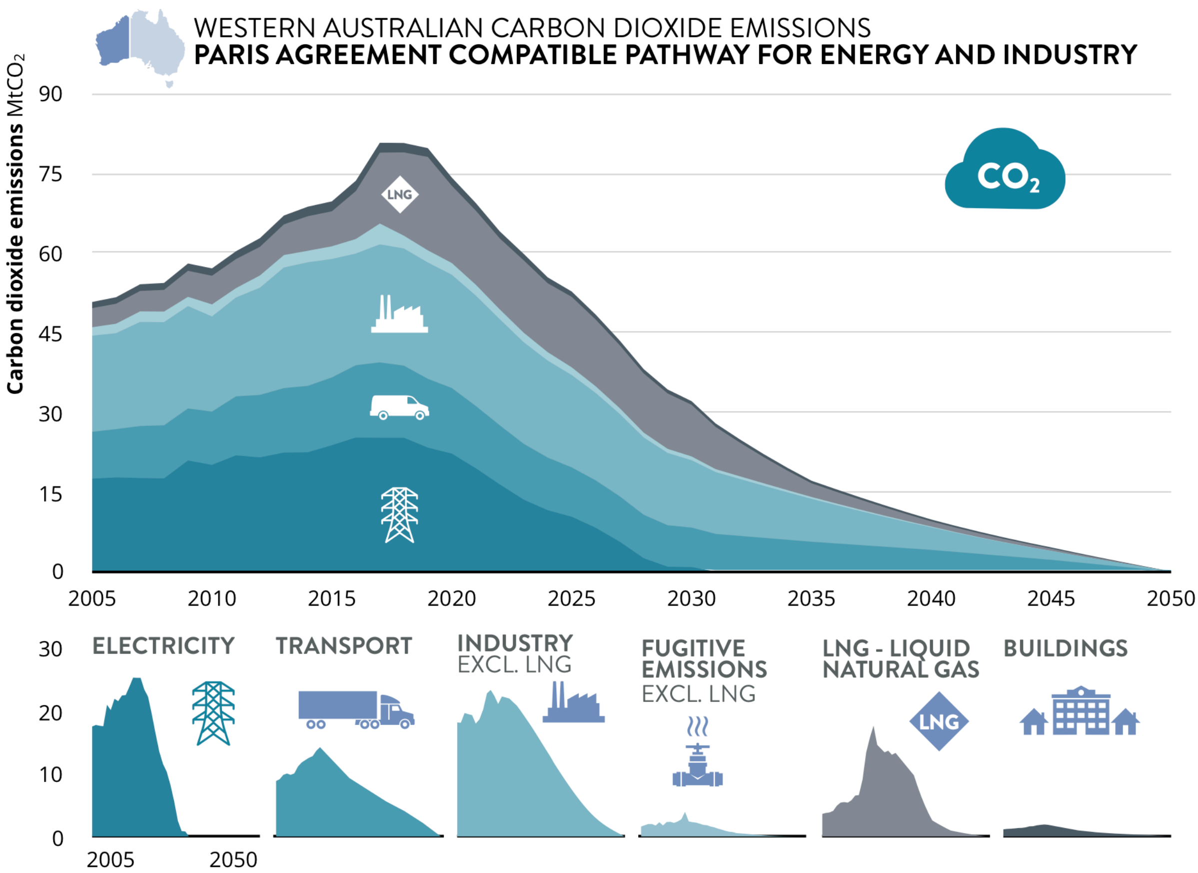

Figure 1: CO_2 emissions pathway for each of the sectors and energy and industry following transformation is consistent with the Paris agreement in each of those sectors. Total CO_2 emissions peak around 2020 and decline to about 37% below 2005 levels in 2030, for total budget of around 950 $MtCO_2$. Excluding the LNG industry, energy and industry CO_2 emissions would reduce by about 53% by 2030 below 2005 levels, for a total budget of 716 $MtCO_2$.

Achieving zero greenhouse gas emissions by 2050 – need for fast reductions by 2030

Total GHG emissions (including LULUCF) would need to peak as soon as possible and fall by 49% below 2005 levels by 2030. This translates into a reduction by 52% in 2030 compared to 2010. This is a key milestone for Western Australia – and Australia – to do their part to keep the Paris Agreement long-term temperature goal within reach and avoid the risks of escalating costs and institutional and economic lock-ins of carbon-intensive infrastructure, which will then be costly or more difficult to phase out later.

Unlike the other sectors, agriculture and waste emissions are difficult, if not impossible, to reduce to zero. Even with all the other transformational measures described in this report, remaining missions from these sectors would need to be compensated with negative emissions from the LULUCF sector.

In the LULUCF sector, native vegetation clearing and deforestation essentially need to stop by 2025. Non-CO_2 GHG emissions from the LULUCF sector would need to continue to decline slowly consistent with recent trends. A large sink in the land use sector would need to be maintained over the next decades.

With these assumptions, WA could achieve net zero emissions around 2050. Significant research is needed 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 elements of environmental value.

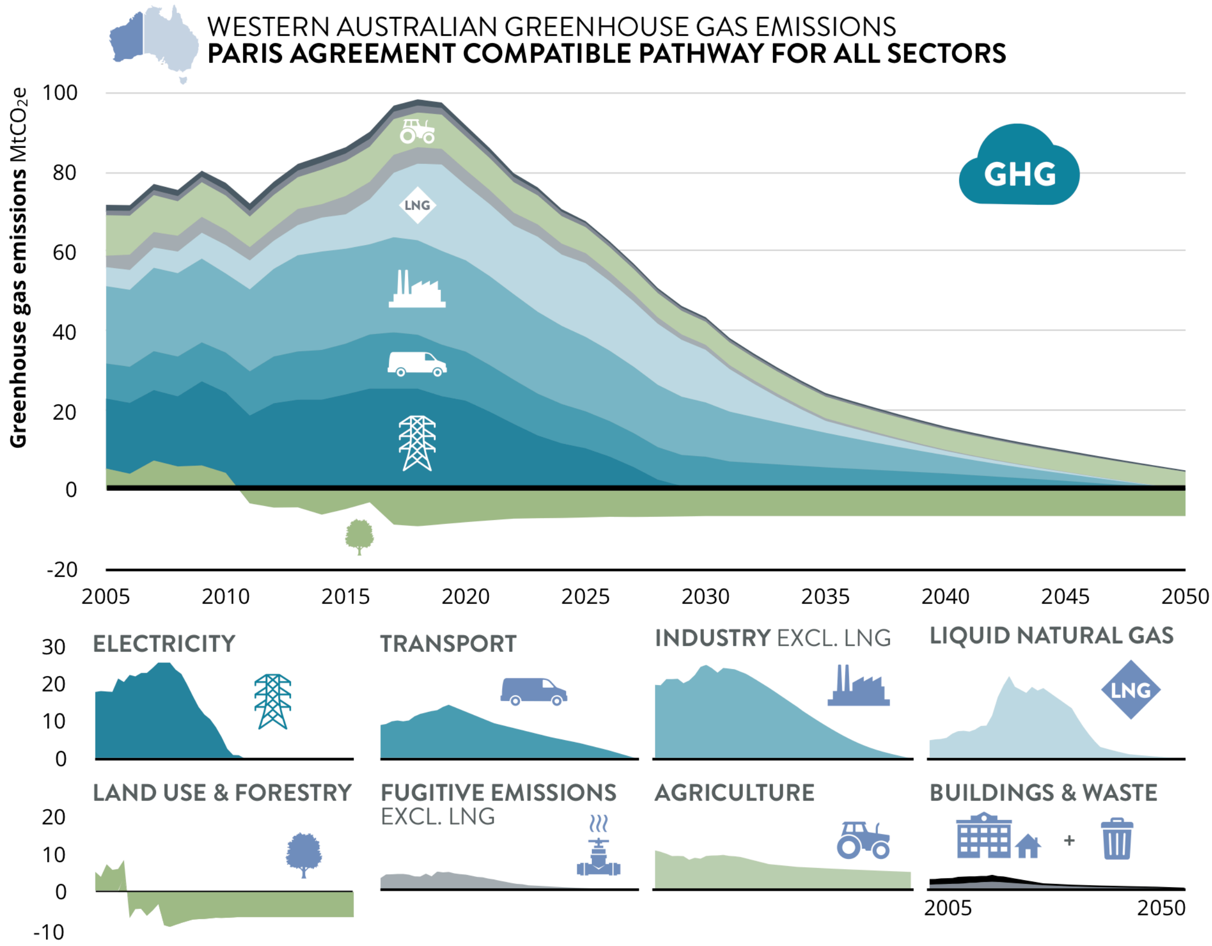

Figure 2: GHG emissions pathway for each of the sectors following a transformation consistent with the Paris Agreement in each of those sectors. Total GHG emissions peak around 2020 and decline to about 49% below 2005 levels in 2030, reaching net zero around 2050 contingent upon maintaining a large sink in the LULUCF sector. Consistent with national projections, the LULUCF sink is expected to slowly decline from recent high levels due to saturation of reforestation and other activities. It also assumes vegetation conversion (deforestation in broad terms) leading to emissions is effectively halted by 2025, which would require policy intervention. National projections assume ongoing deforestation losses.

Staying within the budget: A unique set of opportunities for Western Australia

Western Australia has prime resources that are needed to implement the Paris Agreement including first class wind and solar resources, minerals and critical materials for batteries and other technologies. Technologies associated with renewable energy, such as batteries and electric vehicles require natural resources available in Western Australia and the state is already the world leader in lithium production.

Green hydrogen offers Western Australia an option to transition the LNG industry into a renewable energy export industry as the state has a number of advantages:

- Ability to offer lower landed costs of hydrogen,
- Proximity to markets,
- Well established energy trading relationships,
- Experience in large scale energy infrastructure construction,
- Possibility of supplying hydrogen from a range of sources

Western Australia has a lot to gain from such a strategy, if such a transition is planned well, given it can move away from relying on exporting fossil fuels (LNG) towards exporting zero emissions energy

carriers (direct electricity or green hydrogen) or zero emissions energy intensive products such as zero emissions steel – with opportunities for additional manufacturing employment.

One of the key comparative advantages that Western Australia has is its geopolitical proximity to Asian energy markets, its relationship through the LNG industry with these markets, and through the export of mineral commodities. It is these advantages that have led, amongst other things, to the rise of the export on a global scale of iron ore, other minerals and LNG, but it is also this context that gives rise to a unique opportunity to effect a transition away from carbon intensive fuels to zero carbon industries.

The transition to a zero-carbon economy in Asia will require large amounts of energy, hence the market for energy carriers similar to LNG will not disappear. A number of Asian economies have - or are - developing hydrogen strategies, for a variety of different reasons, including energy security and climate change. A Paris Agreement driven decline in Asian demand for LNG would be matched by a corresponding increase in demand for clean energy carriers, in particular green hydrogen.

The key elements of the zero-carbon transition outlined here for the LNG industry involve developing new markets for green hydrogen, which requires a major ramping up of renewable energy generation capacity in regions near to the present LNG facilities. This fundamental transition in the energy market driven by Paris Agreement needs to be fully anticipated by the government based on independent scientific and objective analysis of likely market developments, rather than selective application of scenarios by industry. Unless the government has available to it independent and scientifically rigorous analyses, rather than those put forward by sectoral interests, there is a serious risk that it will fail to anticipate and miss the transition opportunities available to it, and large disruptions could occur that otherwise it would have avoided. Other Australian states appear to be moving ahead with elements of this transition strategy, which Western Australia probably should have led.

LNG sector in Western Australia: Need to transition

Emissions from the LNG industry that occur in Western Australia are estimated here to be around 22 Mt of carbon dioxide equivalent (CO_2e) per annum in 2019, about 22-25% of the state's emissions, and can be expected to approach 35 Mt CO_2e/year (30-33% of 2005 state emissions) or higher by the late 2020s if all present plans go ahead and the plants operate close to full capacity.[1]

The reference case for LNG cumulative emissions for 2018-2050, if not abated, are likely to be in the range of 1 $GtCO_2$, of the same order as the entire carbon budget for Western Australia – or equivalent to about 14 times the state's entire emissions in 2005. When the LNG is burnt offshore in power stations significantly greater missions occur but these are not counted domestically in Australia or in Western Australia. Under the agreed international greenhouse gas accounting systems used in the UNFCCC, Kyoto Protocol and the Paris Agreement, emissions are accounted for in the country in which the LNG is consumed.[2]

LNG manufacturing is an emissions intensive process and in Western Australia is estimated to have a total greenhouse gas intensity in the range of 0.39-0.74 tonnes of CO_2 equivalent per tonne of LNG ($tCO_2e/tLNG$) produced depending upon the plant, the gas reservoir being exploited and the timeframe.

1 These emissions are sometimes referred to as Scope 1 emissions.

2 These emissions are sometimes referred to as Scope 3 emissions.

The average intensity over the last 20 years is about 0.4 tCO_2/tLNG produced, with this intensity projected to increase over the next decade to close to 0.6 tCO_2e/tLNG.

There are three or four main sources of emissions: venting of CO_2 that naturally occurs in the gas reservoir which has to be extracted in the LNG manufacturing process, and is normally vented into the atmosphere; the energy used in converting the natural gas stream into its liquefied form is substantial - requiring about 9% of the energy content embedded per unit of LNG – and leads to significant CO_2 emissions; fugitive emissions from the liquefaction process plant are also significant; finally, in some cases in Western Australia natural gas is used to power pumping systems that move the gas onshore.

Apart from planned capture of CO_2 and storage in geological formations at the Gorgon plant, very few greenhouse gas mitigation measures have been announced or planned at any scale in Western Australian LNG facilities.

Under the Paris Agreement, demand for unabated natural gas in the power sector in Asia, a major source of Western Australian LNG demand, is likely to peak by around 2030 and then decline to close to zero between 2050 and 2060. This is a robust result of an analysis of 1.5°C compatible mitigation pathways assessed by the IPCC to be consistent with the Paris Agreement Long-term Temperature goal, and taking into account that Carbon Capture and Storage (CCS) is increasingly unlikely to be able to compete with renewable energy and storage. Renewable energy and storage provide a more cost-effective solution and additional benefits for sustainable development, with costs continuing to fall, while there are no observed cost improvements for CCS in power generation and incomplete capture would need to be compensated with additional, and likely expensive, efforts to remove carbon dioxide from the atmosphere. These pathways show that Paris Agreement implementation is likely to result in a substantial reduction in natural gas demand in the power sector in Asia without CCS, reducing from peak levels in 2030 to close to zero by 2050.

Irrespective of whether or not the demand reductions implicit in the Paris Agreement Asian power demand scenario above occur, the cumulative emissions of the LNG industry need to be reduced substantially and the basic options examined here - through carbon capture and storage of reservoir CO_2 and by introducing renewable energy quickly into the LNG manufacturing process - would need to be deployed in either case. In the reference case, the scale of the emission reductions would be substantially larger than in the Paris Agreement Asian power demand case.

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. 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 from around 2023. This would avoid around 171 $MtCO_2e$ of emission in the Paris Agreement Asian power demand scenario and 304 $MtCO_2e$ of emissions in the reference case.

Processes in the LNG plant themselves require electricity and energy for refrigeration and these can mostly be electrified with clean renewable energy. About 9% of the energy content of LNG is used, in the form of natural gas, to manufacture the product. The corresponding CO_2 emissions can be avoided by using renewables in the LNG manufacturing process, which in large part is essentially driven by aeroderivative gas turbines. 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 would directly avoid around 123 $MtCO_2e$ of emissions in the Paris Agreement Asian power demand scenario and close to 395 $MtCO_2e$ of emissions in the reference case. Taking into account the likely co-reduction of other liquefaction process related emissions the GHG reductions induced by introducing renewable energy in this way could be up to 184 and 441 $MtCO_2e$ respectively.

Applying the options described above to the reference case to LNG production would reduce the peak emissions from Western Australia LNG manufacturing to around 300% above 2005 levels from a projected 600% increase by the mid 2020s in the case of no policy action. This would bring emissions back to about 176% above 2005 levels in 2030, 16% below 2005 levels in 2040 and 46% below in 2050. Zero CO_2 emissions would be needed by 2050 to be Paris Agreement compatible.

Under the Paris Agreement Asian power demand scenario the decline in natural gas demand from 2030 combined with the mitigation options discussed (carbon capture and storage, electrification), LNG related emissions in 2030 would be about 175% above 2005 levels, around 80% below by 2040 and approach zero by 2050.

To achieve these emissions reductions in the absence of a carbon pricing system would require the state government to introduce binding regulatory requirements on the LNG industry to meet or exceed greenhouse gas intensity benchmarks consistent with these emission reductions or conditions, or more specific technology standard based requirements that would apply to both existing and planned facilities.

Key conclusions for climate policy in Western Australia

It is critically important to take a whole of economy approach to a climate strategy and take into account the role of the power sector in decarbonising end use sectors. Our study confirms the importance of **fast reductions in the short and medium term.**

It is key to decarbonise the power sector via a fast transition to renewable energy, taking advantage of the vast potential and low and falling costs of renewable energy and storage technologies and the opportunities for a range of sectors. Every sector will need to contribute to reducing emissions. This would also contribute to achieving other objectives, such as reduced air pollution, protection of biodiversity, sustainable economic development and high-quality employment including in rural Western Australia. Building agricultural resilience to climate change through changes to management practices and regenerative agriculture approaches will help farming communities to adapt to climate change. This would also contribute to mitigation by increasing the storage of carbon in agricultural landscapes, whilst minimising adverse unintended side effects.

The following are conclusions relevant for policy in Western Australia:

- **The need to develop a whole of the economy roadmap and strategy and detailed sectoral roadmaps and strategies in line with Paris Agreement**. This strategy needs to be based on the Paris Agreement Long Term Temperature goal and the importance of **limiting warming to 1.5°C** and the urgent need to **peak emissions and reduce them by around half by 2030**.
- **Strategies and roadmaps need to be based on Paris Agreement scenarios and analysis, that should be developed in a process with the broad participation of all stakeholders – industry and trade unions, civil society, as well as regional and local governments**. Use of non-Paris Agreement compatible energy scenarios in government planning and economic projections risks blinding government to the inevitable policy transitions that need to be made.

- **The pathway to zero is critical and it is dangerous to focus only on an endpoint of net zero emissions by 2050.** The path to get there 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.
- **Energy and industry are the key sectors that need to be addressed for full decarbonisation.**
- **Overall and sectoral strategies and roadmaps need to take into account the critical role of electricity generation transitioning to renewable energy and becoming fully decarbonised by the 2030s,** to contribute to the decarbonisation of end use sectors through direct or indirect electrification.
- **There will be a large increase in electricity demand and therefore a massive ramping up of renewable energy capacity – solar and wind – and this needs to be factored in when planning the transition in electricity generation, with clear targets and management of grid development, distribution systems and market regulation, as well as infrastructure for microgrids and off-grid solutions.**
- **Strategy of "sector coupling"[3] not only helps other sectors such as transport and industry reduce emissions and decarbonise, but also helps to provide grid stability with variable renewable energy – wind and solar – through battery or other storage and demand side management**. Sector coupling helps, for example, people to integrate successfully their electric vehicle (transport sector) and charging via home-based photovoltaics (PV) and battery storage systems (buildings) with the power grid as a whole (energy and industry) whilst boosting the reliability and efficiency of the entire electricity distribution system (whole of economy).
- **Sectoral strategies and roadmaps need to lead to the development of clear mid-term sectoral targets and policies to create incentives and develop the necessary infrastructure** that are consistent with a Paris Agreement sectoral pathway, for example:
    - **Electricity generation**: **one third renewable share by 2025, 90% renewable by 2030 and 100% in the early 2030s.** This means phasing out coal before 2030 and gas shortly afterwards.
    - **Industry: increase efficiency, reduce emissions by 30% in 2030 and 100% in 2050**
    - **Transport: prepare for rapid roll out of electric vehicles and trucks based on batteries and renewable hydrogen powered fuel cells (FCEV) by developing infrastructure** such as charging stations for electric vehicles or hydrogen fuel cell trucks, and through government procurement and supply policies, establish targets for modal shift to public transport and support more cycling and walking, and replace bus fleets with electric and/or FCEV buses.
    - **Forestry**: **halt deforestation as soon as possible and but not later than 2025, develop and secure biological sinks while preserving biodiversity, taking into account climate change.**

It is important to address open research questions in a targeted way, ensuring knowledge is developed and shared broadly with stakeholders, and draw upon, and mobilise, the extensive capabilities of the West Australian research community through the establishment of innovative research funding and coordination centres and/or mechanisms. This is important for example for research on the **role of the land-use sector** and how it can contribute to CO_2 uptake and **negative emissions** either through the sustainable use of biomass and carbon capture and storage or through enhancing and sustaining sinks in forests and ecosystems.

3 Integrating a renewable energy system, connecting energy using sectors such as buildings, transport and industry with the power sector. See for example the discussion at https://www.irena.org/energytransition/Power-Sector-Transformation/Sector-Coupling

The necessity to transform the state's economy from its present energy and carbon intensive configuration to a renewable, zero carbon one poses unique challenges (and provides unique opportunities). To meet this challenge, a number of countries have introduced, or are planning to introduce comprehensive climate change legislation, including mechanisms for establishing legally binding carbon budgets for a period such as five years that are ratcheted up based on scientific and technical assessments. They are also planning to provide appropriate legislative powers and capacity to manage the transition.

The Western Australian government should seriously consider introducing comprehensive climate change legislation, such as a "zero carbon" law. There are many things that the state can do to advance the policy agenda needed to halt the growth of emissions and begin the transition towards zero that is required to protect the state from the worst effects of climate change. Introducing legislation specially designed for this purpose appears to be of critical importance.

INTRODUCTION

This report provides key carbon budget and emissions pathway benchmarks for the energy and industry sectors for Western Australia that are consistent with the state playing its role in national and global efforts to limit global mean warming to 1.5°C above pre-industrial levels. The Paris Agreement's long-term temperature goal (LTTG) aims to limit global average warming to 1.5°C above pre-industrial levels[4]. With the present level of warming at about 1°C above preindustrial levels, limiting warming to 1.5°C will require urgent and rapid action globally. The IPCC Special Report on 1.5°C (SR15) has shown that this remains feasible provided action is initiated very soon. Main messages from the IPCC (2018a) SR15 include:

- Climate Change poses a severe threat, with impacts and risks being significantly lower at 1.5°C compares to 2°C or higher temperature increases above pre-industrial levels.
- Avoiding these severe risks is still feasible, but requires cutting global greenhouse gas (GHG) emissions by 45% -about half - by 2030 compared to 2010 levels, and reaching zero CO_2 emissions from all sources by 2050 globally, and net zero GHG emissions globally by 2070.

Whilst these global reductions levels are not applicable exactly to each national and sub-national context they do provide a basic orientation for policy and the emission pathways needed to meet the Paris Agreement: a 45% reduction in energy and industry CO_2 emission or GHG emissions by 2030 compared to 2010 corresponds to about a 40% and 45% reduction compared to 2005 levels for Western Australia respectively.

Because of the key role of energy and industry CO_2 emissions to achieve the Paris Agreement temperature goal, the carbon budget for Western Australia will focus on what the state's fossil (energy and industry) CO_2 emission limits need to be across all sectors of the economy and energy system, in order to be compatible with its contribution to meeting the Paris Agreement's 1.5°C limit. In addition, the study looks at implications for the overall greenhouse gas pathway to achieve net zero emissions by 2050, in line with Paris Agreement and the WA State Government's 'aspirational' objective, including necessary reductions in non-energy sectors (agriculture and waste), and the role of the land use sector to compensate for remaining GHG emissions, in particular from agriculture. The study will provide key conclusions regarding necessary CO_2 and total GHG reductions by 2030 and key sectoral strategies and policies across all sectors, taking into account Western Australia's unique situation, responsibility and opportunities.

To estimate a carbon budget and emissions pathways for Western Australia consistent with necessary global and national efforts to limit warming to 1.5°C, we use multiple lines of evidence from the scientific and technical literature, making use of state-of-the-art analysis and modelling of technically and economically feasible and plausible emissions pathways and technologies. We also consider sustainability constraints (for example limits to the use of biomass and negative emissions technologies) and economic considerations (we aim to minimise costs).

The requirement for deep carbon dioxide reductions and zero emissions means that all emitters - both large and small - will need to take part. It is argued by some in Australia that because it is a small global emitter - about 1.1% to 1.4% of global emissions - then its actions are irrelevant and not necessary.

4 Article 2.1 of the Paris Agreement (PA) defines its long-term temperature goal (LTTG) as "[h]olding the increase in the global average temperature to well below 2 °C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" (UNFCCC 2015).

However, small emitters, under 2% of global emissions of CO_2, added up to close to 30% of global CO_2 emissions in 2017, showing that achieving zero CO_2 emissions, or even very deep reductions, cannot be achieved without comparable action by all smaller emitters. Western Australia, with an independent energy system and unique opportunities and resources, as well as interest in achieving the 1.5°C limit to protect its unique natural resources, has a special responsibility to act in line with what these necessary efforts.

The **focus of the study is on domestic emissions**, and analyse specifically how much the **growing LNG sector** is contributing to these emissions, but also how it has to and can also contribute to necessary emissions reduction. We will provide an **outlook on the current large carbon footprint and the opportunities for Western Australia** to instead contribute to global emissions reductions through exporting zero emissions energy carriers and products.

PARIS AGREEMENT LONG TERM TEMPERATURE GOAL AND 1.5°C WARMING LIMIT

The long-term temperature goal (LTTG) of the Paris Agreement (PA) is

> *"[h]olding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change"* (UNFCCC 2015, Art. 2.1 PA).

The legally binding long-term temperature goal is, by design, both a substantive and legal strengthening of the previous international goal of holding warming below 2°C, agreed in Cancun at UNFCCC COP16 in 2010[5]. This goal is to be operationalized through the Agreement's different enabling elements, in particular Article 4.1 which establishes a timetable for peaking global GHG emissions as soon as possible, rapidly reducing these, with zero GHG emissions to be achieved globally in the second half of this century. The timetable for these global reductions and timing of achieving zero GHG emissions is to be based on the best available science.

The Paris Agreement LTTG requires a substantially lower level of warming be achieved than the former 2°C Cancun goal, which is still often referred to in Australia. Scientifically, the 2°C Cancun goal is interpreted as emission pathways that have a likely (66% or higher) probability of holding warming below 2°C. Peak 21st century warming in the published mitigation pathways consistent with the 2°C Cancun goal is 1.7-1.8°C and generally these pathways have less than a 50% probability of warming below 1.5°C by 2100[6].

The specific language of the Paris Agreement LTTG means warming should not rise above a level <u>well below</u> 2°C – which means peak 21st century warming needs to be lower than 1.7-1.8°C achieved in

5 UNFCCC 1/CP.16 The Cancun Agreements, Paragraph 4: "Further recognizes that deep cuts in global greenhouse gas emissions are required according to science, and as documented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, with a view to reducing global greenhouse gas emissions so as to hold the increase in global average temperature below 2 °C above preindustrial levels, and that Parties should take urgent action to meet this long-term goal, consistent with science and on the basis of equity; also recognizes the need to consider, in the context of the first review, as referred to in paragraph 138 below, strengthening the long-term global goal on the basis of the best available scientific knowledge, including in relation to a global average temperature rise of 1.5 °C"

6 Note that in the underlying scientific literature, probabilities of holding warming below a certain level for a particular emissions pathway consider uncertainties in the global carbon cycle and climate system. In this context, for example a "median" warming level associated with a particular global emissions pathway means that 50% of a large collection of climate/carbon-cycle models shows warming above, and 50% shows warming below, the specified warming level, for that particular emissions pathway.

pathways consistent with the 2°C Cancun goal with a likely probability (66% or higher probability). The Paris Agreement LTTG excludes interpretations that would have warming rise above a level well below 2°C before declining to a level well below 2°C by, for example, 2100. The latter appears to be a common misunderstanding in the Australian policy debate. In addition, it is important to note that the only temperature limit referred to in the Paris Agreement is 1.5°C above preindustrial levels.

The IPCC (2018a) Special Report on Global Warming of 1.5°C (IPCC SR15) has assessed the impacts of global mean temperature increase of 1.5°C above pre-industrial levels, as well as the impacts avoided compared to higher levels of warming including 2°C. The report details the extent of global warming so far and the risks and impacts for both natural and human systems.

The projected risks on human and natural systems are vast, and the risk levels take a massive leap between 1.5°C to 2°C warming above pre-industrial levels (Climate Analytics 2019a). One example, is that limiting warming to 1.5°C degrees could mean 420 million fewer people would be exposed to exceptional heatwaves in contrast to 2°C global warming (IPCC 2018a). Risks of species losses and extinction are less likely in 1.5°C scenario compared to a warmer climate of 2°C (IPCC 2018a). Keeping warming well below 1.5°C is essential to prevent these adverse impacts.

The impacts of climate change are already being experienced in Western Australia, and the south-west is particularly vulnerable to climate change impacts. The latest data shows average annual temperatures will increase and annual rainfall is declining in the southwest, the intensity and duration of hot spells are projected to rise and increase in frequency (Dept Primary Industries and Regional Development 2019). Modelling suggests the drying trend will continue, with higher risks of droughts and bushfires (Dept Primary Industries and Regional Development 2019). Changes in climate has negative repercussions on the agricultural sector and water supply. Western Australia has experienced sea level rise twice the rate of the global average (Climate Commission 2011). Rising sea levels has created severe risks of coastal erosion in Western Australia (Seashore Engineering 2019).

Western Australia is an internationally recognised biodiversity hotspot. Iconic flora and fauna, such as the quokka, Carnaby's cockatoo and tingle trees, in addition to the Ningaloo reef are at risk from climate change (Climate Commission 2011). The erosion and decline of our native animals, reef, and beaches, also erodes at the identity and culture of the Western Australian. It impacts the quality of life and the drivers of Western Australian tourism. Western Australia has reached a critical crossroad and needs to play its part in climate change mitigation.

Already today marine heatwaves are being observed, such as the record marine heatwave of 2011, with unprecedented sea temperature levels and warming anomalies of 2-4°C persistent for more than 10 weeks, which led to massive coral bleaching in the Ningaloo and Shark Bay region and possibly permanent impacts on algae and marine seagrass of and around Shark Bay (around 36% of the bay's seagrass meadows died off) as well as further negative impacts on other species along the food chain.

Global mitigation pathways for the 1.5°C limit – it matters how we get to net zero

Given the strengthening of the long-term temperature goal in the Paris Agreement, compared to the Cancun Agreements, emissions pathways compatible with the PA must increase substantially both the margin and likelihood by which warming is held below 2°C, and simultaneously satisfy the 1.5°C limit.

The IPCC (2018a) Special Report on 1.5°C (SR15) adopted and published in October 2018 has assessed a new generation of mitigation pathways based on Integrated Assessment Models that examine the technical and economic feasibility of holding warming below 2°C and in particular limiting warming to 1.5°C, simultaneously considering many dimensions of sustainable development. The IPCC (2018a)

SR15 currently provides the "best available science" for operationalising the LTTG and defining key elements of the emission pathway in Article 4.1, because it provides the most comprehensive and up-to-date assessment of mitigation.

The IPCC (2018c) SR15 Summary for Policymakers (SPM) defined 1.5°C compatible mitigation pathways as those with no- or limited overshoot above 1.5°C warming:

- "no- overshoot"- limit median global warming to 1.5°C throughout the 21st century without exceeding that level
- "low-overshoot" - a brief and limited overshoot (<0.1°C) with median peak warming below 1.6°C around the 2060s and drop below 1.5°C by the end of the century (around 1.3°C warming by 2100).

The IPCC (2018a) SR15 is very clear about the increases in climate risks between 1.5°C and 2°C, which reinforces the clause of the LTTG that limiting warming to 1.5°C "would significantly reduce the risks and impacts of climate change". It is important to note that the 2°C Cancun goal ("hold below 2°C") pathways discussed in much of the literature and in the IPCC reports predating the Paris Agreement do not provide a perspective on limiting the temperature increase to 1.5°C.

In policy terms, if the 2°C goal were to be used as a guide, the resulting 2030 emissions levels would be far above those in 1.5°C-compatible pathways, as shown in IPCC SR15, so that the 1.5°C limit would be out of reach, unless extreme carbon dioxide removal levels are achieved by 2050, which the Special Report does not deem feasible for technical, economic and sustainability reasons (Wachsmuth, Schaeffer, and Hare 2018).

The IPCC (2018a) SR15 clearly shows that rapidly reducing global GHG emissions by 2030 – by around 45% compared to 2010 (see Figure 3) – is a key milestone towards limiting warming to 1.5°C and avoiding the risks of escalating costs and institutional and economic lock-ins with carbon intensive infrastructure, which will then be costly or more difficult to phase out later. Delaying emissions reductions would reduce the flexibility of future response options and increase the reliance on negative CO_2 emissions - taking CO_2 from the atmosphere – using Carbon Dioxide Removal (CDR) technologies. All pathways require a rapid decarbonisation of energy systems by 2050, with global anthropogenic CO_2 emissions at net zero by around 2050, and total GHG emissions zero globally by around 2070. Figure 3 below provides an illustration of these pathways.

A 45% reduction in global GHG emissions by 2030 compared to 2010 corresponds to an emissions level of 25-30 $GtCO_2eq$/year by 2030. Excluding pathways that exceed the CDR sustainability limits identified in the IPCC SR15 implies faster reduction of greenhouse gas emissions by 2030 – to a level of 25-28 $GtCO_2eq$/year (Climate Analytics 2019e).

Full implementation of the current Nationally Determined Contributions (NDCs) corresponds to an emissions level of 52-58 Gt CO_2eq/year, nearly twice as much as the 1.5°C compatible pathways imply. The IPCC (2018a) SR15 therefore concludes that the ambition level of the current Paris Agreement national emission commitments – NDCs - are not consistent with limiting global warming to 1.5°C, even if supplemented by very challenging increases in the scale and ambition of emissions reductions after 2030. The Climate Action Tracker (2018b) shows this pathway reflecting the ambition level of current NDCs leads to warming reaching 3°C by 2100. It should also be noted, the Climate Action Tracker estimates that with current policies (as of December 2018), the median warming is projected to result in a rise of 3.3°C by 2100 (Climate Action Tracker 2018b). Whilst 3°C warming is itself likely to be extremely damaging, and catastrophic to many systems, there is at least a one in 10 chance (10%) that the current policy pathway could lead to global warming reaching, or exceeding, 4.5°C by 2100 (Climate Action Tracker 2018b).

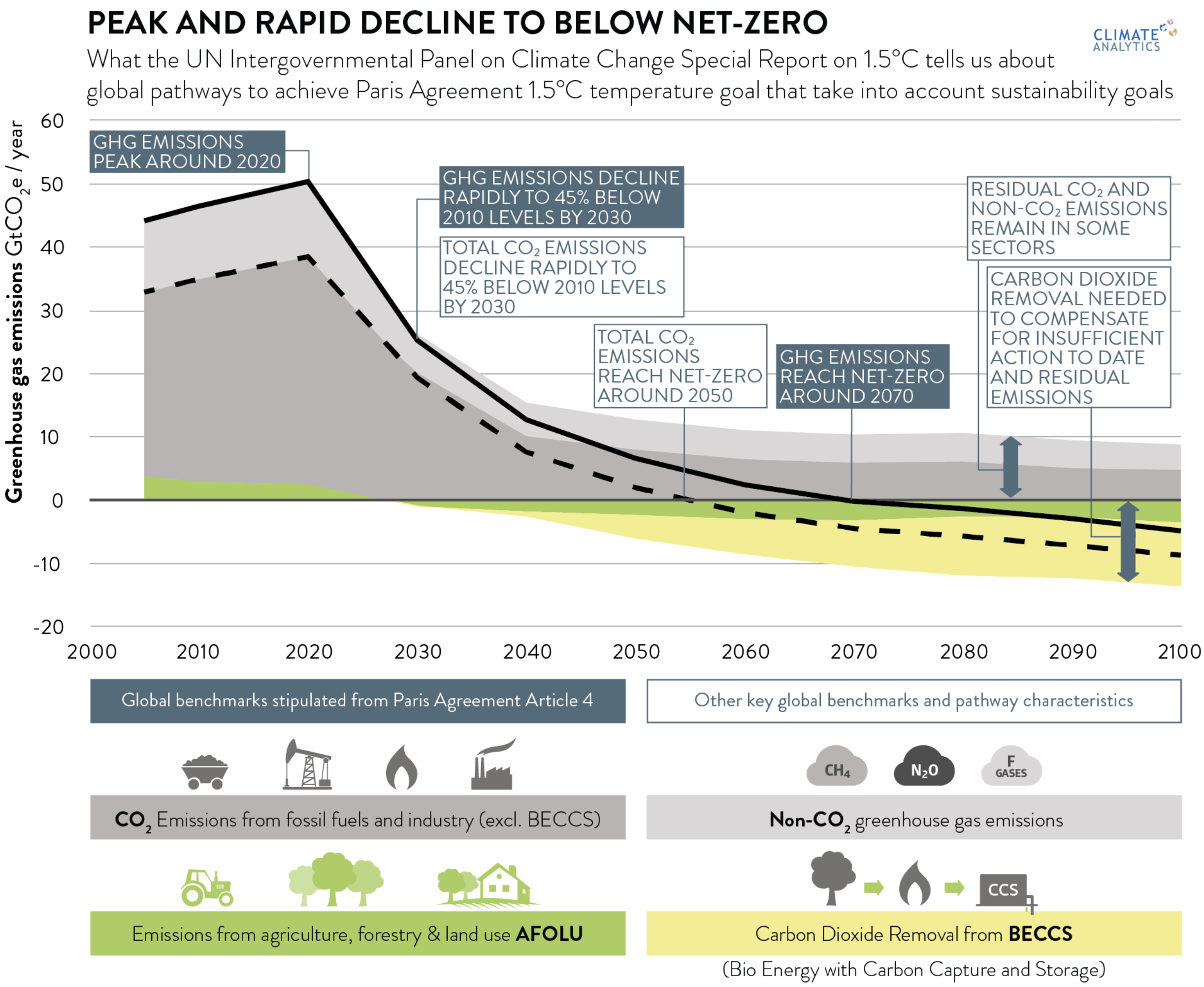

Figure 3: Illustration of the three benchmarks in Paris Agreement Article 4.1 for operationalisation of Article 2.1 (dark blue boxes) and global decarbonisation benchmarks (white box). This representative pathway is the median across all 1.5°C-compatible pathways from the IPCC (2018a) SR15 that reach levels of Carbon Dioxide Removal (CDR) below the upper end of estimates for sustainable, technical and economic potential around 2050 from SR15 in the sector of Agriculture, Forestry and Land-Use (AFOLU), as well as via Bioenergy combined with Carbon Capture and Storage (BECCS)[7]. Source: (Climate Analytics 2019e).

Whole of Economy Approach to net zero emissions – Transformations across all sectors

The IPCC SR15 outlines the range of mitigation strategies that can achieve the emissions reductions required to follow the pathways consistent with the PA LTTG described above. All pathways require a rapid decarbonisation of energy systems, with global net anthropogenic CO_2 emissions declining by about 45% from 2010 levels by 2030 and reaching net zero around 2050. In addition, substantial reductions of emissions of non-CO_2 greenhouse gases such as methane and nitrous oxide from agriculture, industry and other sectors are needed, and as well as a phase-out of HFCs (Climate Analytics 2019e).

7 All emissions and removals where calculated from the median emissions levels across the 46 pathways in the SR15 scenario database that are 1.5°C compatible, that satisfied the limits to CDR mentioned, and that reported data for all variables included here Source: SR15 scenario database (IIASA 2018) https://data.ene.iiasa.ac.at/iamc-1.5c-explorer

Achieving the Paris Agreement Long-term Temperature Goal requires transformative systemic change across the whole economy and society that is integrated with sustainable development to achieve the required deep cuts in GHG, and in particular CO_2 emissions. Carbon dioxide emissions from energy and industry need to reach net zero across all sectors of the economy by around 2060 globally and by around 2050 for a highly developed country like Australia. In addition, steep reductions in deforestation are needed.

The key characteristics of 1.5°C consistent global sectoral transformations based on the scenarios assessed by the IPCC are the following (Climate Analytics 2019e).

- Fully decarbonised primary energy supply by mid-century;
- Large energy demand reductions across all end-use sectors by 2030;
- Large reductions of fossil fuel use, in particular coal (-64% by 2030, -75% by 2050) and oil (- 11% by 2030, -60% by 2050);
- For natural gas, scenarios show a large range of changes by 2030, up to 20% increase and a 25% decrease, and up to a 55% reduction by 2050 with some models showing about the present levels (5% above 2010).
- Lower reductions in coal and natural gas correspond to those scenarios where it is assumed there is a high level of carbon capture and storage (CCS) deployment, which at present seems unlikely given the reducing costs of renewable energy and storage technologies.
- Rapid increase in the use of renewable energy;
- Bioenergy is used in many 1.5°C pathways, both with CCS (BECCS) and without, with uncertainties regarding limits to sustainable use
- Full decarbonisation of electricity generation by 2050, mainly through increased use of renewable energy reaching shares of over 50% by 2030 and over three-quarters by 2050 globally, and phase-out of coal by 2040 globally.
- Electrification of end-use sectors (transport, buildings, and some industry processes) and decarbonisation of final energy other than electricity, for example through the use of biofuels, hydrogen or other zero emissions energy carriers (aviation, shipping, and some industry processes)
- Net-zero land-use emissions between 2025 and 2040, requiring a steep reduction in deforestation and the adoption of policies to conserve and restore land carbon stocks and protect natural ecosystems.
- By 2050, negative emissions will already need to be on a multi-Gigatonne per year scale.

It is important to understand that all these sectoral transformations are needed – it is not a choice of one or the other and there is no room for offsetting one against the other.

Main energy transformation features of 1.5°C compatible pathways

Rapid reductions in energy demand across all sectors are fundamental for 1.5°C compatible pathways that also limit negative emissions through carbon capture technologies. The 1.5°C compatible transformation will require significant additional investment worldwide in low-emission infrastructure as well as redirection of financial resources from carbon-intensive investments toward low-emissions infrastructure.

A rapid and almost complete global phase-out of coal by 2040 in the power sector is a universal message from the new scenario results with many regions in particular OECD phasing out coal much earlier (around 2030/31). The share of coal for electricity generation (without CCS) shows a steep reduction in 1.5°C compatible pathways to 80% below 2010 levels by 2030 (Climate Analytics 2019d).

Substantial reductions in oil use by 2050 are also projected, coming in at around 30-80% lower than 2010 levels. By 2030, oil would need to decline by up to 35% below 2010 levels, but some models show an *increase* of up to 5%, reflecting assumptions about a lower and slower uptake of electric vehicles and transport than in other models.

For natural gas globally, 1.5°C compatible scenarios in line with the Paris Agreement long-term temperature goal assessed by the IPCC show a large range of changes by 2030, but have a median reduction of about 13% below 2010 levels, and by 2050 a 58% reduction compared to 2010 levels for those pathways that do not deploy carbon capture and storage (CCS). A high level of carbon capture and storage (CCS) deployment is very unlikely given the rapidly reducing costs of renewable energy and storage technologies. The use of CCS as a mitigation option in many scenarios is assessed on the basis of capacity factors in the order of 80–90%, which is not likely to be achieved in combination with a high penetration of variable renewables. Due to the high marginal cost of electricity production, CCS plant would be pushed out of operation first (Brouwer, 2015).

Figure 4 shows the projected demand for natural gas for electricity generation without CCS in the Asian region for 1.5°C compatible scenarios, which are assessed by the IPCC to be in line with the Paris Agreement long-term temperature goal. Demand for gas in the power sector will likely peak around 2030 and go down dramatically. These 1.5°C compatible pathways are compared to the IEA B2DS (below 2°C scenario) from 2016 which is not fully Paris Agreement compatible. This pathway peaks higher in 2030 but still drops quickly afterwards. A more recent scenario published by the IEA, the Sustainable Development Scenario (SDS) is also far from Paris Agreement compatible and has an even higher level of natural gas use after 2030 than the B2DS scenario. The SDS scenario substantially exaggerates the amount of natural gas used in the power sector and is an outlier compared to model assessments of limiting warming to 1.5°C. The SDS natural gas use in the Asian region is still rising in 2040 unlike any other of the published 1.5° compatible scenarios. The inconsistency between the IEA SDS scenario and the Paris agreement's 1.5°C temperature limit has been acknowledged by the IEA in its recent 2019 World Energy Outlook. The agency has signalled it will do further the work on the subject8. Whilst industry has chosen to emphasise the IEA SDS scenario this is the obvious reasons as the continued growth of natural gas aligns very well with their interests. Government, stakeholders, financial institutions and others however need to look carefully at scenarios which are fully Paris compatible to understand where the world may head as well as where it needs to go and therefore to be better able to understand and confront the transition challenges ahead.

[8] See WEO 2019, page 30: "The trajectory for emissions in the Sustainable Development Scenario is consistent with reaching global "net zero" carbon dioxide (CO2) emissions in 2070. If net emissions stay at zero after this point, this would mean a 66% chance of limiting the global average temperature rise to 1.8 degrees Celsius (°C) above pre-industrial levels (or a 50% chance of a 1.65 °C stabilisation). In the light of the Intergovernmental Panel on Climate Change Special Report on 1.5 °C, we also explore what even more ambitious pathways might look like for the energy sector, either via "net negative" emissions post-2070 or by reaching the "net zero" point even earlier" at https://www.iea.org/weo2019/

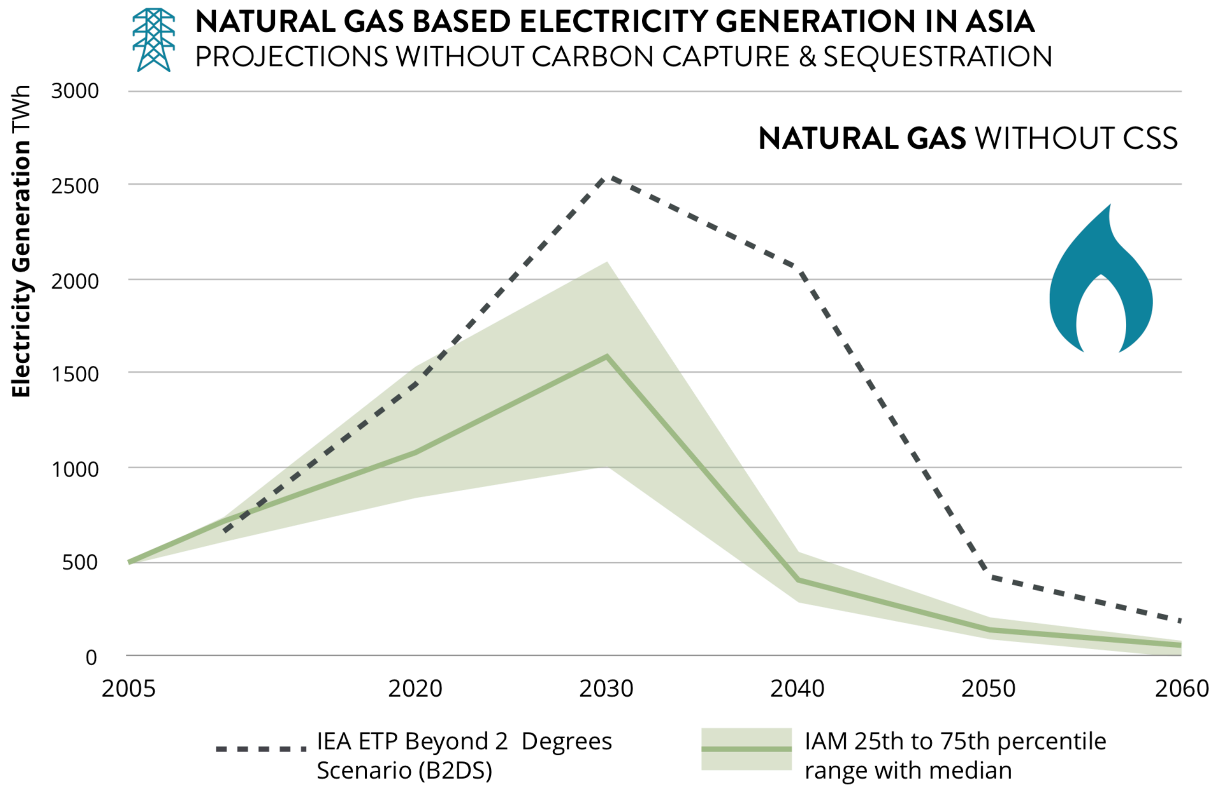

Figure 4: Electricity generation from natural gas without CCS. Shown are the median for PA-compatible Integrated Assessment Models (IAM), as well as the results from the IEA ETP B2DS used in the current study for some of the underlying pathways, both for the Asia region. Source:(Climate Analytics 2019c). The relative cost of CCS makes deployment of this technology unlikely in our assessment. The earlier IEA B2DS scenario shows a much higher natural gas demand than more recent fully Paris compatible scenarios.

The IPCC assessment of mitigation pathways clearly shows (Climate Analytics 2019e). that the continued use of natural gas would only be consistent with the Paris Agreement temperature goal if used with carbon capture and storage (CCS). Even then it would play only a small role in electricity generation by 2050 at around 8% of global electricity generation. Due to incomplete CO_2 capture rates, the use of gas with CCS would have to be balanced out with additional carbon dioxide removal (CDR). While the political, economic, social and technical feasibility of solar energy, wind energy, and electricity storage technologies has improved dramatically over the past few years, with costs dropping rapidly over the last few decades with corresponding growth trajectories much faster over the last years than expected (IRENA 2019b), CCS in the electricity sector has not shown similar improvements, with costs of CCS not coming down over the last decade. Together with more limited co-benefits than renewable energy, this cost trend makes these technologies increasingly unlikely to be able to compete with renewable energy, which is not yet reflected in many energy-economy models (Climate Analytics 2019e).

An important conclusion from this analysis is that sooner or later Western Australia will have to transition away from exporting natural gas, given CCS is increasingly unlikely to be able to compete with renewable energy and storage due to incomplete capture rates, no observed cost improvements in contrast to continuing cost improvements for renewable energy and storage technologies, as well as large additional benefits of renewable energy for sustainable development.

In all scenarios that limit warming to 1.5°C, renewable energy (excl. biomass) has to be ramped up quickly to supply 50-65% of total primary energy by 2050[9], displacing fossil fuels from traditional markets for power generation, mobility and heating. Renewables reach a particularly high share in electricity supply of 45-65% in 2030 and 70-85% in 2050. The political, economic, social and technical feasibility of solar energy, wind energy, and electricity storage technologies has improved dramatically over the past few years, with costs dropping rapidly over the last few decades with corresponding growth trajectories much faster than expected (IRENA 2019b). These fast developments enable more stringent near-term mitigation than currently planned.

The decrease in use of fossil-fuels and increase in renewables is associated with a major shift in investments, where global annual investments in low-carbon energy technologies overtake fossil investments by around 2025 in 1.5°C pathways (IPCC 2018b). The IPCC (2018a) Special Report shows that annual investment in low-carbon energy technologies and energy efficiency increase rapidly by a factor of 4-5 by 2050 compared to 2015. Compared to 2°C pathways, total energy-related investments in both supply and demand side increase by 12%.

9 Information on this was included by IPCC authors in the final draft of the SPM , but was not included in the final government-approved SPM. This data can however be extracted from the publicly available scenario data in IPCC's online scenario database: (IIASA 2018) https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/

ROLE OF LAND SECTOR IN 1.5°C PATHWAYS

Limiting warming to 1.5°C will require global-scale transitions in global and regional land use, and in agricultural practices. In the near term, a focused effort will be needed to rapidly reduce and then reverse CO_2 emissions from land use. The majority of 1.5°C-compatible pathways achieve net zero land use emissions between 2025 and 2040, requiring a steep reduction in deforestation and the adoption of policies to conserve and restore land carbon stocks and protect natural ecosystems. By 2050, negative emissions will already need to be on a multi-Gigaton scale. This will likely require the deployment of bioenergy with carbon capture and storage in addition to reforestation, afforestation, and other land-based activities for sequestering carbon, such as land restoration and improved soil management (Climate Analytics 2019e).

Limiting warming to 1.5°C will require marked reductions in non-CO_2 emissions in the agriculture sector, even though these cannot be reduced to zero. Substantial reductions can be achieved through enhanced agricultural management and best practice farming on the supply side (for example, manure management, improved livestock feeding practices, and more efficient fertiliser use), as well as through demand side mitigation opportunities such as dietary shifts to healthier, more sustainable diets and measures to reduce food waste (Climate Action Tracker 2018c, 2019c).

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WA ECONOMY AND ITS CONTRIBUTION TO 1.5°C – CHALLENGES AND OPPORTUNITIES

Economy and Emissions profile

Western Australia's economy relies heavily on the mining of minerals and petroleum/gas, producing a significant proportion of the world's minerals and petroleum commodities. Mining currently generates 30% of Gross State Product (GSP) (in 2017-2018) and about 8% of employment (in 2018-2019). In terms of employment, the largest sectors are services industries (including retail, trade, healthcare, social assistance, and tourism) (72%), followed by construction (9%) in 2018-2019 (Government of Western Australia 2019a).

By far the biggest component of the mining industry is the mining and export of iron ore with AU$ 78.2 billion sales in 2018-2019 (share of 54% of minerals and petroleum sales), followed by LNG with AU$ 29 billions of sales (share of 20%). Both sectors have grown strongly over the past years, with Western Australia now being the source of 14% of global LNG exports (Government of Western Australia 2019b).

The heavy dependence on the resource extraction and export is reflected in the sectoral composition of GHG emissions: In 2017, more than 30% of all greenhouse gas emissions came from the mining sector (including gas extraction and processing, in particular LNG processing) – a bit more than the electricity supply (29%), and followed by manufacturing with 17% of greenhouse gas emissions, and agriculture with a share of 11%. The mining sector emissions have increased sharply since 2015, mostly due to the sharp increase in LNG processing and related emissions.

In 2017, Western Australia contributed 16.6% to Australia's total national emissions (all GHG, with LULUCF) and emissions have increased by 23.5% since 2005 (DEE 2019)[10], despite a reported decrease in emissions in the land use sector (LULUCF) from being a source of 5.3 Mt to being a sink of 8.8 Mt in

10 AGEIS trend data result in different share and increase, due to different LULUCF data – KP categories.

2007[11]. **Without the highly fluctuating and uncertain LULUCF emissions, Western Australia's GHG emissions contribute 17.6% to national emissions and have increased by 47% since 2005.**

Energy and industry (fossil fuel) CO_2 emissions are by far the most important current source of emissions and are the largest source of emissions increases. CO_2 emissions account for 83% of all WA GHG emissions excluding LULUCF, with almost all of these from fossil fuel combustion (which is 84% of total CO_2 emissions without LULUCF). The second largest source of CO_2 emissions are fugitive CO_2 emissions mostly from venting during gas extraction and processing (contributing 11% to total CO_2 emissions), and a smaller share of 4% from industrial processes (for example cement production). In addition, fugitive methane emissions are also related to extracting and use of fossil fuels with a share of 5% of total GHG emissions without LULUCF. **Together, fossil fuel energy and industry related CO_2 and methane (CH_4) emissions add up to a share of 89% of total GHG emissions (without LULUCF).**

Because of the large share of emissions from energy and industry, in particular energy industry (mainly LNG processing), **Western Australia contributes 20% to the national energy and industry (fossil) CO_2 emissions and these have increased even more than overall GHG - by 60% since 2005. (See** Table 2**).**

As discussed earlier, decarbonising energy and industry sectors and reaching net zero carbon emissions from fossil fuel and industry across all sectors of the economy by around 2060 globally and by around 2050 for a highly developed country like Australia is a key strategy to achieve the Paris Agreement temperature goal. This will be achieved through eventually phasing out all fossil fuels not only for power generation but for all other industry processes. This is why this study focuses on the carbon budget and emission pathways for fossil fuel and industry related CO_2 emissions.

The largest emitting sector in Western Australia is industry with a share of 48% of CO_2 emissions (excluding LULUCF) in 2017 (see Figure 5 and Figure 6). It is also the sector with the highest increase since 2005 - by 74% since 2005. Here we follow the sectoral definition used in greenhouse gas accounting (see Annex I for further details) and include the following categories under the Industry sector:

- direct combustion in manufacturing and other industry sectors, including mining,
- direct combustion in energy industry (in particular LNG processing),
- fugitive emissions (CO_2 and Methane) from energy industry (that is from coal mining, as well as extraction, production and processing of gas), and
- industrial processes (mostly CO_2 emissions from cement and ammonia production) and product use (non-CO_2 emissions).

Within industry, it is the fast ramping up of LNG processing that has contributed most to the increase of emissions. It alone has a share of 18%, and CO2 emissions have tripled since 2005.

Electricity use in industry is not accounted for under the industry sector, but under the electricity generation sector, which is the second largest sector (31% share, increase of 44% since 2005), followed by transport (17% share, increase of 61% since 2005). The buildings sector contributes 2% of direct CO_2 emissions, and these have increased by 62% since 2005. Indirect emissions from the building sector due to electricity use are accounted for under the electricity generation sector.

11 This is based on the published state inventory. However, there are uncertainties around LULUCF data. Here we look at the emissions profile without LULUCF.

Other, non-energy or industry related emissions – mainly from agriculture – need to be reduced as well, but are not expected to be reduced to zero. In Western Australia, about half (51%) of the other emissions (not fossil fuel and industry related CO_2 emissions) are from agriculture (methane and nitrous oxide emissions) which makes up 10% of total WA GHG emissions. This is the only sector where emissions have actually decreased (by 12% since 2005). Industrial processes and product use contribute 8% to other GHG emissions, through emissions from use of F-gases, which can largely be phased out.

Table 2 shows emissions from these sectors in the past as well as their current share. The LNG sector is shown separately because of its large contribution to emissions and emissions growth.

Table 2 Western Australia energy and industry sector carbon dioxide emissions ($MtCO_2$) and total Western Australia greenhouse gas emissions ($MtCO_2e$). Industry emissions include manufacturing and mining, energy industries excluding electricity, fugitive emissions, and process emissions and product use. The LNG Sector is shown separately because of its large contribution to emissions and emissions growth. Source: AGEIS (2019), own estimates (for LNG). Fugitive emissions outside the LNG sector are also shown separately because of the different nature of mitigation options. See discussion of emissions pathways for economic sectors, and Annex I for details regarding the categorisation of sectors.

Sector	2005	2010	2017	Share of 2017 emissions (excl. LULUCF)	Increase 2017 Since 2005 in %
Carbon dioxide – $MtCO_2$					
Electricity generation	17.5	20.1	25.2	31%	44%
Transport	8.8	10.0	14.2	17%	61%
Industry (excluding LNG)	18.1	17.9	22.2	27%	23%
LNG (including CO^2 venting/fugitives)	3.5	5.2	14.5	18%	318%
Fugitives - other	1.2	2.5	2.5	3%	110%
Buildings	1.2	1.4	1.9	2%	62%
Total energy and industry	50.3	57.1	80.6	99%	60%
Agriculture	0.7	0.7	0.9	1%	39%
Waste	0.0	0.00	0.00	0%	29%
Total WA emissions w/o LULUCF	**50.9**	**57.8**	**81.5**	**100%**	**60%**
LULUCF	12.3	6.5	-10.8		-188%
Greenhouse gases – $MtCO_2e$					
Electricity generation	17.6	20.2	25.4	27%	44%
Transport	9.1	10.3	14.6	15%	60%
Industry (excluding LNG)	19.5	19.9	23.9	25%	23%
LNG (including CO^2 venting/fugitives)	5.0	7.5	17.8	19%	256%
Fugitives - other	0.6	0.3	0.6	1%	10%
Buildings	1.3	1.5	2.0	2%	54%
Total energy and industry	**53.0**	**59.8**	**84.3**	89%	59%
Agriculture	10.2	8.7	9.0	10%	-12%
Waste	1.4	1.8	1.5	2%	5%
Total WA emissions w/o LULUCF	64.7	70.2	94.8	100%	47%
LULUCF	15.9	10.1	-7.8		-149%

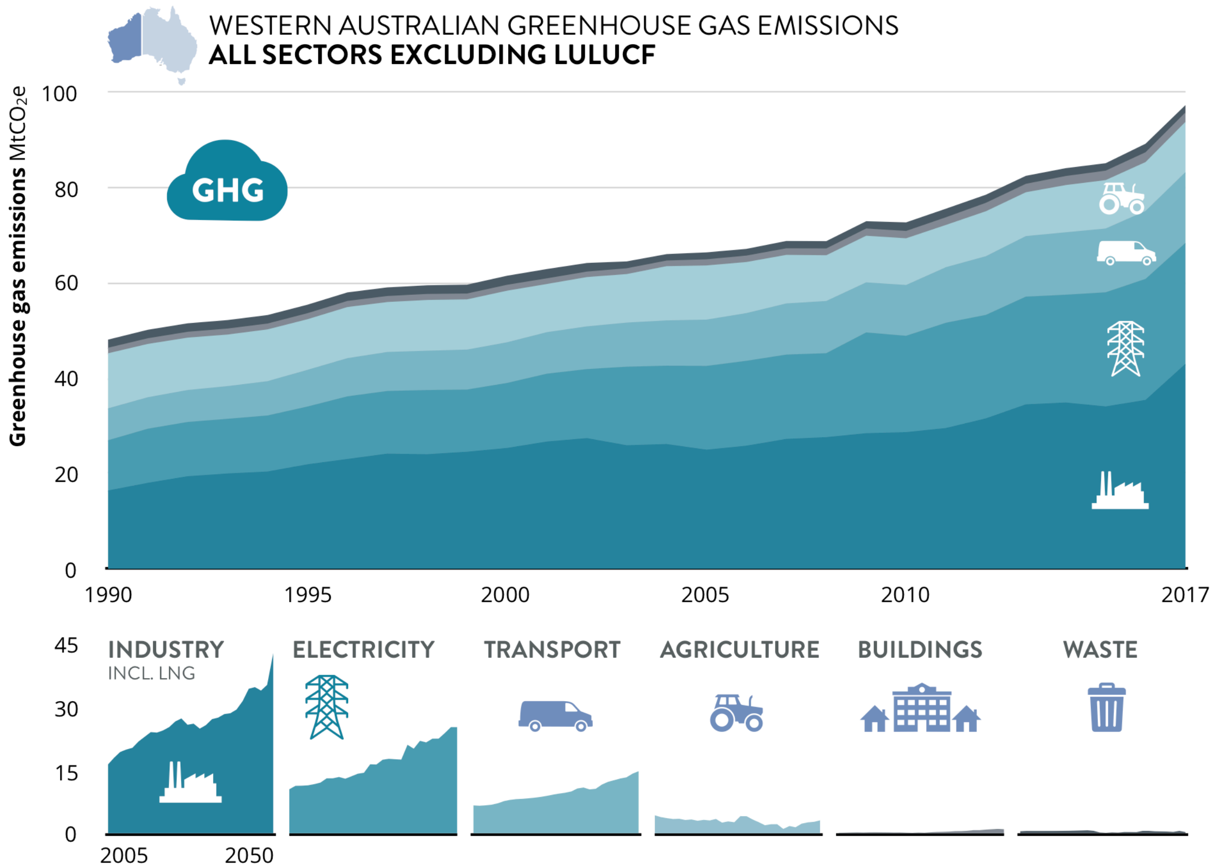

Figure 5: Historical emissions in Western Australia by sector, based on national greenhouse gas accounting. See also

Table 2 and annex II for explanation of sectors. Emissions and removals from land use, land-use change and forestry are not shown. Source: AGEIS (2019).

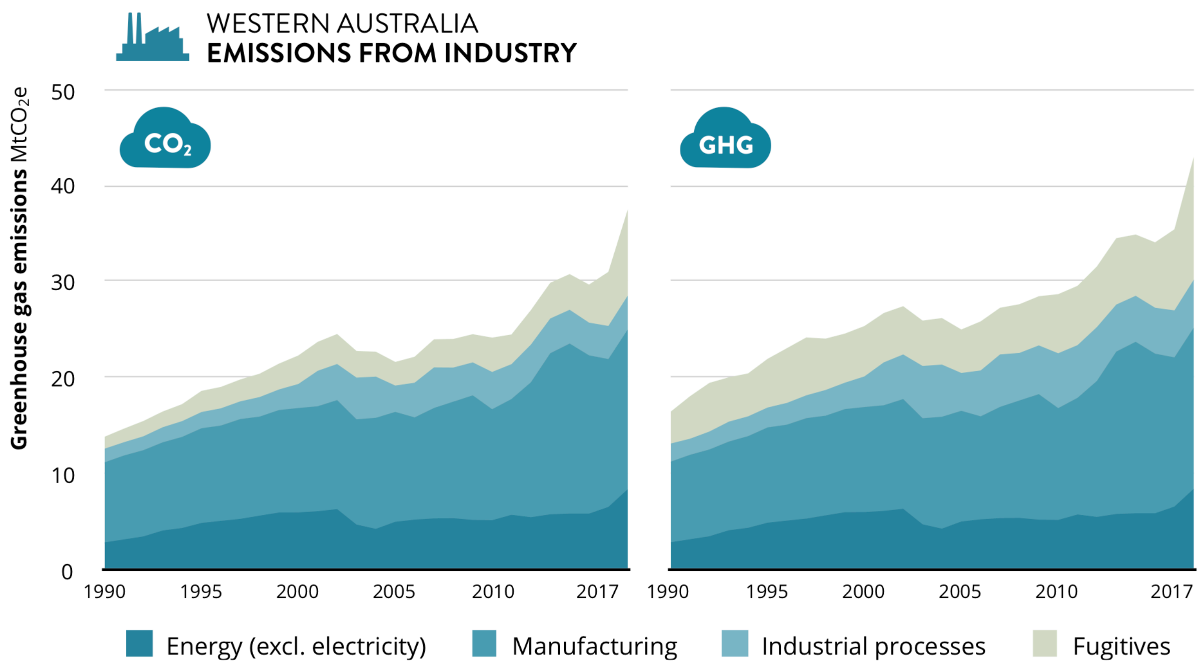

Figure 6 : Historical emissions in Western Australia in the industry sector – CO_2 (left) and all Greenhouse gases (right), with subsectors based on national greenhouse gas accounting. Most of industry emissions are CO_2 emissions, see also

Table 2 and see Annex II for explanation of sectors. Source: AGEIS (2019).

Electricity generation and distribution in WEstern Australia– ready for the future?

Electricity generation in Western Australia is the second largest source of emissions (after industry) and contributes almost a third (31% share in 2017) to energy and industry carbon emissions, and these have increases by 44% since 2005. Despite having an independent electricity system and market[12], Western Australia and New South Wales are the only states that do not have a renewable energy target. Nor does Western Australia have an energy efficiency scheme. The state is lagging behind other states and territories with renewable energy despite having prime resources for solar and wind. Similarly, Western Australia does not have energy saving schemes, despite Victoria, New South Wales, South Australia and the ACT having schemes in place (ESIA 2018). In 2018 Western Australia had a low renewable energy share of only 8% of power generation, well below the national share of 19% (Department of the Environment and Energy 2019, Table O). However 27% of WA households have installed rooftop solar (Climate Council 2018) – the third highest proportion of all states and territories behind Queensland and South Australia.

2018 – a boom year for investment in Renewable energy in Australia – only saw two projects completed in WA with a total of 30 MW capacity (two solar farms, Emu Downs and Northam). A further 395 MW are under construction or financially committed (Clean Energy Council 2019), and a further eight projects with a total of 1GW of capacity have been approved for connection in December 2018, including a 210MW wind farm in the Mid-West. By October 2020, a total of 515 MW is expected to connect, including a 100 MW solar farm (Merredin) (RenewEconomy 2019e).

While uptake of large-scale renewable energy is still slow compared to other states, solar PV has become the largest source of generation capacity in the South West Interconnected System (SWIS) (WA Government. 2019) with households and businesses increasingly switching to rooftop solar and batteries, leading to a lower peak demand and challenging the management of the "most isolated grid of its size in the world" (RenewEconomy 2019e), with rooftop solar possibly tripling over the next ten years, forcing operational demand below a level of 700 MW, seen as a threshold below which system security becomes challenging to secure (RenewEconomy 2019d).

The WA government expects the share of renewable energy in the SWIS to double from around 16% to a share of over a third by 2030. It has reacted to the challenge for the isolated SWIS with the development of an Energy Transformation Strategy (WA Government. 2019). A number of innovative stand-alone power systems, distributed energy resources and microgrid trials are currently operating in Western Australia, in particular in regional and remote areas (WA Parliament 2019).

Given the prime resources for solar and wind and availability of infrastructure and skilled workforce, there is an increasing interest in large scale projects to generate power from renewable energy and store it in hydrogen for export into neighbouring Asian countries: A large scale combined wind and solar 15 GW project (twice the current capacity of installed large-scale wind and solar) is in development in the Pilbara, focusing on green hydrogen production for domestic and export markets, targeting mainly Japan and South Korea and expecting a very large market for green hydrogen over time (RenewEconomy 2019b). Another project is planned near Kalbarri, proposed by Hydrogen Renewables Australia with plans for up to 5 GW combined solar and wind to supply production of low-cost hydrogen (RenewEconomy 2019c). ARENA is looking into options for starting to use hydrogen domestically, before the export market develops, by injecting it into gas networks, or using it in transport or in industry, for example for the production of ammonia (instead of using natural gas, with

12 The electricity market is not part of the NEM and the gas market is not part of the eastern Australian gas market.

a potential of a sevenfold increase in electricity generation from renewable energy in order to produce hydrogen in addition to meeting the direct electricity demand (RenewEconomy 2019a).

There is an increasing recognition including with the WA Government's Green Hydrogen strategy, of the opportunities through the large potential for renewable energy, in particular solar and wind, combined with available infrastructure and skilled workforce in the energy industry – and the proximity of energy hungry Asian countries, some of them currently main importers of Western Australian natural gas.

WA needs to develop its own strategy and targets

Western Australia, with its own, independent energy system and unique resources and opportunities, needs to do its fair share to contribute to achieve the Paris Agreement temperature goal. Western Australia has an important role to play in reducing national emissions, given it is currently largely responsible for national emissions increasing, in particular because of the increase in emissions from LNG processing.

Given it is well known that the current federal emission reduction target of 26-28% reduction compared to 2005 levels that the government has committed to in its Nationally Determined Contribution (NDC) to the Paris Agreement is not consistent with the Paris Agreement (Climate Action Tracker 2019; Climate Analytics 2019b) and given the failure of the federal government to recognise this and even to develop any policies that would ensure achieving the insufficient current target for 2030, there is no reason for Western Australia to align with the federal target and its inadequate policies. To the contrary, as we can see in other countries, there is a responsibility and opportunities for subnational states to show leadership and move ahead with emissions reductions and an energy transition to renewable energy, and energy efficiency that benefits the state's economy, as can be seen in South Australia, or in California in the USA.

As we have outlined above, Western Australia has an own vital interest in achieving the Paris Agreement 1.5°C temperature limit, to protect its unique and iconic ecosystems and the services these provide, including the economic value through tourism, its agricultural regions, and the health well-being of its population.

Western Australia also has globally prime resources that are needed for the Paris Agreement consistent transition to renewable energy, not only with globally first-class wind and solar resources, but also with minerals and critical materials needed for batteries and other technologies.

Again, Western Australia has a lot to gain from such a strategy, if such a transition is planned well, given it can move away from relying on exporting fossil fuels (LNG) towards exporting zero emissions energy carriers (direct electricity or green hydrogen) or zero emissions energy intensive products such as zero emissions steel – with opportunities for additional manufacturing employment.

A fair share contribution

In addition to Australia's own domestic emission reductions to meet the Paris Agreement, Australia also needs to make a contribution to assisting other countries and reducing their emissions, which gives rise to what is called a "fair share" contribution to global emission reductions. This general fairness principle is one of the underpinning elements of the Paris Agreement. For wealthier countries, such as Australia, this almost always means that a "fair share" contribution when expressed in terms of national emission reductions by a certain date is greater than the least-cost domestic emission reductions consistent with meeting the global temperature goal of the Agreement.

It is easy to confuse a "fair share" contribution of a country or region with the actual domestic reductions a country needs to make. In this study we have focused on the budget for the actual domestic reductions that Western Australia needs to make and the least cost emission pathway to achieve this.

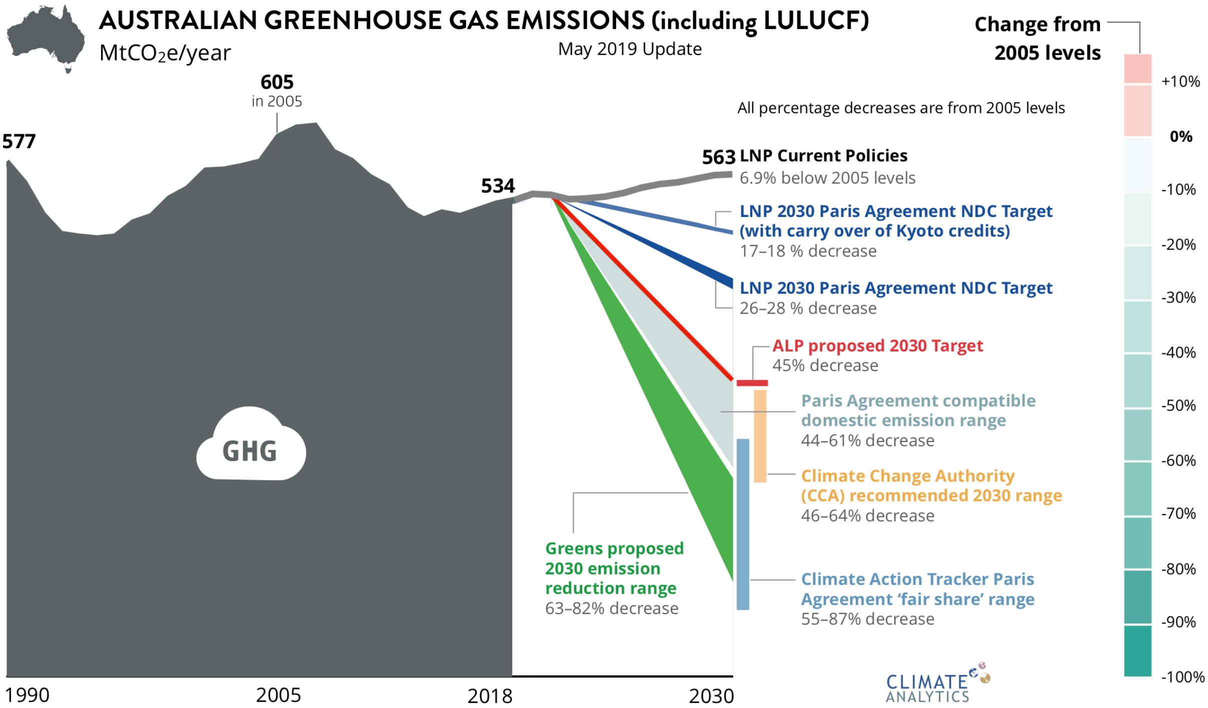

Figure 7: Schematic overview of national emission targets proposed by political parties on the May 2019 Australian Federal election compared to Paris Agreement compatible domestic emission pathways, Climate Action Tracker estimated fair share emission reduction ranges, and the 2015 recommended 2030 range of the Climate Change Authority. This figure shows the emission reductions with respect to emissions including land use, land use change and forestry

Australia, being a developed country, needs to make both domestic emission reductions and contributions to assisting poorer countries in order to move the Paris Agreement in reducing theirs. An estimation of what reasonable domestic emission reductions need to meet global climate goals such as the Paris Agreement to be made by Australia can be derived from examining what global, integrated assessment and energy models are telling us about the kind of energy transformations, and other actions, are needed in different regions, including Australia's own. For this evaluation we have applied one set of models, that provides a good perspective on the least-cost domestic emission reductions for Australia[13]. Given the reductions in renewable energy costs and storage, ongoing reductions in electric vehicle costs and other technological developments these emission reductions may indeed be conservative.

A Paris Agreement compatible 2030 domestic emission commitment target would be in the range of 44-61% emission reduction by 2030 below 2005 emissions, including land use change and forestry sources. Excluding land use change and forestry sources a Paris Agreement compatible domestic emission commitment target would be in the 35-55% reduction by 2030 from 2005 emission levels. There is a large range of least cost domestic emission reductions for Australia deriving from Paris

13 The pathway is derived from results from IAMs (Integrated Assessment Models) results under RCP 1.9 scenarios of (Rogelj et al. 2018) and methods of (Sferra et al. 2019)

Agreement global emission pathways due in part to the range of model results in the scientific literature.

If Australia's Paris Agreement 2030 NDC were to be expressed as a fair share target and be consistent with the range of scientific assessments of this it would be in the range of a 55-87% reduction below 2005 emission levels[14], including land use change and forestry sources (48-85% reduction below 2005 emission levels, excluding land use change and forestry sources). A fair share target represents a country's contribution to meeting the Paris Agreement globally, which includes domestic emission reductions plus contributions to reductions elsewhere, the NDC goal. There is a large range because of the wide range of fairness viewpoints in the scientific literature, with the range here drawn from the Climate Action Tracker (2019).

What this would mean in practice is that the total sum of domestic reductions + emission reductions overseas (from climate finance or acquisition of emission units) would need to add up to the total NDC "fair share" target. In general, this means that in addition to domestic emission reduction targets, the fair share contribution requires further effort abroad. If, for example, the fair share NDC was for a 70% reduction by 2030 then it could mean that domestic reductions of about 50% were achieved and emission units equivalent to 20% of the 2005 base year were supported by Australia internationally.

WA Climate policy in national and international context

Currently, there is no coherent climate or energy transition policy in Western Australia. Western Australia and New South Wales are the only states or territories without any renewable energy target. While WA has recently, in August, finally joined other states adopting an aspirational goal of achieving net zero greenhouse gas emissions by 2050, it does not have any targets for renewable energy nor does it have a specific 2030 reduction target, which Victoria and Queensland have adopted, and Victoria has also legislated. A discussion about the development of a State Government policy and roadmap was initiated with the Issues paper in September this year (WA Government 2019b).

There are elements of policies in energy and resources sector that are relevant for the development of the overall climate strategy, such as the Energy Transition Strategy and the Renewable Hydrogen Strategy. However, none of these are using the relevant Paris Agreement benchmarks outlined in the previous section, with the only exception of the issue paper referring to "well below 2°C" (but omitting the Paris Agreement's 1.5°C limit) and the 'aspirational' 2050 net zero greenhouse gas emissions target. In order to keep the 1.5°C limit within reach achieving key short-term benchmarks to peak emissions by around 2020 and reduce emissions by around 45% below 2010 levels by 2030 are essential.

Opportunities from transition to Renewable energy

Several studies have found that WA's transition to renewable energy is technically and financially feasible. Lu, Blakers and Stocks found that 90% to 100% renewable electricity is technically and financially feasible for SWIS of WA (Lu, Blakers, and Stocks 2017). They modelled several high renewable penetration scenarios and found renewables can be deployed and balance the grid, with different options available from solar PV, wind, and pumped hydro energy storage (Lu et al. 2017).

14 The higher limit (55%) is the boundary between 1.5°C Paris Agreement Compatible and 2°C Compatible and the lower limit (87%) the bottom of fair share range between Role Model and 1.5°C Paris Agreement Compatible (Climate Action Tracker 2019).

An analysis (Rose et al. 2016)[15] of different options for an 85% or even complete decarbonisation of electricity supply by 2030 for Western Australian South West Interconnected System (SWIS), focuses on ensuring reliability and grid stability, including a combination of energy efficiency measures and currently available technologies such as residential and commercial roof top photovoltaic systems, solar thermal power stations with heat storage, wind power and distributed battery storage systems. Laslett et al. (2017) also looks at a new technology option for longer-term storage of excess electricity by producing gas - so called "Power-to-Gas" technology, which can build on the gas infrastructure in Western Australia, using the ample solar and wind resources for electricity. Other options studied are wave power (presently in development stage) and biomass (from oil Mallee) to replace natural gas, as well as pumped hydro storage. These studies also assume an increased electricity demand due to an increased uptake of electric vehicles. They confirm what has been shown for other parts of Australia or other countries and globally: gas can play a limited role in a transition phase to 100% renewable energy, but with a declining share in electricity generation, given gas capacity would be mostly used to cover periods of low variable renewable energy power. Current development and falling costs of storage technologies would reduce this transition role even further.

WA is in close proximity to Asian countries with huge energy demand and global pressure to decarbonise their economies from the Paris Agreement. WA can offer renewable sources of energy, to help meet energy demand in Asia without the emissions of conventional energy sources. Furthermore, the natural resources needed in renewable energy related technologies create opportunities for the WA industry sector.

Technologies associated with renewable energy, such as batteries and electric vehicles require natural resources available in WA. The global demand for battery-based energy storage and electric vehicles requires resources that are mined in WA, and the state is informally dubbed "Lithium Valley". WA has huge reserves of battery materials such as lithium, nickel, cobalt, manganese and alumina (Dept. of Jobs Tourism Science and Innovation. 2019). WA is already the world leader in lithium production, and has rare earth minerals used for electric motors (Dept. of Jobs Tourism Science and Innovation. 2019).

The government has realised WA is in a position to benefit from the renewables boom, and published the "Future Battery Industry Strategy Western Australia", detailing the supportive government approach to create the industry, including attracting investment, facilitating projects, research and technology for sector development and new opportunities for domestic uptake in battery technology (WA Government n.d.). The state aims to have a future battery industry by 2025, and so far, the state has set up a Funding Assistance Register to support the battery sector including research groups, mining and processing companies, renewable energy companies and enterprises in the battery value chain (PV Magazine 2019). This is an approach that could also be followed for other opportunities to develop manufacturing value chains in Western Australia.

Green hydrogen offers WA an option to transition the LNG industry in renewable energy export industry (Climate Analytics 2018b). A report commissioned by the Australian Renewable Energy Agency (ARENA) found that prospective markets for Australian hydrogen were China, Japan, Republic of Korea, and Singapore (ACIL Allen Consulting 2018). The report lists the competitive position for Australia in the hydrogen market, which applies to WA. The factors mentioned include Australia's ability to offer lower landed costs of hydrogen, proximity to the market, having well established energy trading relationships and experience in large scale energy infrastructure construction, and the possibility of supplying hydrogen from a range of sources (ACIL Allen Consulting 2018). The report modelled 3 scenarios of different levels of demand for hydrogen (ACIL Allen Consulting 2018). The direct economic contribution

15 See also (Climate Analytics 2018b; Laslett et al. 2017)

in hydrogen production for export is estimated at A$201 million in the low demand scenario, $417 million in the medium scenario and $903 million in the high scenario for 2030 (ACIL Allen Consulting 2018). Although, these estimates are for Australia in general, WA has the opportunity to take the lead role in Australia's hydrogen development, considering its close proximity to Asia and renewable resource potential in its sparsely populated huge landmass.

In addition, a scheme involving energy efficiency can tackle pressing issues within Australia to help deal with escalating energy prices and the need for network upgrades to meet peak demands (ESIA 2018). The Energy Saving Industry Association (ESIA) has developed a policy setting guide serving as a case for introducing energy saving schemes in WA from 2019 to 2030 (ESIA 2018).

The widespread adoption of renewable energy technologies would create employment opportunities along the supply chain. Sustainable Energy Now (SEN) found that the development of new renewable energy infrastructure in WA could create 37,000 job years in construction, 6,000 job years in manufacturing and 1,400 job years for operations and maintenance (SEN 2017). The Climate Institute assessed the impacts of a clean energy boom in WA, finding that the large untapped resources of renewables offers opportunities for state-wide employment of over 4,700 new jobs in the electricity sector by 2030 (The Climate Institute 2011).

The Asia Renewable Energy Hub (2019a) is a wind and solar project proposed in the Pilbara in WA, with 15GW of wind and solar to be developed over 6,500 square kilometres. The project can power local industry and export to the Asia market using green hydrogen. The project has secured land, it has been granted Lead Agency Status by the WA government, and construction is scheduled to commence in 2022/3, and the first electricity generation is expected 2023/4 (The Asian Renewable Energy Hub 2019a). The Hub claims the $21 billion project would create 3,000 construction jobs over 10 years and 400 jobs for maintenance and operations, and the employment of a further 11,500 for indirect jobs (The Asian Renewable Energy Hub 2019b).

WESTERN AUSTRALIA'S ECONOMIC SECTOR PATHWAYS

In this section, the core of this study, we outline results of the energy system scenario analysis across all sectors of WA economy. We provide, for each sector, a **Paris Agreement compatible emissions pathway that is based on underlying least-cost emissions pathways**, and cost optimal pathways for the electricity sector. We also look at implications for fuel mix, key technologies, and sectoral transformations and key sectoral strategies and policies at state level.

Building Sector – Decarbonising through Efficiency and Electrification

The buildings sector (including both residential and commercial buildings) contributes 2% of direct CO_2 emissions, and these have increased by 62% since 2005, rising until 2016 and declining slightly in 2017. Indirect emissions from the building sector due to electricity use are accounted for under the electricity generation sector.

While the building sector is already largely (56%) using electricity and therefore is already decarbonised with power generation shifting to renewable energy, electrification is a key strategy to accelerate this decarbonisation either directly or indirectly through replacing fossil fuel combustion with biomass or (not included in the underlying model but likely a more sustainable option) "green" hydrogen (generated from renewable electricity). Full decarbonisation of this sector by 2050 leads to a **carbon budget for 2018-2050 of about 22 $MtCO_2$, and a reduction by 41% in 2030 compared to 2005. At current emissions rates, this budget would be used up in 12 years.**

Despite an increase in efficiency and resulting lower energy demand, electricity demand would increase slightly, by 23% from 2014 to 2050 due to electrification. Gas demand would go down both in absolute terms as well as in terms of the share of overall demand for buildings, and oil demand would decrease even faster, essentially phased out by 2040.

Key policies to support this development at state level are incentive schemes to refurbish existing buildings, as well as additional regulation and incentives to reduce energy demand, aiming for near net zero energy (fossil fuel free) new buildings from 2020 onwards, support programmes and information campaigns (working with local councils and appliances retailers) to install heat pumps and electric appliances to replace natural gas, as well as developing supporting regulation and research and development to support blending (green) hydrogen into the gas grid and eventually replacing natural gas with hydrogen in the grid, building on lessons learned from the ARENA (2018) pilot project with ATCO and on international experiences.

An essential further policy would be ambitious renewable energy targets and planning for ramping up renewable energy, taking into account additional electricity demand through decarbonisation of buildings and other end-use sectors.

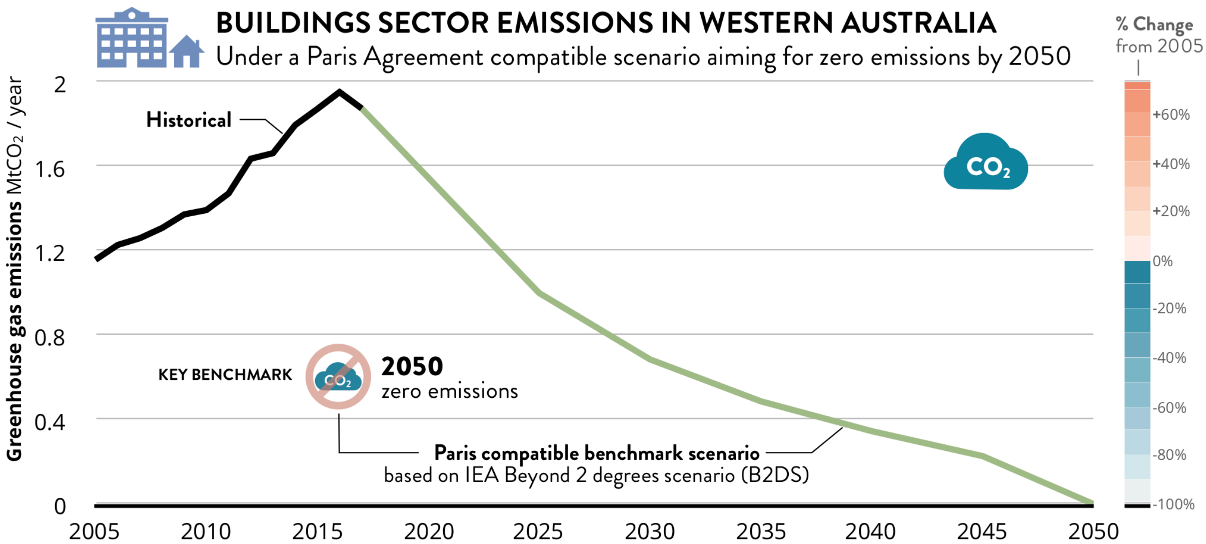

Figure 8: Carbon emissions from the buildings sector (residential and commercial) in Western Australia, for Paris Agreement benchmark scenarios based on the IEA "Beyond 2 Degrees" Scenario (B2DS) downscaled to Western Australia, with the benchmark of full decarbonisation by 2050, used to calculate the sectoral carbon budget) and adjusted to take into account historical emissions until 2017 Delayed mitigation leads to the need for more reductions to keep within the same budget (cumulative emissions).

Table 3: Fuel mix for WA building sector under a Paris Agreement compatible pathway based on technology assumptions in IEA (2017) ETP B2DS and benchmark of full decarbonisation by 2050, (delayed pathway). 2014: Historical data, Source Australian Energy Statistics.. Natural gas could be replaced with hydrogen in the gas grid (the underlying model did not assume availability of green hydrogen infrastructure)

		PARIS COMPATIBLE BENCHMARK SCENARIO		
	2014	2030	2040	2050
Oil	15%	3%	1%	0%
Natural gas	18%	14%	9%	0%
Electricity	56%	68%	75%	85%
Biomass	11%	15%	15%	15%
All fuels	**100%**	**100%**	**100%**	**100%**

Transport sector – Decarbonising with shift to electric mobility and green hydrogen

Transport is the third largest contributor to emissions, after industry and electricity generation. Emissions have increased by 61% since 2005, and it contributes 17% to energy and industry carbon emissions. Western Australia gas one of the highest rates of car use per person in the world and emissions intensity of vehicles is very high compared to international standards (WA Government 2019b). The WA state government has a goal to increase the number of homes in the Perth and Peel region to close proximity to public transport nodes by 45% from 2018 to 2031 (WA Government 2019a). Plans involve a new METRONET infrastructure, and 18 new train stations, and new precincts (WA Government 2019a). The Western Australian Electric Vehicles Working Group was created in 2018 to coordinate government action in delivering EV outcomes in the state (Dept. of Water and Environmental Regulation 2019). The group was established after the WA Minister for Water; Innovation and ICT; and Science, Hon. Dave Kelly MLA signed the Memorandum of Understanding on Electric Vehicles. The MOU was signed by several parties in Australia, to identify opportunities to accelerate the transition to EVs, with current uptake of EV in Western Australia well behind global average.

This section focuses on the energy transformation that needs to happen in Western Australia's transport sector in line with the Paris Agreement long term goal: full decarbonisation by 2050, in line with previous analysis on Paris Agreement benchmarks for achieving a fully decarbonised passenger and freight land transport by 2050 (Climate Action Tracker 2016, 2018c). This is supported by recent technological developments and opportunities through electrification and introduction of renewable hydrogen or synthetic fuels generated with electricity from renewable energy, as outlined in a national energy system scenario analysed earlier by Climate Analytics, where the transport sector (like other energy sectors) is fully decarbonised by 2050 (Climate Analytics 2018b; Teske et al. 2016).

Oil consumption is expected to decline sharply over time and phased out by 2050, mainly due to increasing reliance on clean electricity generation powering electric vehicles but also due to increased use of hydrogen fuel cell trucks for freight transportation.

For the Paris compatible benchmark scenario, **we get a total carbon budget of about 207 $MtCO_2$ and a reduction by 16% in 2030 compared to 2005. At current (2017) emissions, this budget would be used up after 15 years.**

The reduction by 2030 compared to 2050 is slower than in other sectors, given the high increase of emissions. However, and important benchmark is that **last fossil fuel combustion engine car should be sold before 2035** in order to achieve full decarbonisation of passenger transport by 2050. Similarly, infrastructure needs to be addressed now to achieve full decarbonisation of freight transport by 2050.

For aviation, technologies are also emerging zero emissions fuels and/or propulsion systems. The International Renewable Energy Agency (IRENA) (2018) has reported on a variety of pathways to produce renewable jet fuel, short range electric aircraft, and hybrid electric propulsion systems. 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.

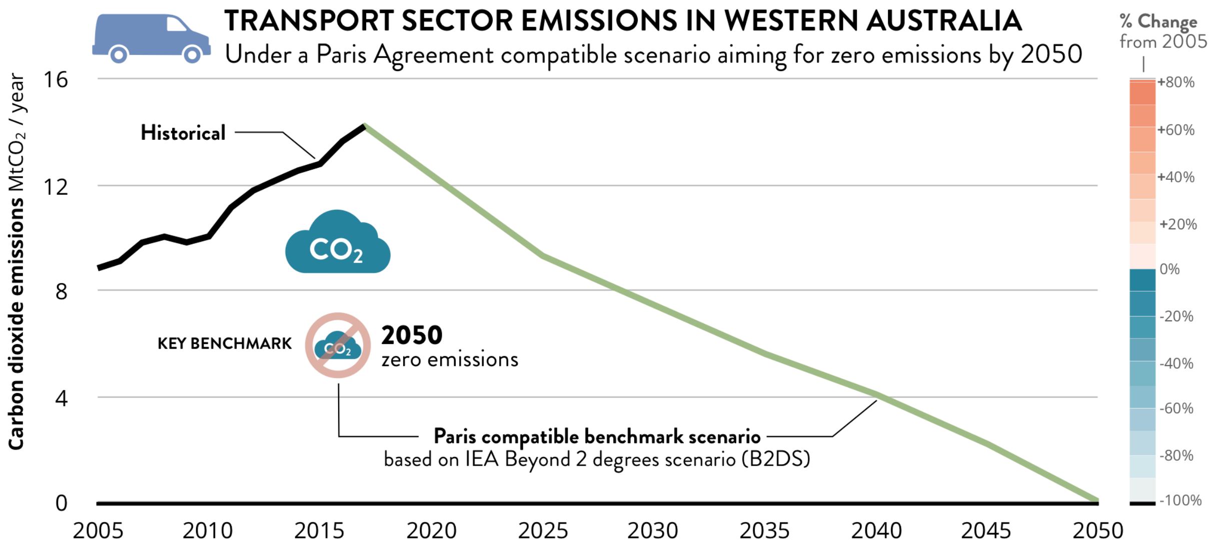

Figure 9: Carbon emissions from the transport sector in a Paris Agreement compatible pathway for Western Australia based on an IEA Technology scenario (IEA B2DS scenario) and the benchmark of full decarbonisation by 2050. We show the original pathway starting decarbonisation in 2014, and an adjusted pathway taking into account the sharp increase in real emissions from 2014 to 2017, keeping within the same carbon budget.

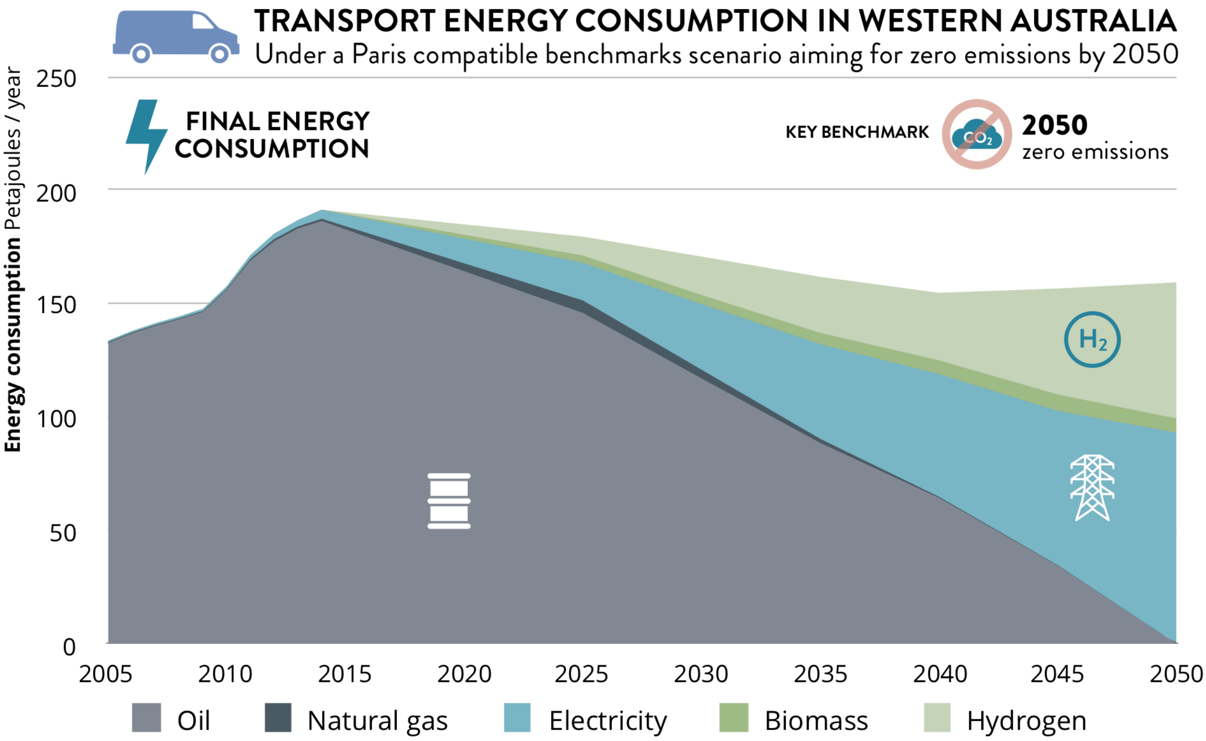

Figure 10 : Energy demand and fuel mix for the transport sector in a Paris Agreement compatible pathway for Western Australia based on an IEA Technology scenario (IEA B2DS scenario) and the benchmark of full decarbonisation by 2050. This pathway starts decarbonisation in 2014, and an adjusted pathway taking into account the sharp increase in real emissions from 2014 to 2017, keeping within the same carbon budget, has been developed to create the Paris Agreement pathway in Figure 8 and Table 4.

Table 4: Fuel mix for WA transport sector under a Paris Agreement compatible pathway based on technology assumptions in IEA (2017) ETP B2DS and benchmark for decarbonisation by 2050.

		PARIS COMPATIBLE BENCHMARK SCENARIO		
	2014	2030	2040	2050
Oil	97%	63%	39%	0%
Natural gas	1%	2%	0%	0%
Electricity	2%	23%	38%	58%
Biomass	0%	2%	4%	4%
Hydrogen	0%	10%	19%	38%
All fuels	100%	100%	100%	100%

Electric car sales are increasing worldwide, especially in countries like Norway or sub national states like California. Those countries and states have successfully introduced incentives and policies to accelerate the adoption of electric vehicles and other e-mobility options including metros, trams etc. An increasing number of countries are introducing targets to ban internal combustion cars, ending the sale of fossil-fuel dependent internal-combustion engines. For example, the UK plans to stop the production of petrol and diesel cars by 2040, Scotland stepped up this target to phase out combustion cars by 2032, France by 2040, and Netherlands by 2030 (World Economic Forum 2017).

Key State policy implications include:

- The need to support modal split away from individual passenger car transport to public transport, cycling, and walking, including through urban and regional planning
- Develop a roadmap and strategy to roll out charging infrastructure and hydrogen fuelling infrastructure with industry
- Work with local councils to support procurement towards electric mobility, including shifting to replace bus fleet with EV buses, building on international examples.

Industry: Manufacturing, Energy Industry –zero emissions through electrification, zero emission fuels, process innovation, energy and material efficiency

As outlined above, industry is the largest emitting sector in Western Australia with a total share of 48% of CO_2 emissions in 2017 – higher than the contribution from electricity generation. It is also the sector with the highest increase since 2005 - by 74% since 2005.

Here we consider direct combustion emissions in manufacturing and mining, excluding the LNG sector (analysed separately in the next section, given the importance of the LNG sector both for WA industry and its emissions[16].), as well as fugitive emissions because of the different nature of mitigation options. We also take into account process emissions (for example from cement or ammonia production) and emissions from product use.

These emissions from direct combustion in manufacturing and mining (excluding LNG sector) and from industrial processes and product use together comprise a share of 28% of energy and industry carbon emissions and have increased by 23% compared to 2005 (see table 2).

We analyse this part of the industry sector based on the analysis of international and national scenarios and research on option for electrification of industrial processes (BZE 2018) and international best practice examples (see Annex for details) and taking into account the specific Western Australia economic profile and structure and show how the Western Australian industry sector can achieve zero CO_2 emissions by 2050, discussing implications for key sectors: manufacturing and mining.

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 in particular for steel, cement, and ammonia production. Apart from increasing efficiency and

16 Fugitive emissions for production of natural gas for domestic use (factoring out gas used in producing LNG), oil production and coal production are calculated with respect to the published inventory of these sources and government energy balance and/or data. These calculations are done in such a way that they are consistent with the federal Government's December 2018 greenhouse gas projections and related historical emissions time series. This means that where our approach results in fugitives exceeding the results are scaled to the government inventory and/or starting point for greenhouse gas projections in 2018. For the purposes of calculating LNG emissions in this report a bottom-up, plant by plant, approach has been taken which reconciles quite closely with Clean Energy Regulator reports and other data sources. The domestic gas fugitives for Western Australia are inferred as the difference between the total gas fugitives and LNG estimates based on our approach over the historical period. Projections of domestic gas fugitives going forward are based on domestic gas demand arising from the modelling results in this work multiplied by the recent historical fugitive emissions intensity ($MtCO_2e/PJ$) of domestic gas production. Whilst this does not capture the decreasing intensity of fugitives estimated for domestic natural gas industry in Australia and evident in government inventories, because natural gas is phased out in the Paris agreement scenario there is no real benefit to modelling more complicated assumptions. Fugitives from West Australian coal production is calculated with respect to national emission factors historically, and projected forward based upon the projected coal demand in the Paris agreement scenario modelled in this report, with the recent average fugitive emissions intensity ($MtCO_2e/PJ$) of coal production applied. Fugitives from domestic oil production in Western Australia are calculated in a similar way. Overall, the estimate of fugitives based on the methods used here are quite close to the published government inventories. Nevertheless, there are significant differences and the scaling down of inventories could make small but significant (2.5-5%) difference to the future carbon budget calculated for Western Australia. Under the reference pathway where it could be assumed that oil production (e.g. condensates and other natural gas liquids) tracks LNG production this could amount to 50 Mt CO_2e cumulative extra emissions in the period 2018 to 2050, and for the Paris Agreement Asian demand scenario, could amount 250 Mt CO_2e cumulative extra emissions for the same period.

decarbonising energy supply, decarbonisation of these sectors (cement and ammonia production are currently relevant for Western Australia) requires a shift in production methods (including more circular production routes) or in product use (Climate Analytics 2018a). Steel and cement manufacturing are among the most carbon intensive industries involving process emissions. While Western Australia does not have steel production at present, it does have the potential to introduce zero emissions steel production based on its iron ore and renewable energy resources. Process emissions contribute a share of 9% to industry greenhouse gas emissions in Western Australia, mainly from cement production. The largest share of CO_2 emissions is from direct combustion for heat demand in industry.

Full decarbonisation of the industry sector by 2050 implies eventually replacing coal, oil, and gas with renewable energy not only for power generation but also for heat demand in industry, with hydrogen as a renewable fuel option for high-temperature applications in the industry sector, together with biomass. Gas can also be replaced by renewably-produced hydrogen as feedstock for ammonia production. While cement production is often considered a difficult to abate sector, recent research shows the possibility for full decarbonisation, 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).

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 (IRENA 2019a) and nationally (ACIL Allen Consulting 2018, CSIRO 2018) in the development of strategies for (renewable) hydrogen including at national and state level offer opportunities for a faster decarbonisation of industry sectors in Western Australia.

More recent cost estimates, with CSIRO (2018) in the National Hydrogen Roadmap estimating that in or around 2025, clean hydrogen could be cost-competitive with existing industrial feedstocks such as natural gas, and energy carriers such as batteries in many applications[17], making it much more likely for these to become least cost options in particular with adequate policies in place at federal and state level.

Recent estimates show that hydrogen technology can be competitive with coal-based plants for steel production by 2030, with the cost of renewable hydrogen falling below $2.20 a kilogram (Bloomberg 2019).

While Western Australia does not have steel production at present, this opens opportunities for developing a new manufacturing industry.

An important strategy across all industry (and other end use) sectors is an increase in energy efficiency. Australia is lagging behind most other developed and even many developing countries with policies to incentivise energy efficiency. Such policies can and have to also be introduced at state level. 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.

17 See also (Bloomberg 2019)

In our scenario, emissions start reducing more slowly than in other sectors – by 30% in 2030 compared to 2005, mainly due to efficiency gains, but also with industry processes starting to get electrified and fossil fuels starting to get replaced by biomass or green hydrogen. Direct electrification of processes increases to 80% by 2050, with replacement of coal with gas or biofuels for remaining heating processes over the next ten years, and replacement of fossil fuels by green hydrogen and fossil fuels phased out completely by 2050, coal faster (by 2040). Natural gas demand increases only slightly reaching a peak before 2030 and then declining. Electrification, including the use of green hydrogen, leads to an increase in demand for electricity which needs to be decarbonised ramping up renewable energy power generation.

Based on this scenario, we calculate a carbon budget for the industry sector excluding LNG production and processing for 2018-2050 of **328 Mt CO_2 and emissions would have to be reduced by 30% in 2030 compared to 2005. At current emission level, the budget would be used up within 15 years.** Emissions from electricity generation are not included in this budget, but in the budget for power generation.

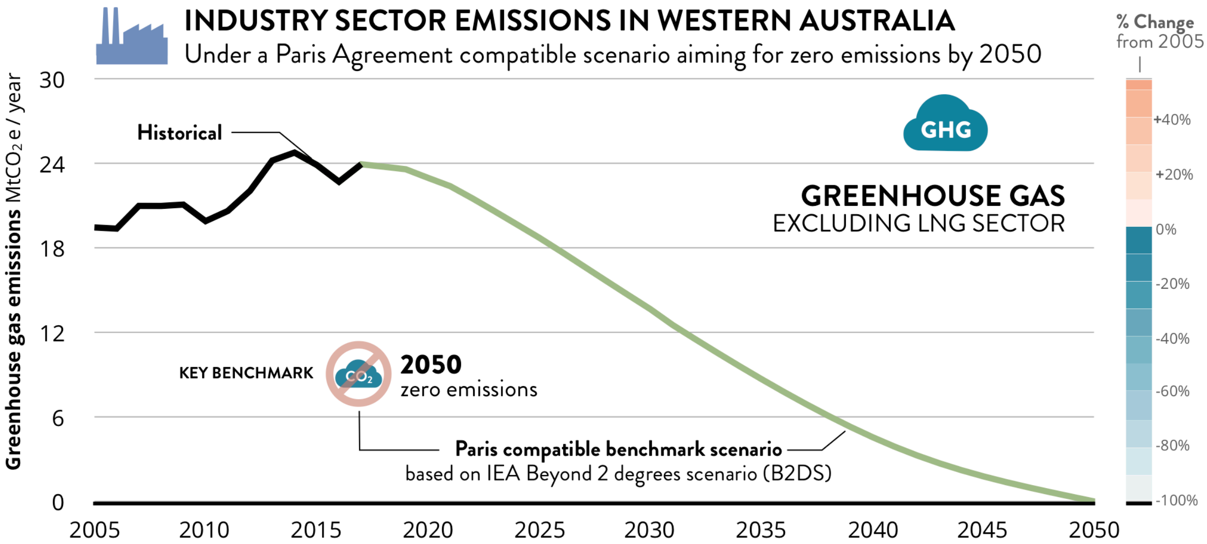

Figure 11: Carbon emissions from the industry sector (excluding LNG sector) in a Paris Agreement compatible pathway for Western Australia based on analysis of national and international scenarios and indicators with the PROSPECTS tool (Climate Action Tracker 2018a) and the benchmark of full decarbonisation by 2050. We show historical data until 2017 (Source AGEIS 2019).

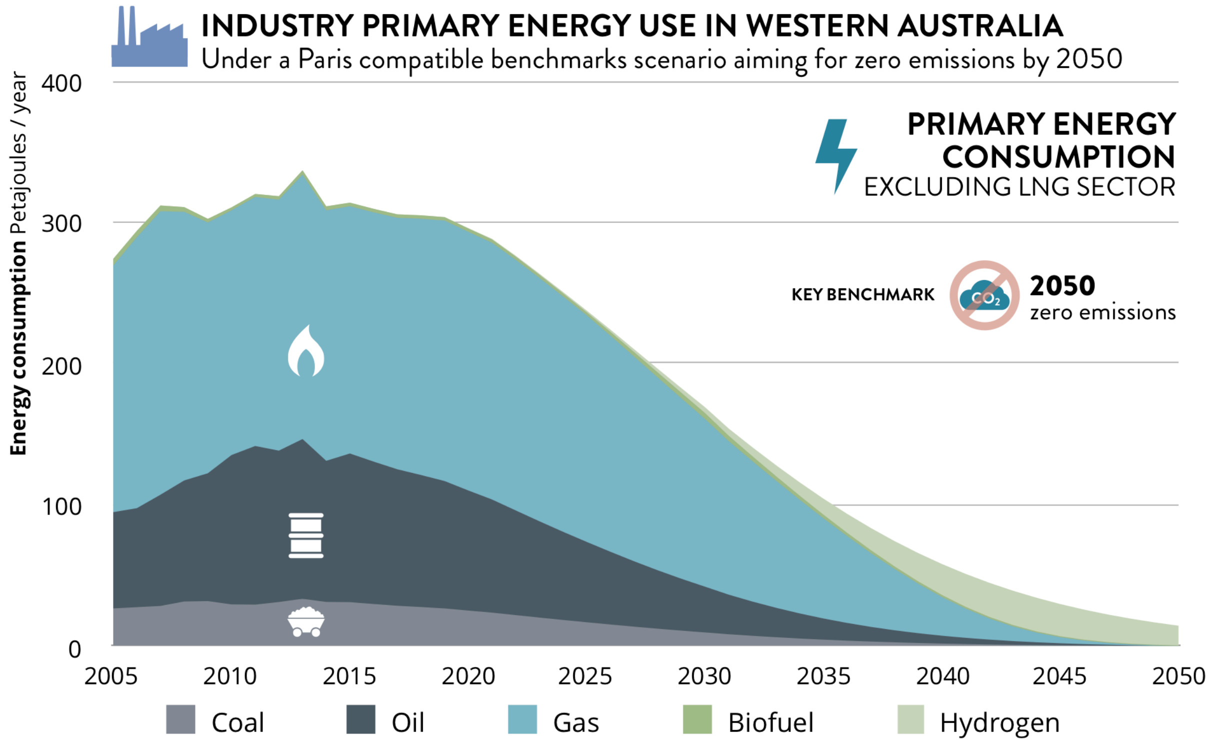

Figure 12: Primary Energy demand and fuel mix for direct combustion in the industry sector (excluding LNG sector) in a Paris Agreement compatible pathway for Western Australia based on analysis of national and international scenarios and indicators with the PROSPECTS tool (Climate Action Tracker 2018a) and the benchmark of full decarbonisation by 2050. We show historical data until 2017 (Source AGEIS 2019). It is important to note that this does not include electricity demand, as emissions from power generation are included in the power sector. The scenario assumes electrification of industry processes reaching 80% in 2050, and fossil fuels being gradually replaced by biomass and, increasingly, green hydrogen. This leads to increased electricity demand taken into account in the mitigation pathway for the power sector.

Table 5: Fuel mix for WA industry sector (excluding LNG sector) under a Paris Agreement compatible pathway based on technology assumptions from a range of scenarios, as analysed with the PROSPECTS tool (Climate Action Tracker 2018a) and benchmark for decarbonisation by 2050. Source: Own calculations, 2014 historical value: Australian Energy statistics.

		PARIS COMPATIBLE BENCHMARK SCENARIO		
	2014	2030	2040	2050
Oil	32%	19%	10%	0%
Natural gas	57%	70%	47%	0%
Coal	10%	6%	3%	0%
Biomass	1%	3%	3%	3%
Hydrogen/Solar Thermal	0%	2%	38%	95%
All fuels	**100%**	**100%**	**100%**	**100%**

This scenario is an indicative Paris Agreement compatible benchmark scenario, based on existing international scenarios and analysis of mitigation options and least cost mitigation pathways, applied to the Western Australia context and structure of the industry sector. It is outside of the scope of this report to look at new manufacturing and export opportunities, for example for zero emissions steel, aluminium, cement production or for export of green hydrogen or other energy carriers.

Given the complexity and diversity of the industry sector, there is a need to develop detailed industry specific scenarios involving stakeholders from industry, trade unions, and civil society, in order to derive roadmaps for research, development, and deployment. This can be the basis to develop a transition strategy, bringing all stakeholders on board, and including roadmaps to take advantage of unique opportunities and competitive advantage of Western Australia.

An important element of a decarbonisation strategy for the industry sector is to include an assessment of macroeconomic impacts and impacts for employment in regions, as well as developing a transition strategy for regions affected by phasing out production and use of coal as well as extraction, processing and use and export of gas, developing roadmaps for new manufacturing industries in specific regions.

Western Australia also needs to introduce an energy savings scheme, as it is one of the states without any such scheme (ESIA 2018).

Power sector – decarbonising fast and delivering zero emissions power for electrified end use sectors

As discussed above, electricity generation in Western Australia is the second largest source of emissions (after industry) and contributes almost a third (31% share in 2017) to energy and industry carbon emissions, and these have increases by 44% since 2005.

This section provides a pathway for Western Australia's power sector, under a Paris Agreement cost optimal compatible emissions pathway, considering key technology and market trends, the state context (see above) and previously analysed international, national and sectoral scenarios for fossil fuel and renewable energy benchmarks (coal phase out, only short transition role for gas, move towards 100% renewable energy with storage and transmission).

In all 1.5°C compatible pathways fast decarbonisation of the power sector paves the way for deeper emissions reduction in other sectors by means of increasing electrification. This implies a very fast ramp up of renewable energy generation, to take into account a fast growth in electricity demand in the 2030s when electrification kicks in considerably across end use sectors, reaching an almost fourfold demand in 2050 compared to the reference case.

While even in the reference case, renewable energy quickly becomes the dominant source of electricity generation, reaching 50% ahead of 2030, 70% in 2040, and 95% in 2050, driven by the cost-competitiveness of renewable energy technology, the Paris Agreement benchmark pathways reaches a third in the mid 2020s, and around 90% in 2030, with a fully renewable energy based and fully decarbonised electricity generation by 2035– but with much higher absolute generation given the higher electricity demand (see Figure 13 and Figure 14).

We take into account the announcement by the WA government (Booth 2019) for a staged shut down of two of the remaining four coal units in 2022, as well as the projections by the AEMO (2019) and available information about already approved connections for 2019-2021 (RenewEconomy 2019e) for expected increase in rooftop solar and large-scale wind and solar projects, with half a gigawatt scale growth in utility scale PV over the next few years and a share of 65% of Variable Renewable Energy (VRE) supply expected by 2024 AEMO (2019).

The assumed growth of rooftop solar at 25% per year until it reaches an assumed maximum share of 80% from present 27%, and the continued growth in large-scale renewable energy projects leads to lowering demand for gas, being phased out in the early 2030s, and coal being phased out before 2030 already, with wind and solar becoming the main power sources from the early 2020s onwards (See

Figure 15). While some of this development is already occurring due to market forces, it will need a careful management as well as clear policy direction, given the crucial role of the power sector to address additional demand from electrification of end-use sectors.

The carbon budget we calculate for power sector is 160 Mt CO_2, requiring emissions reductions of 95% by 2030 from 2005 levels, and reaching zero emissions in the early 2030s. At current level of emissions, this budget would be used up after only 6 years.

Key benchmarks for the electricity generation pathway for Western Australia are:

- **Coal is phased out before 2030, and gas shortly after**
- **Renewable energy share needs to grow from 8% now to a third in the mid 2020s and 90% in the early 2030s.**
- **Renewable energy capacity needs to ramp up very fast to take into account an expected increase in demand from electrification of end-use sectors.**

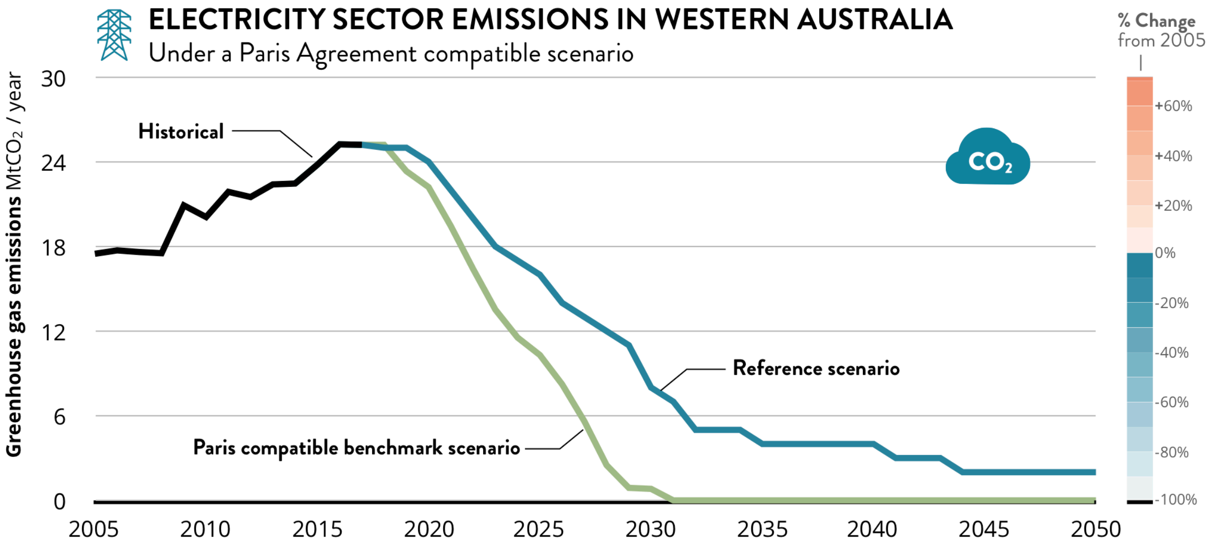

Figure 13: Emissions from power generation in Western Australia - Reference and Paris Agreement Pathways. The power sector needs to and can decarbonise by the early 2030s.

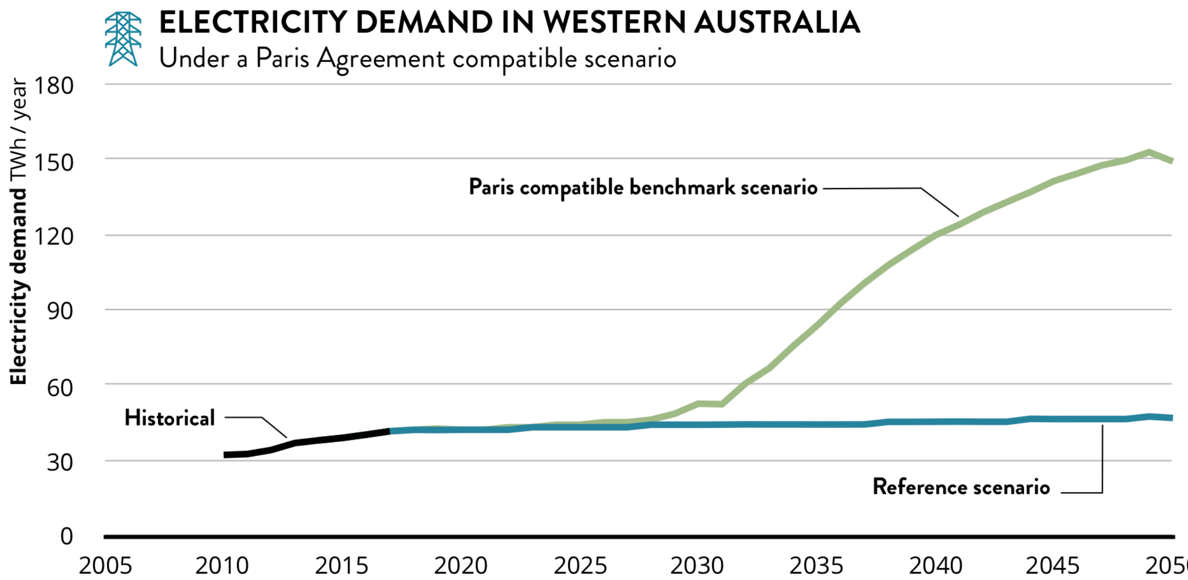

Figure 14: Electricity demand in Western Australia - Reference and Paris Agreement Pathways. With electricity demand increasing due to electrification of end-use sectors (transport, buildings, industry), electricity demand increases by a factor of 3.7 by 2050 compared to current levels, despite increased energy efficiency in end-use sectors.

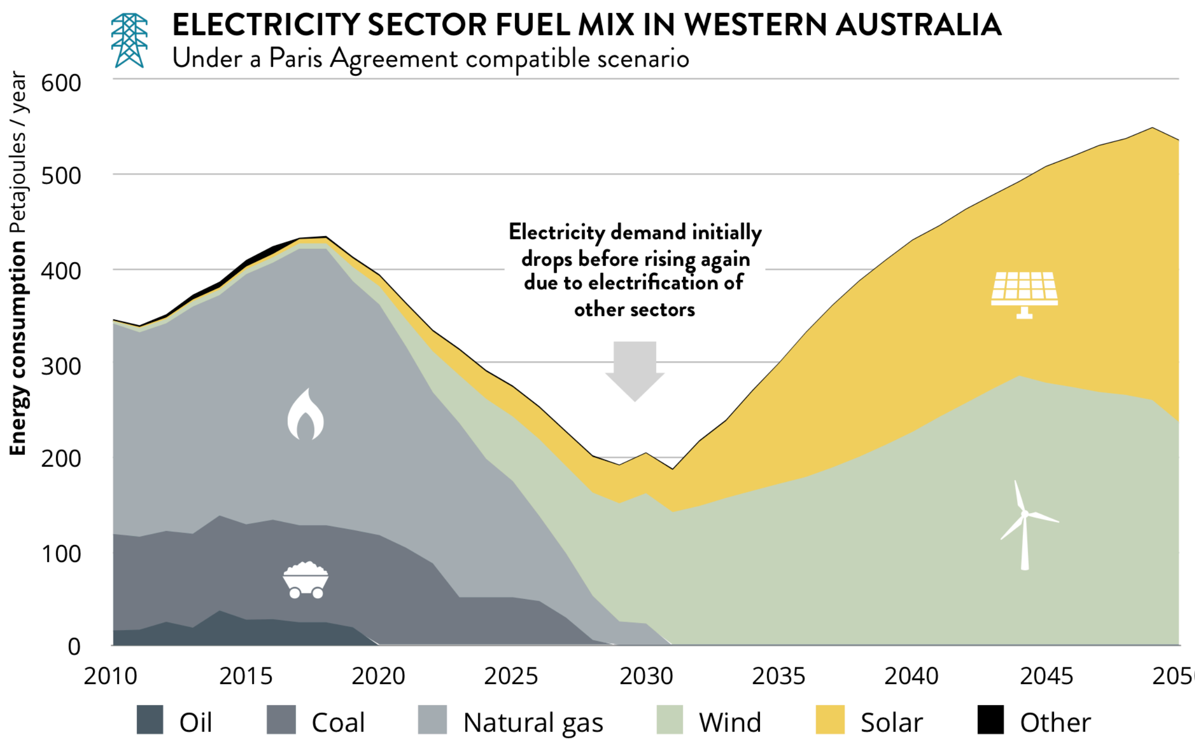

Figure 15: Western Australia's Fuel Mix for the Paris Agreement Pathway. Solar and Wind energy become dominant sources from the early 2020s. Coal is phased out before 2030, and gas shortly after 2030.

The analysis of a Paris Agreement compatible benchmark scenario shows the critical importance of a whole of economy approach to a climate strategy, and the need to take into account the role of the power sector in decarbonising end use sectors.

The WA government has developed an Energy Transition Strategy (WA Government. 2019), as a reaction to the current developments in the market, including the increased share of distributed energy resources, battery systems, and microgrids. This can be developed further to integrate a roadmap with clear midterm targets, taking into account the increased electricity demand and the need for a fast decarbonisation, including phasing out coal before 2030 and gas by the early 2030s. This needs to provide planning certainty for legislation and market design, transmission and storage investments and fast ramping up of large scale solar and wind projects.

LNG Sector: preparing for transition to zero carbon, green hydrogen

The LNG sector is analysed with more detail and granularity, given its importance for WA economy and emissions profile, as well as its contributions to international emissions. We show:

- A mitigation pathway in comparison to a business as usual pathway
- Implications of reduced gas demand globally/in Asia in a Paris Agreement pathway
- Options for decarbonisation of LNG processing through electrification.

The liquefied natural gas (LNG) sector has grown rapidly in Western Australia over the last decades, doubling in size over the last five years to about 45 million tonnes of LNG (MtLNG) per annum production in 2018[18] capacity, and is set to increase by about 35% to 60 MtLNG p.a. by, or shortly after, 2025 (Figure 16). The primary energy demand for gas in the LNG processing sector has increased correspondingly and now approaches 240 PJ per year.

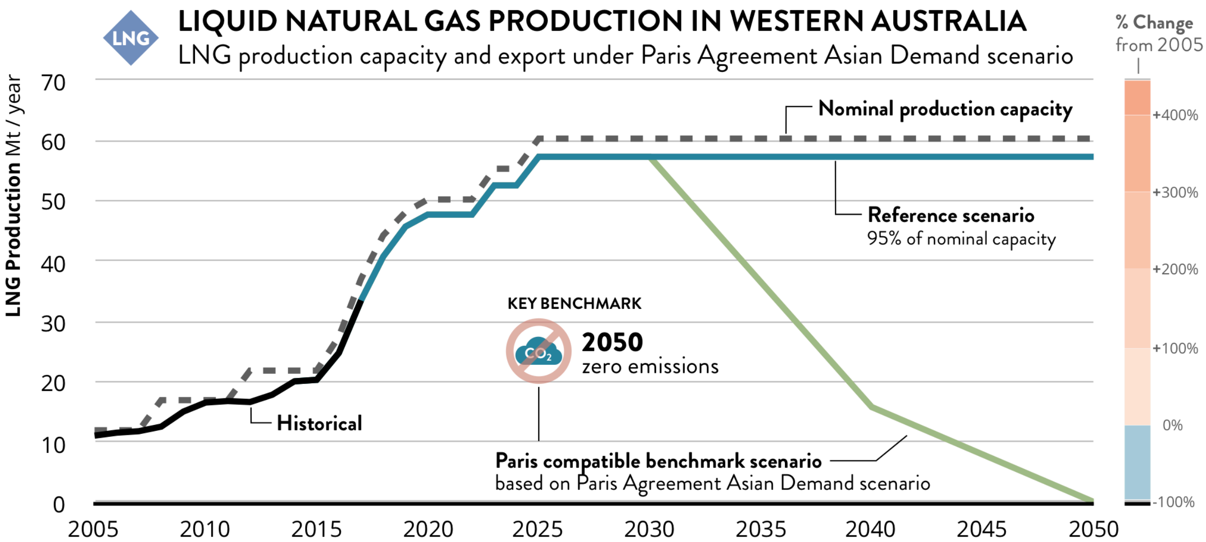

Figure 16 Growth of LNG production capacity and exports until 2019, with projections until 2030 based upon projected changes/increases in LNG production capacity and assuming 95% of nominal capacity is produced and exported. LNG exports in the reference case are limited to 95% of nominal LNG production capacity.

18 See https://www.jtsi.wa.gov.au/docs/default-source/default-document-library/wa-lng-profile---september-2019.pdf?sfvrsn=413f701c_6

Along with the rapid growth of CO_2 emissions from the natural gas used to produce LNG[19], fugitive emissions from LNG processing and related activities and venting of the CO_2 from the natural gas reservoirs, have also increased rapidly. Emissions from the LNG industry in WA are estimated here to be approaching 22 Mt CO_2e per annum and can be expected to approach 35 Mt CO_2e per annum by the late 2020s[20].

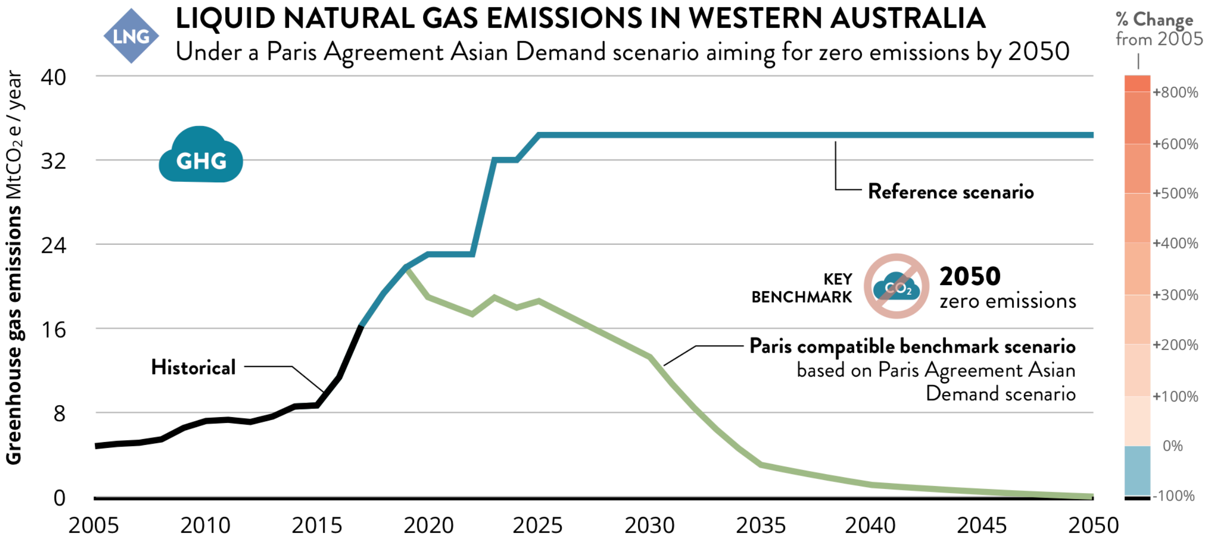

Figure 17 Growth of LNG processing emissions in Western Australia from natural gas used in liquefaction, CO_2 from natural gas reservoirs and fugitive emissions from the LNG manufacturing process until 2019 with projections to 2030. Whilst the intensity of CO_2 emissions from direct energy use and liquefaction have remained fairly stable, in terms of tonnes of CO_2 per tonne of LNG produced, there has been an increase in CO_2 vented from natural gas reservoirs due to the concentration of CO_2 in more recently exploited natural gas reservoirs. The reference case projection does not include CO_2 CCS at the Gorgon LNG plant, however this is included in the Paris Agreement case and explains the drop of total emissions from 2019 to 2020, when it is assumed that the Gorgon CO_2 CCS is capturing 80% of the reservoir CO_2 and storing it in a secure geological formation.

Apart from planned capture of CO_2 and storage in geological formations at the Gorgon plant very few greenhouse gas mitigation measures have been announced or planned at any scale in Western Australian LNG facilities.

With the reference case emissions of the natural gas industry of at least 1 billion tonnes of CO_2 equivalent greenhouse gas emissions between 2018 and 2050 it is clear that there has to be substantial mitigation if the sector is to become Paris Agreement compatible. The projected cumulative emissions from the present trajectory of the LNG industry in Western Australia equal or exceed a Paris Agreement compatible carbon budget for the state.

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. Scenarios vary, however a common denominator is that in the next decade natural gas demand would have to peak and began to decline, and in central case estimates fairly rapidly. A critical variable in this equation is the likely role of carbon capture and storage. We view that deployment of CCS technology particular in the context

19 For every tonne of LNG produced it is assumed that natural gas equivalent to 9% of the energy content of the LNG is required for the manufacturing process.

20 Emissions from LNG production facilities are estimated here based on standard emission factors, energy balance, physical estimates of CO_2 losses from natural gas reservoirs and plant specific emission intensity based on environmental impact statements and other studies. These estimates are approximately 5% lower than the Clean Energy Regulator Scope 1 plant specific reports for the NWS Karratha, Pluto and Gorgon operations in Western Australia in 2017/18. The estimated Wheatstone emissions are only 45% of the CER Scope 1 reports for 2017/18, however this may be do higher than normal emissions associated with the scaling up of operations at this plant. In general LNG operations also supply domestic gas and data in respective EIS documents emissions associated with this are of order of 5% of the LNG related emissions.

of gas turbines used in the power sector as being very unlikely due to high cost and the fact that this technology cannot eliminate 100% of emissions.

As shown above, the analysis of global mitigation pathways in line with the Paris Agreement as assessed by the IPCC shows that under the Paris Agreement demand for natural gas in the power sector in Asia, a major source of LNG demand, is likely to peak by around 2030 and then decline to close to zero between 2050 and 2060 (Figure 4). One scenario therefore for the LNG industry in Western Australia under Paris Agreement implementation would be to more or less follow the modelled trajectory for natural gas demand in the power sector in Asia for the period 2030 to 2060 which would result in a substantial reduction in LNG demand, reducing from peak levels in 2030 to close to zero by 2050.

Of course, the transition to a zero-carbon economy in Asia will require large amounts of energy, hence the market for energy carriers similar to LNG will not disappear, and this is where the potential for renewable hydrogen exports from Western Australia becomes much more visible. A number of East Asian economies have, or are developing hydrogen strategies, for a variety of different reasons, including energy security and climate change. A Paris Agreement driven decline in Asian demand for liquefied natural gas would be matched by a corresponding increase in demand for clean energy carriers, in particular Green Hydrogen. Hence the key elements of the zero-carbon transition outlined here for the LNG industry involved building up new markets for green hydrogen, which needs a major ramp up in renewable energy generation capacity in regions near to the present LNG facilities.

A decline in demand for LNG industry consistent with the Paris Agreement reaching close to zero by 2050 would reduce all LNG related emissions very substantially. Nevertheless, in order to meet the commitments of the Paris Agreement, and stay within the carbon budget and minimise the need for negative emissions, significant additional abatement measures would need to be introduced. These would include extending carbon capture and storage for reservoir CO_2 losses to all LNG plant in Western Australia as well as replacing a significant fraction of natural gas used in LNG processing by renewable electricity. The broad approaches assumed here is that the level of CCS planned for the Gorgon plant of 80% from 2020 (which would capture approximately 60% of present total CO_2 reservoir emissions for LNG operations in WA) extended to all plant from 2023, combined with the phasing in of renewable energy so that by 2030, 50% of LNG manufacturing natural gas use is replaced by renewable energy, 90% by 2035 and by 2050, 100%.

Irrespective of whether or not the demand reductions implicit in the scenario above occur, the cumulative emissions of the LNG industry need to be reduced substantially in the basic options examined here would need to be deployed in either case. In the reference case, the scale of the emission reductions to be achieved through carbon capture and storage of reservoir CO2 and by introducing renewable energy quickly into the LNG manufacturing process would be substantially larger than in the Paris Agreement Asian power demand case. For completeness we show both scenarios which achieve similar levels of cumulative reductions by 2050.

Applying the options described above to the reference case LNG production, as is shown in Figure 19 would reduce the peak emissions from Western Australia LNG manufacturing to around 300% above 2005 levels from a projected 600% increase by the mid 2020's in the case with no policy action. This would bring emissions back to about 176% above 2005 levels in 2030, 16% below 2005 levels in 2040 and 46% below in 2050. Zero CO_2 emissions would be needed to be Paris Agreement compatible.

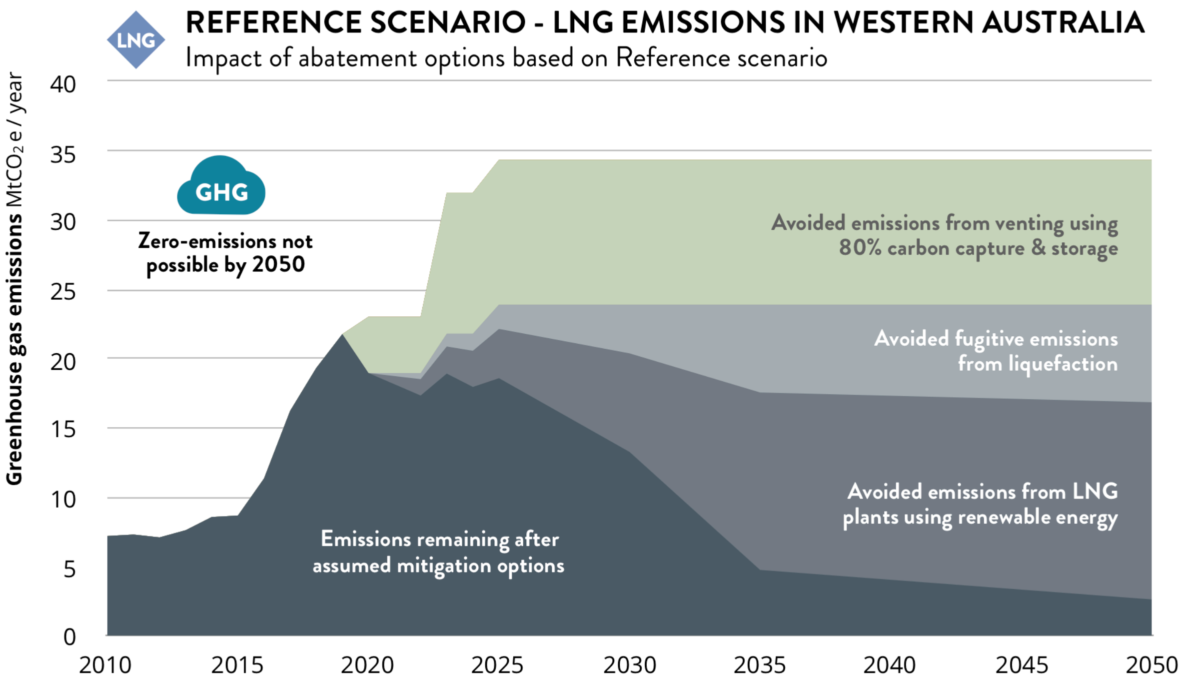

Figure 18 Relative role of the abatement options described in the text for reference case LNG demand and see Table 6. Zero emissions are not achieved by 2050. The cumulative emissions remaining between 2018 and 2050 after the assumed mitigation options are applied in this reference scenario is 323 MtCO2e. This amounts to approximately one third of the Western Australian Paris agreement compatible carbon budget for the energy system. There could be more or less emissions left depending upon the rate and scale of the actual mitigation options deployed.

Under a Paris Agreement induced decline in demand from 2030 combined with the mitigation options discussed (carbon capture and storage, electrification), this would lead to LNG related emissions in 2030 being about 175% above 2005, around 80% below 2005 levels by 2040 and approach zero by 2050 (Figure 19).

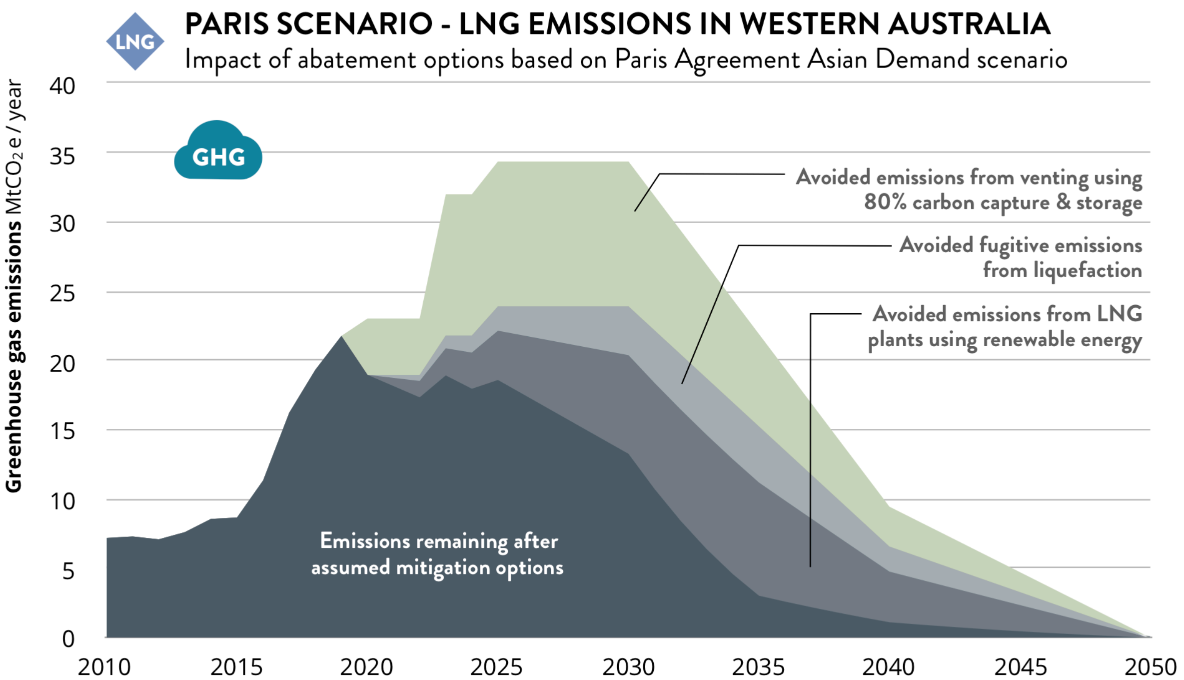

Figure 19 Relative role of different elements of a Paris Agreement LNG demand reduction scenario and mitigation options in reducing emissions from the reference case to close to zero emissions by 2050. The cumulative emissions remaining between 2018 and 2050 after the assumed mitigation options are applied un this Paris Agreement LNG demand scenario is 274 $MtCO_2e$. This amounts to approximately about 29% of the Western Australian Paris agreement compatible carbon budget for the energy system. There could be more or less emissions left depending upon the rate and scale of the actual mitigation options deployed.

Table 6 below compares the reference case and Paris Agreement LNG demand reduction scenario. In the reference case, with no abatement, cumulative emissions in the period 2018-2050 are likely to be in the range of 1 $GtCO_2$, of the same order as the entire carbon budget for WA. A Paris Agreement Asian demand reduction scenario would reduce this by over 60% to around 438 $MtCO_2e$ without abatement options. Cumulative emissions can be reduced much further to around 274 $MtCO_2e$ through CCS and renewable energy replacing natural gas in the LNG manufacturing process. With this the LNG industry would take up about a quarter of the WA carbon budget for this period. The cumulative emissions from the reference case with all mitigation options is about 20% higher at about 320 $MtCO_2e$, and zero emissions would not be reached. This would imply the need for the LNG industry to generate negative CO_2 emissions elsewhere to compensate.

Table 6 Cumulative emissions from LNG Reference and Paris Agreement scenarios

Cumulative emissions 2018-2050 $MtCO_2e$	Paris Asian Natural Gas power demand	Contribution to avoided emissions (%)	Reference case – production at 2030 levels	Contribution to avoided emissions (%) [21]
Reference case cumulative emissions 2018-2050	1,067		1,074	
Cumulative Paris carbon budget emissions	274		323	
Where do avoided Emissions come from?				
Demand decline	438	56%	0	9%
Avoided CO_2 from renewabilizing LNG plant	123	16%	395	40%
Avoided CO_2 from venting with 80% CCS	171	20%	304	41%
Avoided liquefaction fugitives	61	8%	146	20%
Total avoided emissions	**793**		**745**	

The WA government provides strong support to the LNG industry, epitomized in the new LNG Futures Facility. The Premier Mark McGowan announce $10 million to support the facility, aiming for WA to be a global leader in developing and testing LNG technology (WA Government 2019c). It has been argued that the facility will "future-proof" the state's LNG industry (WA Government 2019c) to ensure the industry persists into the future, however there is little sign that this has taken of the fundamental energy transitions required to meet the Paris Agreement goals globally. A further large LNG project, Browse is proposed by Woodside that could scale up the LNG industry in WA, if approved, with start-up likely around 2026 (Toscano 2019). The Scarborough gas field is proposed also for development which would extend the life of the North West Shelf Project (Reputex 2018).

To ensure the transition outlined here, in particular the need to extend the level of CCS planned for the Gorgon plant of 80% capture and storage of reservoir CO_2 from 2020 to all LNG operations from 2026, combined with the phasing in of renewable energy for liquefaction, the government would have to likely introduce regulation given there is no carbon pricing at federal level.

If there is less demand reduction than assumed here, the same emissions pathway needs to be reached. This would imply a higher abatement to be reached with CCS and renewabilisation of the LNG manufacturing process.

21 May not add to 100% due to rounding errors.

Requesting offsetting emissions would not be a viable option to achieve this mitigation pathway, as the mitigation achieved outside of the LNG sector (for example as noted in the (Reputex 2018) report would need to be implemented in any case, and not to compensate for no, or insufficient, mitigation in the LNG sector. A requirement for offsetting would only be viable for any mitigation below the pathway outlined here. This would imply, de facto, a pricing mechanism that would allow raising funds for some of the mitigation outlined for other sectors, which can be justified given the high cumulative emissions in the LNG sector since 2005.

Carbon budgets for Western Australia energy and Industry sectors

Table 7 summarises the results the preceding analysis to produce a Western Australian Paris Agreement compatible budget and pathway and related sectoral carbon budgets and pathways for the period 2018-2050, as well as benchmarks for emission reductions for 2030 compared to 2005 levels to establish both the state and its key sectors on 1.5°C compatible pathways.

We calculate the carbon budget for Western Australia's fossil fuel (energy and industry) CO_2 emissions for the period 2018-2050 to be a bit below 1 $GtCO_2$, which is about 0.17% of the remaining global carbon budget until zero emissions.

Table 7: Paris Agreement compatible energy and industry carbon budget for Western Australia 2018-2050. Source for historical data: AGEIS 2019. LNG sector emissions include emissions from venting/fugitive emissions (own estimate).

Sector	Paris Agreement compatible carbon budget 2018-2050 $MtCO_2$	2030 reduction (compared to 2005 baseline) CO2 only	2005 Baseline $MtCO_2$	Remaining years at 2017 emissions rates
Electricity generation	160	-95%	17.5	6
Transport	207	-16%	8.8	15
Industry: LNG Sector	208	+170%	3.6	16
Fugitive emissions (excl. LNG)	25	-55%	1.6	6
Industry: other	328	-30%	18.1	15
Buildings	22	-41%	1.2	12
Total energy/industry emissions	**949**	**-37%**	**50.8**	**12**
Total energy/industry excluding LNG sector	**716**	**-53%**	**45.6**	**11**

Figure 20 shows the pathway for CO_2 emissions from energy and industry towards zero emissions that is consistent with this budget.

An overall CO_2 emission reduction of about 37% by 2030 from 2005 levels, 81% by 2040 and zero emissions by 2050 is needed to limit cumulative emissions to the carbon budget to its 950 million tonne carbon budget.

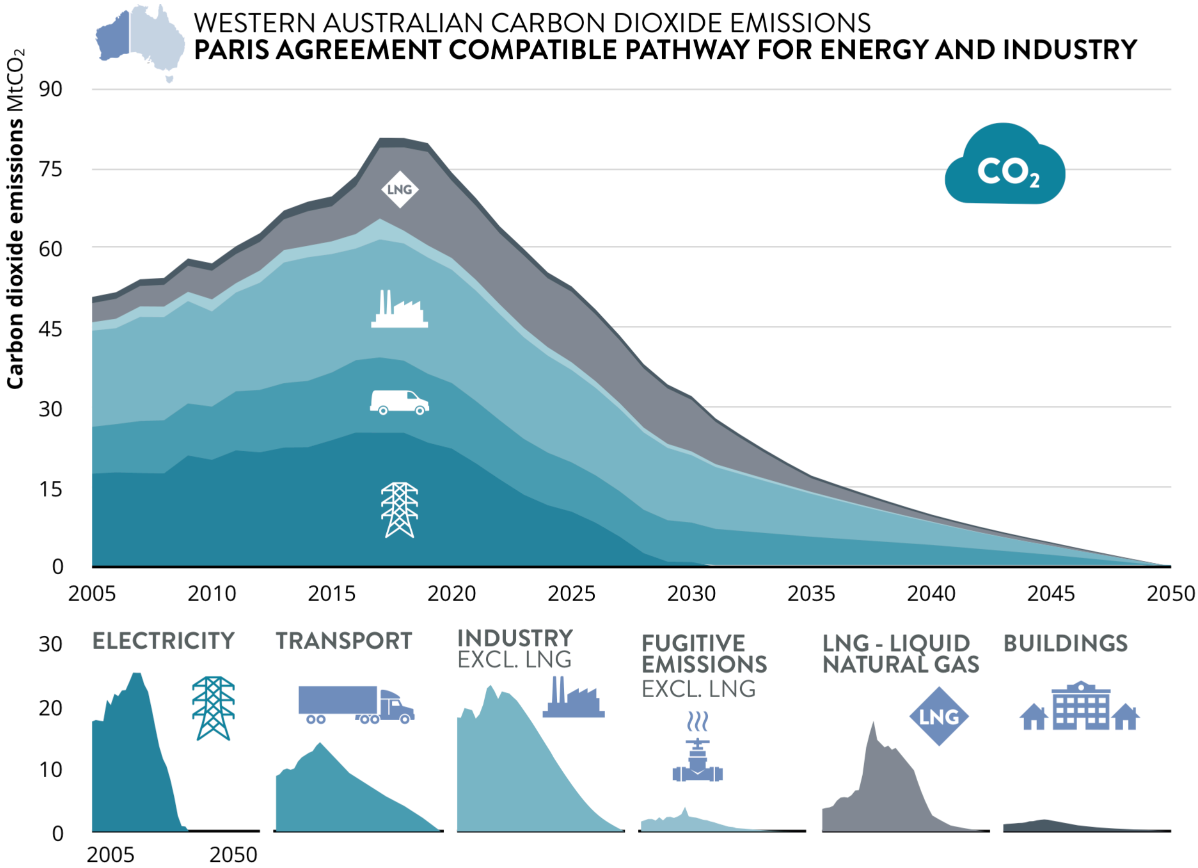

Figure 20. CO_2 emissions pathway for each of the sectors and energy and industry following transformation is consistent with the Paris agreement in each of those sectors. Total CO_2 emissions peak around 2020 and decline to about 37% below 2005 levels in 2030, for total budget of around 950 Million Tonnes CO_2. Excluding the LNG industry, energy and industry CO_2 emissions would reduce by about 53% by 2030 below 2005 levels, for a total budget of 716 $MtCO_2$.

A key conclusion is the need to **reduce emissions in the immediate term** given the current growth in emissions – every delay in reducing emissions will imply faster reductions later to stay within carbon budget, implying higher costs and disruption, and risks locking further into fossil fuel infrastructure.

If current (2017) emission rates were to be continued, the overall energy and industry carbon budget of about 950 Mt CO_2 would be consumed within 12 years.

Another key conclusion is that the electricity sector needs to and can reduce emissions faster than any other sector, by 95% in 2030 compared to 2005 (and zero by 2035). All sectors except for LNG and transport would have to be reduced faster than the Australian reduction target of 26-28% by 2030. The transport sector would need to reduce emissions by about 16% by 2030 compared to 2005 levels. On the other hand, the peculiarities of the LNG industry mean that its increase would be limited to about 170% increase above its 2005 levels (compared to a reference case increase of 630%), however it would be reaching reductions of about 73% below 2005 levels by 2040 and 100% by 2050.
We compare our findings and estimated carbon budget for Western Australia's energy and industry sectors for plausibility against other methodologies used to generate national or state carbon budgets, to confirm our estimate is a robust estimate for a Paris Agreement, compatible energy and industry carbon budget for Western Australia:

- If we apply Australia's share of current global emissions of about 1.1% of global fossil fuel (energy and industry) emissions in 2017 (C. Le Quéré et al.2018) to the global carbon budget of 610 $GtCO_2$ (range 555 to 730 Gt) until the year of zero emissions estimated earlier (Climate Analytics 2019a), this results in a budget for Australia of 6.7 $GtCO_2$ (range 6.1-8.0 $GtCO_2$). With the current Australian share of 20% for Western Australia of fossil energy and industry CO_2 emissions the Western Australia budget would be **1.3 $GtCO_2$ (range 1.2- 1.6 $GtCO_2$).**
- Total **global carbon budget until 2100 is considerably lower** than until net zero emissions, implying the need for negative emissions after reaching net zero. Australia's share of this budget until 2100 would be, based on the current 1.1% share of global emissions, 5.2 GtCO2 (range 3.5-7.7 GtCO2), and **WA's share** would be **1.0 GtCO2** (range 0.7 – 1.5 GtCO2) based on a 20% share.
- As a cross check for consistency against the global carbon budget derived from Integrated Assessment Modelling results outlined above, we have produced an estimated budget for Australian energy related CO_2 emissions over 2018-2050 in the range of 4.8-6.6 $GtCO_2$. A 20% share for Western Australia would correspond to **1.0 to 1.3 $GtCO_2$**.
- Based on a national scenario for decarbonising the entire energy system, we have, earlier, estimated a national budget for Australia of about 5.5 Gt CO_2. Assuming a share of 20% of this national budget for Western Australia, corresponding to the share of energy CO_2 emissions in 2017, this would result in a budget of **about 1 $GtCO_2$ and is confirmed with this study.**

ACHIEVING ZERO GREENHOUSE GAS EMISSIONS BY 2050

In order to assess how Western Australia gets to net zero GHG emissions by 2050, we have analysed Paris Agreement consistent mitigation pathways in sectors outside of energy and industry, and also take into account emissions apart from carbon in energy and industry – mainly industrial emissions from product use (so called F-Gases) that can be phased out, as well as fugitive emissions that will be phased out with the phasing out of fossil fuel extraction.

The key remaining sectors are agriculture (10% of WA emissions) and waste (small share of 2% of WA emissions). While there are cost effective options to considerably reduce emissions from waste, that are already being implemented in other countries, agriculture is a more challenging sector, and emission cannot be reduced to zero.

Remaining emissions will have to be compensated by negative emissions from the land-use sector.
It is also important to look at how Western Australia will contribute to negative emissions beyond reaching net zero, consistent with the Paris Agreement.

The carbon budget derived in this report for energy and industry is focused on the budget up to the point in time of net zero emissions. While this study aims at providing guidance on a budget that would limit the need for negative emissions, this does not mean that the need for negative emissions after achieving net zero emissions can be ignored. The timing, scale and opportunities for net negative emissions needs to also be analysed in the Western Australian context in future work. The need for negative emission technologies and their deployment on a sustainable basis would need to be considered for the energy system transformation and land-use sector strategies in Western Australia, and is beyond the scope of this study. However, by developing sector specific mitigation pathways, we are providing a benchmark pathway for overall greenhouse gas emissions in Western Australia.

Agriculture Sector

The agriculture sector is responsible for 10% of emissions in WA (Figure 2) and the sector's emissions have been on an upward trajectory since 2008 (DEE 2019). Agriculture is a sector that is highly vulnerable to climate change, especially, temperature changes, hot spells, frost, rainfall intensity, drought and water supply, cyclones, and fire risk (Dept. Primary Industries and Regional Development 2019a). Despite these risks, there is not a state specific climate policy under the list of current initiatives on the WA Department of Primary Industries and Regional Development website (Dept. Primary Industries and Regional Development 2019b). There is also a lack of specific mitigation analysis and scenarios, with national scenarios published in the past focusing on offsetting emissions from agriculture with sequestration in forests.

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 fertilisers, crop residues and cultivation of organic soils. Thus, here we do not cover emissions from electricity use or fuel combustion from operating equipment, which are included in the energy-related emissions covered in pervious subsections. 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 2018a). 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. The higher ambition level of the "Paris Agreement Compatible Scenarios" is based on the most ambitious end of the ranges given by the selected scenarios from IPCC (2018a), projecting an annual average rate of -1.9 % p.a. reduction of non-CO_2 emissions from agriculture sector in the OECD region over 2016-2050.

Applied to Western Australia, this implies a potential reduction by 43% in 2030 and 56% in 2050 compared to 2005.

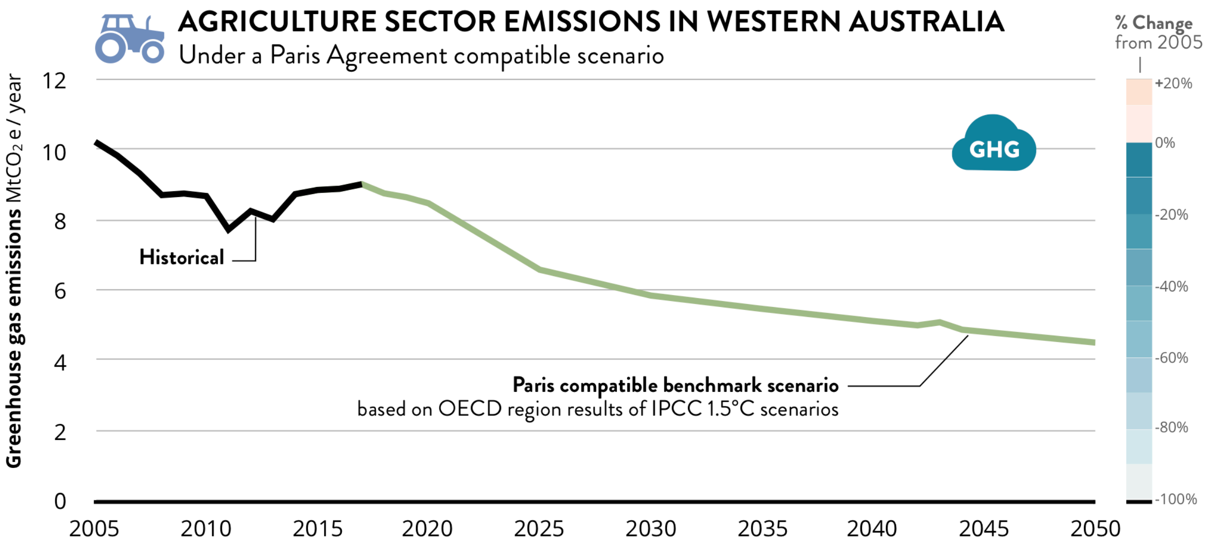

Figure 21: Western Australia Paris Agreement benchmark scenario for the agriculture sector, based on OECD region resutls of global scenarios analysed by the IPCC that are consistent with the Paris Agreement Temperature goal. See text for details. Emissions are reduced by about half towards the end of the century.

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 2018a).

There are no national scenarios published that lead to reductions in emissions from agriculture. The Deep Decarbonisation Pathway Scenario (ClimateWorks Australia 2014) leads to an increase in emissions by 2050 by 20%. A recently published study (FABLE Consortium 2019) also assumes agriculture emissions to stay at a level of 80 Mt CO2eq in 2050.

Waste Sector

The waste sector accounts for 2% of the state's emissions (Figure 2) and the emissions in the waste sector have increased 5% since 2005 (DEE 2019). Western Australian had the highest rates of waste kilograms per capita compared to Australia's other states and territories (all waste excluding fly ash) (Waste Authority WA 2019). In the same year, WA had the second to highest rates in amount of waste to landfill, and came joint second to worst for lowest rate of resource recovery (at 48%) (Waste Authority WA 2019). The state government has a target of 75% of waste generated in WA to be reused or recycled by 2030, through the State Waste Strategy (WA Government 2019a; Waste Authority WA 2019).

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. To derive the projections of emissions from waste sector for the Paris Agreement Compatible Benchmark Scenario, similar to the agriculture sector, we applied annualized growth rates for the OECD region over 2018-2050 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 2018b). Under the '1.5°C Paris Agreement compatible' pathway, the emissions from waste sector shows a reduction by 69% in 2030 and about 77% in 2050. Mitigation in the waste sector has been identified as highly cost effective and could even return a net profit (IPCC 2018b).

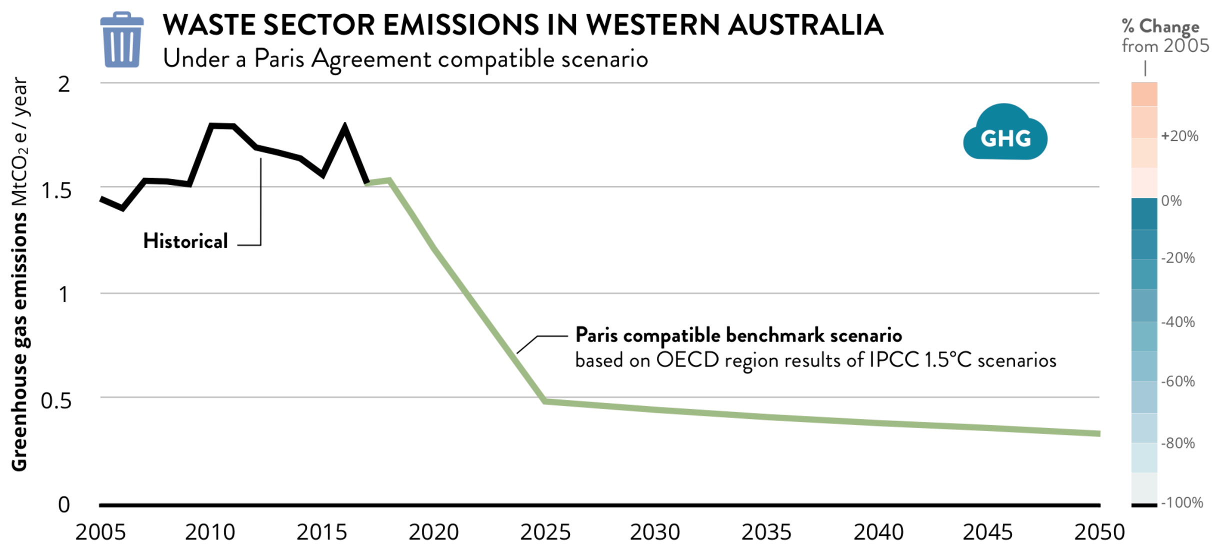

Figure 22: WA Waste Emissions PA Scenario $MtCO_2e$ (historical data 1990 to 2017, from AGEIS). The PA benchmark scenario is based on the results for the OECD region of a PA 1.5 scenario assessed by the IPCC.

Western Australia would need to reduce organic waste levels, creating a smaller task in also diverting the rest of organic waste from landfill. Current organic material in landfill areas will continue to emit GHG emissions until fully decomposed, making it imperative to begin plans to divert all organic matter. Western Australia's waste policy needs to be more ambitious and focus on organic material waste, with specific emissions targets for an emissions reduction pathway for this sector. Local government policy needs to align with state level policy and targets to tackle waste at the source.

LULUCF Sector

The land use, land use change and forestry (LULUCF) sector has a history of high fluctuations in emissions in WA. The LULUCF has transitioned between being an emissions source to an emissions sink in 1999, back to an emissions source in 2003, and then an emissions sink from 2011 to current (AGEIS 2019). The WA government plans to create five million hectares of new national, parks, marine parks, and other conservation reserves, which converts to a 20% increase in the WA conservation estate (WA Government n.d.). The plan is under development and the WA government is in consultation with stakeholders such as local governments, conservation groups and Traditional Owners (WA Government n.d.).

It is beyond the scope of this study to examine scenarios for land use, land use change and forestry however to enable a total greenhouse gas pathway for Australia it is important to make some simple stylised assumptions about the likely future trajectory of the carbon sink in this sector. In recent years the LULUCF sector has become a significant sink, storing carbon in forests, vegetation and soils. A number of projections indicate that the recent sink will reduce gradually over the next decade without substantial incentives to maintain and increase it. In this scenario we assume that the vegetation deforestation essentially stops by 2025, and that the non-CO_2 GHG emissions from the LULUCF sector decline slowly consistent with recent trends. Absent a detailed assessment we have assumed that the sink would reduce following the December 2018 Federal Government projections (Department of the Environment and Energy 2018) so that by 2030 it is about 30 percent below 2017 levels. For the purpose of this stylised scenario we maintain the sink at a constant level after that time until 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. Whilst the results were not specifically reported for Western Australia, this region was modelled, and 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. Figure 24 shows the relative scale of the increase land sink required to offset ongoing LNG sector emissions if there is no abatement at source.

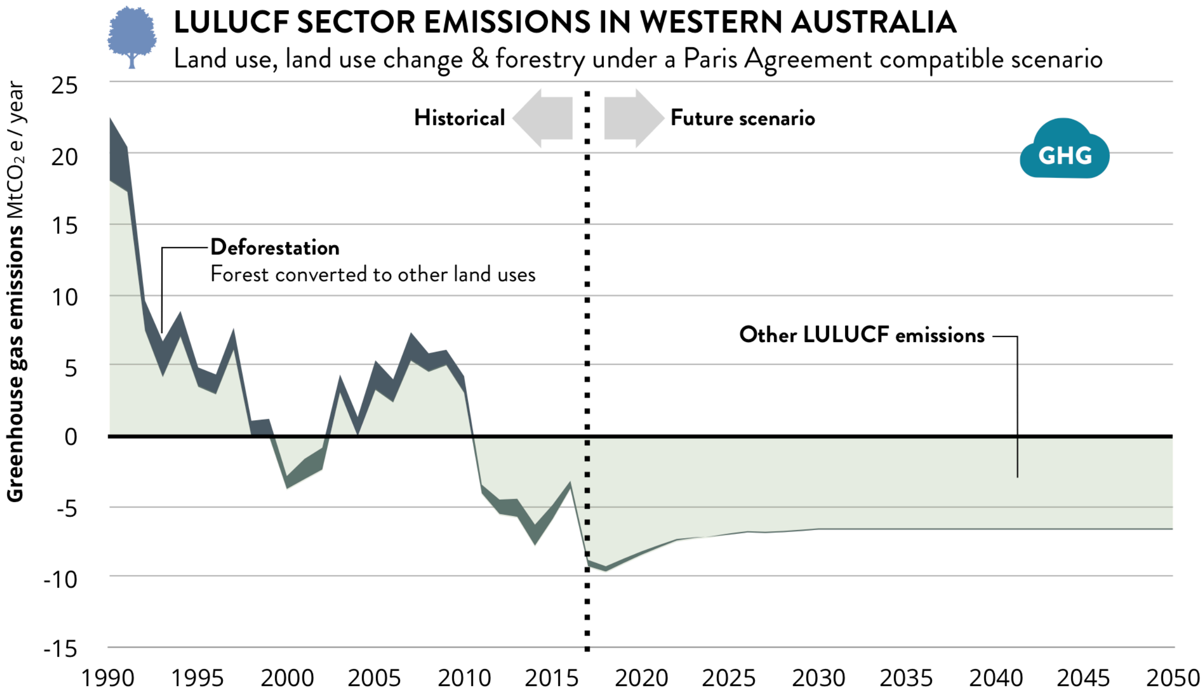

Figure 23 This figure shows the historical trajectory of land use, land use change and forestry (LULUCF) drawn from the June 2019 "State and Territory Greenhouse Gas Inventories 2017" for total LULUCF for all greenhouse gases (mainly carbon dioxide) and deforestation (defined as Forest converted to other land uses). A stylised scenario for the future development of the sector is shown assuming deforestation ending by 2025 and the recent uptake of CO_2 due to afforestation reforestation and other processes gradually reduces without further policies, essentially following the relative pathway from the December 2018 national greenhouse gas projections for the Australia wide LULUCF sink, maintained at 2030 levels until 2050.

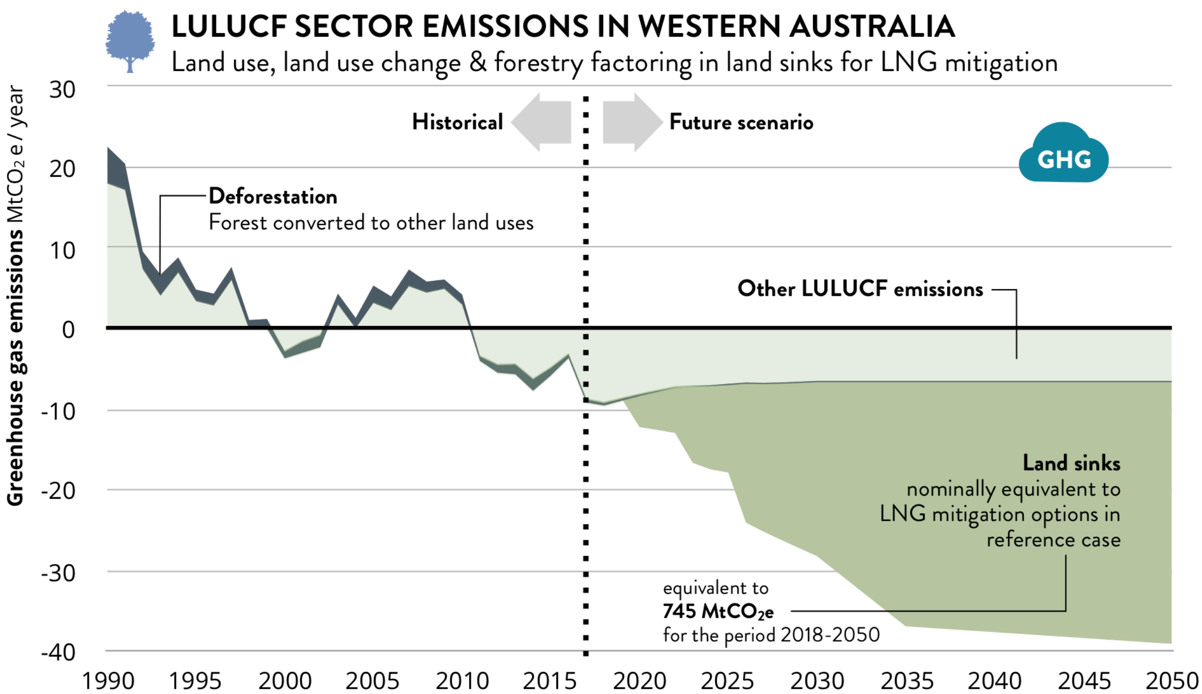

Figure 24 As in Figure 23 but showing the additional annual land sink nominally equivalent to the LNG mitigation options in reference case and shown in Table 6 and which total around 745 $MtCO_2e$ for the period 2018-2015.

Overall pathway

Figure 25 shows the overall greenhouse gas emissions in the Paris Agreement Benchmark Pathway for Western Australia. The only remaining emissions in 2050 would be from the agriculture and waste sector. They would need to be compensated with negative emissions from the Land-use sector.

GHG emissions would need to peak as soon as possible and then reduced steeply, **overall by 49% in 2030 compared to 2005 (35% without LULUCF)**. This is a much stronger reduction than the national federal target and confirms the inadequacy of that target and of assuming it as a benchmark for Western Australia. It is within albeit at the lower end of the range estimated for a domestic federal emissions reduction target for 2030 in line with the Paris Agreement.

This pathway achieves net zero emissions around 2050, if the size of the sink in the Land-use sector is maintained at high levels. Not shown is the pathway after 2050, where emissions would need to continue to be negative, leading to a net uptake of CO_2.

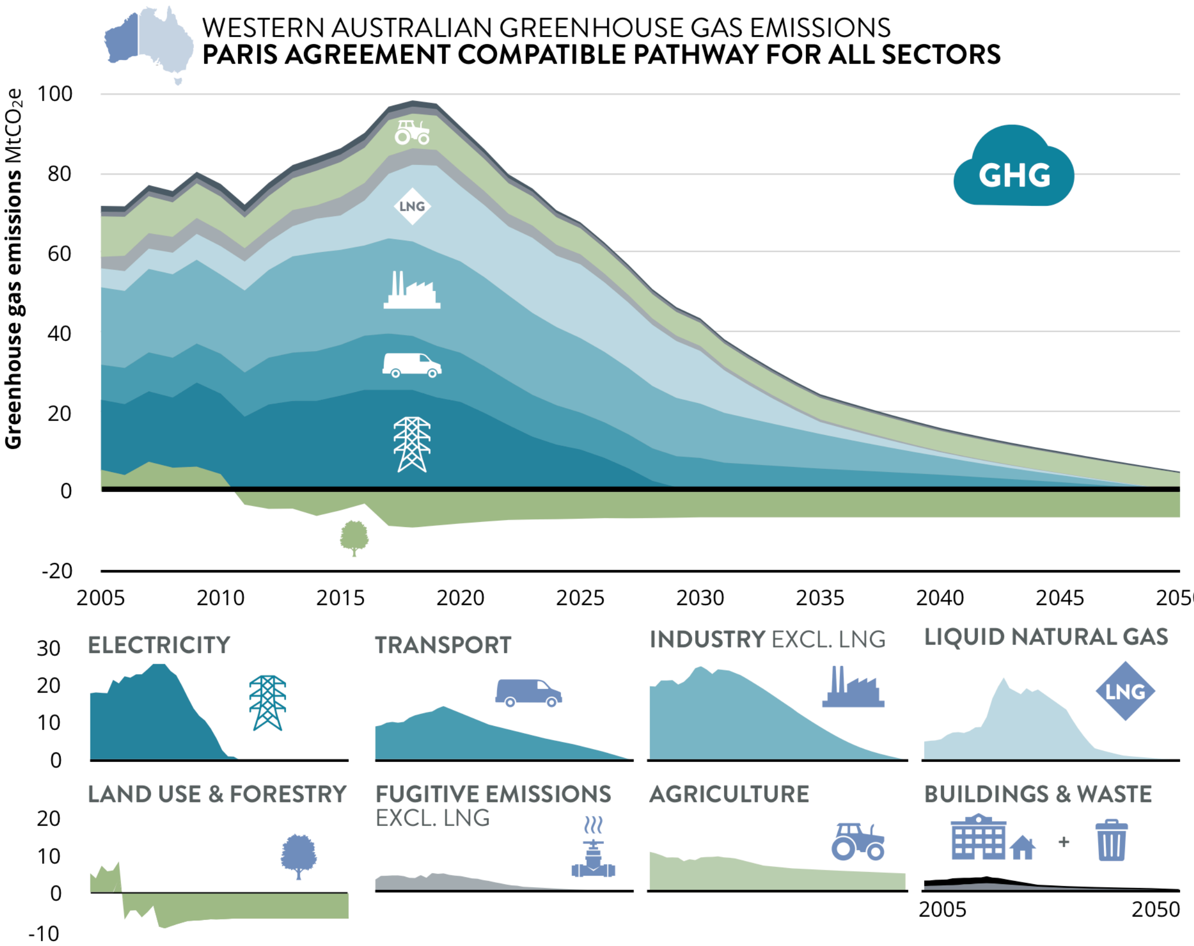

Figure 25 GHG emissions pathway for each of the sectors following transformation consistent with the Paris Agreement in each of those sectors. Total GHG emissions peak around 2020 and decline to about 63% below 2005 levels in 2030, reaching net zero in the 2040s contingent upon maintaining the recent large sink in the LULUCF sector.

CONCLUSIONS AND OUTLOOK

Policy Implications

This analysis has produced an energy and industry Paris Agreement compatible carbon budget for Western Australia that is consistent with the global carbon budget and the necessary global and national energy transformation across different regions required to limit warming to 1.5°C.

It shows how the **Western Australia carbon budget relates to the global carbon budget** and also provides information on the **emissions pathway** by which the budget needs to be met in order to ensure the Paris Agreement goal to limit warming to 1.5°C does not get out of reach.

It shows how this needs to be complemented with reductions in the **sectors outside of energy** and industry, in particular agriculture and waste, and the **role of land use and forestry to compensate** for **remaining emissions in particular from agriculture** that cannot be fully decarbonised.

It confirms the importance of **fast reductions in the short and medium term**, and the key strategy to decarbonise the power sector by a fast transition to renewable energy, taking advantage of the **vast potentials and low and falling costs of renewable energy and storage technologies** and the opportunities for a range of sectors.

Key conclusions for climate policy in Western Australia:

- Need to develop a **whole of the economy roadmap and strategy** and **detailed sectoral roadmaps and strategies** in line with Paris Agreement. This strategy needs to be based on the Paris Agreement Long Term Temperature goal and the importance of **limiting warming to 1.5°C** and the urgent need to **peak emissions and reduce them by 2030**.
- Such strategies and roadmaps need to be based on **robust scenarios and analysis**, that should be developed in a process with **broad participation of all stakeholders** – industry and trade unions, civil society, regional and local governments.
- It is **dangerous to focus only on an endpoint of net zero emissions by 2050.** The pathway there 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.
- **Energy and industry** are the **key sectors** that need to be addressed for full decarbonisation.
- The overall and sectoral strategies and roadmaps need to take into account the critical role of **electricity generation transitioning to renewable energy and fully decarbonised by the 2030s,** to contribute to the decarbonisation of end use sectors through direct or indirect electrification.
- Such a strategy involves a large increase in electricity demand and therefore a **massive ramping up renewable energy capacity – solar and wind** - that takes this into account and needs to be factored in when planning the transition of electricity generation, with clear targets and management of grid development and market regulation, as well as infrastructure for microgrids and off grid solutions.
- This strategy of "**sector coupling**" not only helps other sectors such as transport and industry reduce emissions and decarbonise, but also helps providing stability of the grid with variable renewable energy – wind and solar - through battery or other storage and demand side management.

- Sectoral strategies and roadmaps need to lead to the development of clear mid-term **sectoral targets** that are consistent with a Paris Agreement sectoral pathway, such as targets for expansion of renewable energy capacity that take sector coupling into account, and targets for electrification of transport and a shift to public transport and more cycling and walking, as well as targets for efficiency and shift to zero emissions fuels in industry, as well as a target to stop deforestation and develop and secure biological sinks while preserving biodiversity, taking into account climate change.
- In addition to roadmaps and targets, sectoral strategies need to include necessary near term transformational **policies to create incentives and develop the necessary infrastructure** to allow for a timely transition, such as charging stations for electric vehicles or hydrogen fuel cell trucks, or expanded public transport. This can also include **state-level legislation** to ensure sectoral targets are met despite the lack of action at federal level.
- **Every sector will have to contribute** to reducing emissions, and **linking it to other objectives** such as reduced air pollution, protection of biodiversity, sustainable economic development and high quality employment including in regional Western Australia.
- It is important to **address open research questions** in a targeted approach, and ensuring knowledge is developed and shared broadly with stakeholders. This is important for example for the **role of the land-use sector** and how it can contribute to uptake of CO_2 and **negative emissions** either through the sustainable use of biomass and carbon capture and storage or through enhancing and sustaining sinks in forests and ecosystems.

Western Australia has unique opportunities to develop its own vision and strategy and reap benefits of being a global leader in implementing the Paris Agreement, independent of the current failure at the federal level: with its own independent energy system, unique opportunities, prime renewable energy but also minerals resources, it has the opportunity to develop new manufacturing industries with added value and employment creation and moving away from being an exporter of carbon to becoming an exporter of zero emissions energy carriers (green hydrogen, ammonia, or electricity to neighbouring South East Asian countries) and products.

ANNEX I: METHODOLOGY AND MODELLING APPROACH

We have used as the starting point for developing the 1.5°C compatible energy and industry pathway for Western Australia global and regional data from the "Beyond 2°C Scenario" (B2DS) in the "Energy Technology Perspective" (ETP 2017) report of the International Energy Agency (IEA 2017). The ETP model enables a technology-rich, bottom-up analysis of the global energy system. We recently analysed the B2DS and this analysis (Climate Action Tracker 2018b) is reproduced in the next paragraphs.

The IEA (2017) estimated that the B2DS pathway has a peak global warming of 1.75°C above pre-industrial with a 50% likelihood meaning that its warming exceeds that of a 1.5°C compatible scenario. In its estimation of the peak warming level associated with the B2DS scenario, the IEA assumed that non-CO2 GHG would add about 0.35°C to the CO2-only warming. We however have evaluated the IEA B2DS pathway applying the same climate model approach to warming levels as was used in the IPCC Special Report on 1.5°C and earlier IPCC Fifth Assessment Report, enabling a comparison of "like with like" with the IPCC 1.5°C compatible scenario set. As the IEA provides only energy-related CO2 emissions, land-use and non-CO2 GHG emissions need to be estimated. When we assume comparable non-CO2 GHG emissions pathways to the ones analysed by the IPCC, and allow for negative emissions also comparable to the IPCC 1.5 pathways, we find that the B2DS scenario until 2050 is a close analogue climatically to the more recent 1.5°C compatible pathways.

There are however significant caveats, some related to the limitations of downscaling (see below) and others to the faster than expected cost reductions in key technologies for decarbonisation in particular renewable energy, storage (battery and pumped storage), electric vehicles and renewable hydrogen.

Since the IEA (and in general scenarios in the scientific literature) does not provide scenario data at sub-national state levels, nor at national level for Australia, in this report we first downscale the results of the B2DS scenario for the OECD region to Queensland, by using a model-based approach: SIAMESE (Simplified Integrated Assessment Model with Energy System Emulator) (Sferra et al. 2019).

SIAMESE is a reduced complexity IAM (Integrated Assessment Model), which provides cost-optimal emission pathways at the country, or state level, taking into account the complex interactions between economic growth, energy consumption and carbon emissions. While downscaling the energy-sector results from a given model (e.g. the IEA/ETP 2017), SIAMESE takes into account a coherent set of assumptions in line with a "middle of the road" socio-economic storyline (Dellink et al. 2017; Fricko et al. 2017). This storyline relies on a continuation of historical trends regarding technological developments and GDP growth at the country (or state) level. At the same time, SIAMESE has a cost optimisation perspective when allocating how much a country or a region would need to contribute to global emissions reductions in line with the Paris Agreement long term goal.

The SIAMESE downscaling approach can be applied to the overall economy (e.g. scaling down the overall primary energy consumption and emissions), or to individual sectors (e.g. transport, power and others). SIAMESE takes as input the original IEA B2DS (pathways for the OECD region, which start in 2014 in this scenario) and the observed energy consumption and emissions data for Western Australia. Based on the SIAMESE simulation we calculate the B2DS compatible carbon budget for Western Australia' transport and building sectors as the cumulative emissions remaining from 2018 to 2050 considering historical emissions until 2017.

Limitations of the downscaling are embedded in the driving scenario, which in this case is weak in several areas including decarbonization in industry, electrification of transport, and costs of renewable hydrogen as an energy carrier. We therefore use the SIAMESE simulation and estimate of a B2DS compatible carbon budget as an initial estimate which provides an upper bound on the carbon budget for the transport and building sector to evaluate against the Paris Agreement benchmark of achieving zero CO2 emissions by around 2050 for developed economies. These leads to Paris Agreement benchmark budgets for transport and building sectors, as well as fuel mix and demand estimates, in particular electricity demand. Given electrification is an important strategy for decarbonisation of transport and building sectors, the paris Agreement benchmark pathways for these sectors imply an increased electricity demand.

To determine the pathway and carbon budget for the electricity sector, given its important role for decarbonising end use sectors, but also to make sure it is consistent with global cost-optimal mitigation pathways consistent with the Paris Agreement temperature goal.

We compare the IEA B2DS results for the OECD region 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 subset of scenarios we consider here excludes those that exceed the sustainability limits for carbon-dioxide removal options identified in the literature. Fuss et al. (2018) identify a sustainability limit of 0-3.6 GtCO2 (removal)/yr for Agriculture, Forestry and Other Land Use (AFOLU), and 0.1 – 5 GtCO2/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. The cumulative CO2 emissions from the electricity sector in OECD of 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 scenarios (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). Staying on the more ambitious end of the range of CO2 budgets would minimise the amount of negative emissions needed for Paris Agreement compatibility over the second half of the century. The lower end of the range of IPCC SR1.5 pathways assessed here exceeds the cumulative CO2 emissions from IEA ETP B2DS by about 30%. Detailed assumptions will be published in (Climate Action Tracker 2019 b – AUS SU report).

As the downscaling model SIAMESE does not resolve technologies within either the fossil-fuel or renewable energy sectors, as well as for scenario analysis of the electricity supply sector, we apply the Australian electricity system optimisation model AUSeMOSYS, developed by Climate Analytics based on the current version of the Open Source energy Modelling SYStem (OSeMOSYS). The model provides a cost-optimised energy system pathway to meet the given demand for electricity, and taking into account the limit to cumulative emission derived as described, as well as taking into account increased electricity demand in industry, transport, and buildings from decarbonisation through electrification. The AUSeMOSYS model is multi-regional, dividing Australia into seven regions including New South Wales (NSW), Queensland (QLD), Victoria (VIC), Tasmania (TAS), South Australia (SA), Western Australia (WA), and Northern Territory (NT). The model time horizon covers the period from 2010 until 2050 in 1-year-steps, while each year is split into six time slices. Here we analyse the results for the Western Australia region. For a detailed description of the modelling framework and assumptions we refer to (Climate Action Tracker 2019 b – AUS SU report). Specific assumptions for Western Australia based on available projections for renewable energy uptake are explained in the main text.

Given the importance contribution and very region-specific economic profile of the industry sector in Western Australia, we determine the electricity demand and fuel mix as well as related emissions for the industry sector, by analysing a range of scenarios and literature related to key benchmarks for selected indicators, and applying them to the specific Australian and Western Australia context with the scenarios analysis tool PROSPECTS developed by the Climate Action Tracker consortium (Climate Action Tracker 2019 – Methodology annex), applied for an analysis of scaling up mitigation action options for Australia (Climate Action Tracker 2019b – Australia scaling up report, forthcoming), and downscaling this to Western Australia specific economic and energy system as well as emissions input data.

Assumptions for other sectors (LNG, agriculture, waste, land-use), not directly modelled, are explained in the main report.

ANNEX II: SCOPE OF EMISSIONS BY SECTOR FROM THE AUSTRALIAN GREENHOUSE EMISSIONS INFORMATION SYSTEM (AGEIS).

Energy and Industry Emissions

Electricity generation emissions are from fuel combustion for public electricity and heat production (AGEIS 1.A.1.a).

Transport sector includes fuel combustion emissions from domestic aviation (AGEIS 1.A.3.a), road transportation (AGEIS 1.A.3.b) (cars, light commercial vehicles, heavy duty trucks and buses, motorcycles, and other), railways (AGEIS 1.a.3.c), domestic navigation (AGEIS 1.A.3.d) (pleasurecraft and domestic marine). It does not include other transportation (AGEIS 1.A.3.e) which is included in the industry sector (consistent with the sector definition in the IEA ETP).

LNG Production includes emissions from fuel combustion for LNG processing (included in AGEIS 1.A1) and emissions from fugitives related to LNG (as a subsector of Industry) (own estimates).

Industry other emissions include:

- Energy industries (AGEIS 1.A.1) minus public electricity and heat production (AGESIS 1.a.1.a). This includes fuel combustion from petroleum refining, manufacture of solid fuels industries (i.e. coal mining, gas production and distribution minus fuel combustion for LNG processing) and other energy industries.
- Manufacturing industries and construction (AGEIS 1.A.2) includes fuel combustion emissions from iron and steel; non-ferrous metals; chemicals pulp, paper and print; food processing, beverages, and tobacco; non-metallic minerals; and other, as well as agriculture, forestry and fisheries energy sector emissions (AGEIS 1.A.4.c).
- Fugitive emissions from fuels (AGEIS 1.B) including from coal mining (underground and surface mines); oil (exploration, crude oil production, transport, refining and storage, and distribution); natural gas (exploration, production, transmission and storage, distribution and other); and venting and flaring. (Fugitives (AGEIS 1.B) data is categorized as confidential on AGESIS. We calculate it here by deducting fuel combustion (AGEIS 1.A.) from energy (AGEIS 1.) and based on own estimates.
- Industrial Processes (AGEIS 2) which includes the mineral, chemical, metal and electronic industries; plus non-energy products from fuels and solvent use; product uses as substitutes for ozone depleting substances, and other.

Building sector emissions include fuel combustion from commercial/ institutional (AGEIS 1.A.4.a) and residential buildings (AGEIS 1.A.4.b).

Other sectors (non-energy and industry related emissions)

Agriculture emissions (AGEIS 3) from enteric fermentation, manure management, rice cultivation, agricultural soils, prescribed burning of savannas, field burning of agricultural residues, liming, urea application and other carbon-containing fertilisers.

Waste emissions (AGEIS 5) include solid waste disposal, biological treatment of solid waste, incineration and open burning of waste, wastewater treatment and discharge, other.

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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. Our mission is to synthesise and advance scientific knowledge in the area of climate change and on this basis provide support and capacity building to stakeholders. By linking scientific and policy analysis, we provide state-of-the-art solutions to global and national climate change policy challenges.

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