Climateworks CENTRE

LAND USE FUTURES

Living within limits:

Adapting the planetary boundaries to understand Australia's contribution to planetary health

SUMMARY REPORT

APRIL 2022

ACKNOWLEDGMENT OF COUNTRY

We acknowledge and pay respect to the Traditional Owners and Elders – past and present – of the lands and waters of the people of the Kulin nation on which the Climateworks Centre office is located, and all Elders of lands across which Climateworks operates nationally. We acknowledge that sovereignty was never ceded. More information.

ACKNOWLEDGMENT OF SUPPORT

We wish to acknowledge the valuable contributions of input and feedback by members of the Land Use Futures Technical Reference Panel, as well as a panel of expert reviewers and editors.

This work was made possible by generous philanthropic support for the Land Use Futures program.

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ABOUT US

Climateworks Centre bridges research and action, to achieve the system-level transitions required to reach net zero emissions across Australia, Southeast Asia and the Pacific. We act as trusted advisers, influencing decision-makers with the power to reduce emissions at scale. Co-founded by The Myer Foundation and Monash University in 2009, Climateworks is an independent non-profit working within the Monash Sustainable Development Institute.

This report is part of the Land Use Futures program. Find out more about Land Use Futures.

Climateworks Centre, 2022, *Living within limits: Adapting the planetary boundaries to understand Australia's contribution to planetary health*.

ISBN: 978-0-9924232-2-3

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Summary

Global momentum is building for the different actors involved in agriculture, forestry and other forms of land use to better support a sustainable future; one that helps curb climate change, enhances biodiversity and supports the production and consumption of affordable and nutritious food.

Yet understanding the environmental limits within which the land use sector must operate remains a challenge. What do the global environmental limits and goals mean for Australia? And how do we define and measure what sustainability means and looks like for a particular sector, especially one as complex as land use?

Understanding what sustainability means in practical, measurable terms is important in a context in which the land use sector is under increasing pressure from growing populations, the impacts of climate change and extreme weather events. The latest climate change reports highlight that climate change is already having dramatic impacts on the health of human societies and the natural systems that support them, with implications for food and land use systems.

The Intergovernmental Panel on Climate Change reports that globally, climate extremes are already exposing millions of people to diseases and food and water insecurity, as well as slowing growth in agricultural productivity.

Australia faces unique challenges in supporting food and land use sustainability given its export-oriented agricultural industry, highly variable climate and geography, and an agricultural industry profile where nearly 50 per cent of Australia's land mass is used for agriculture.

The planetary boundaries framework is one way to set global environmental limits in which humanity can continue to thrive without compromising the health of the natural environment.

This report summarises work undertaken through the Land Use Futures program to adapt the planetary boundaries to the Australian context, highlighting key insights derived from a foundational technical report, which is forthcoming. It outlines how Australia is tracking against its share of planetary boundaries and considers how the land use sector is both contributing to and affected by environmental limits.

The findings in our report demonstrate that across a number of variables used to assess planetary health, key environmental systems in Australia are showing signs of stress or near failure.

Assessing limits at a national scale, Australia has transgressed limits for three of the planetary boundaries: biodiversity, land-system change, and nitrogen and phosphorus flows. It is approaching national limits for climate change and freshwater use.

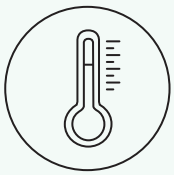
Despite these trends, the land use sector can take steps to function within a safe operating space for planetary health. The sector itself holds many of the solutions to help tackle climate change and protect the natural environment. Leveraging these opportunities will mean the land use sector can play a key role in helping Australia and the world meet critical sustainability goals, and in doing so reduce its own high level of vulnerability to climate change and ecosystem decline.

Future work in Land Use Futures will describe and quantify the most effective solutions available to Australia and its land use sector to reduce emissions and sequester carbon and contribute to broader sustainability goals.

Key findings

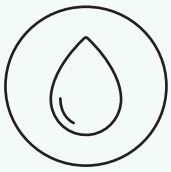
This report adapted five global planetary boundaries to the Australian context and considered the relevance of these boundaries to Australia's land use sector. A summary of the key findings for each of the five boundaries is below.

Climate change



- At the global scale, the planetary boundary for climate change has been transgressed.
- At current rates of greenhouse gas emissions, within four to nine years from 2021 Australia will have exceeded its budget for how much greenhouse gas can be emitted to limit warming to 1.5°C.
- The Australian land use sector is not reducing emissions at the pace and scale needed to help achieve the global goal of limiting warming to 1.5°C.
- The land use sector directly contributes to greenhouse gas emissions but also holds many solutions to support climate action.

Freshwater

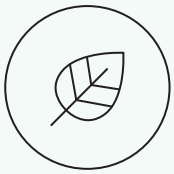


- At the global scale, freshwater use is currently within safe limits.
- National freshwater use is approaching the safe limit. However, there is variability across different freshwater systems, with some exceeding the limit.
- The land use sector is a major cause of stress in different freshwater systems across Australia, although this varies across different regions.
- 13 per cent of river regions (catchments) across Australia are under stress from water withdrawal for human activities.
- Stressed water catchments correlate with high intensity and high value agricultural production zones, and urban and industrial zones.

Land-system change

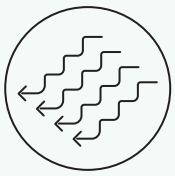
- Across various scales and metrics, the Australian land use sector is exceeding the land-system change boundary, largely due to the conversion of key climate-regulating forests to farmland.
- A primary driver of this land use change in Australia is agriculture, with approximately 49 per cent of the continent now used for agriculture.
- The area of land undergoing land use change for agriculture in Australia is more than three times what is deemed a safe level of land use conversion.
- Almost half of Australian ecosystems have either crossed or are approaching the threshold beyond which they are considered endangered.

Biosphere integrity – biodiversity loss and extinction



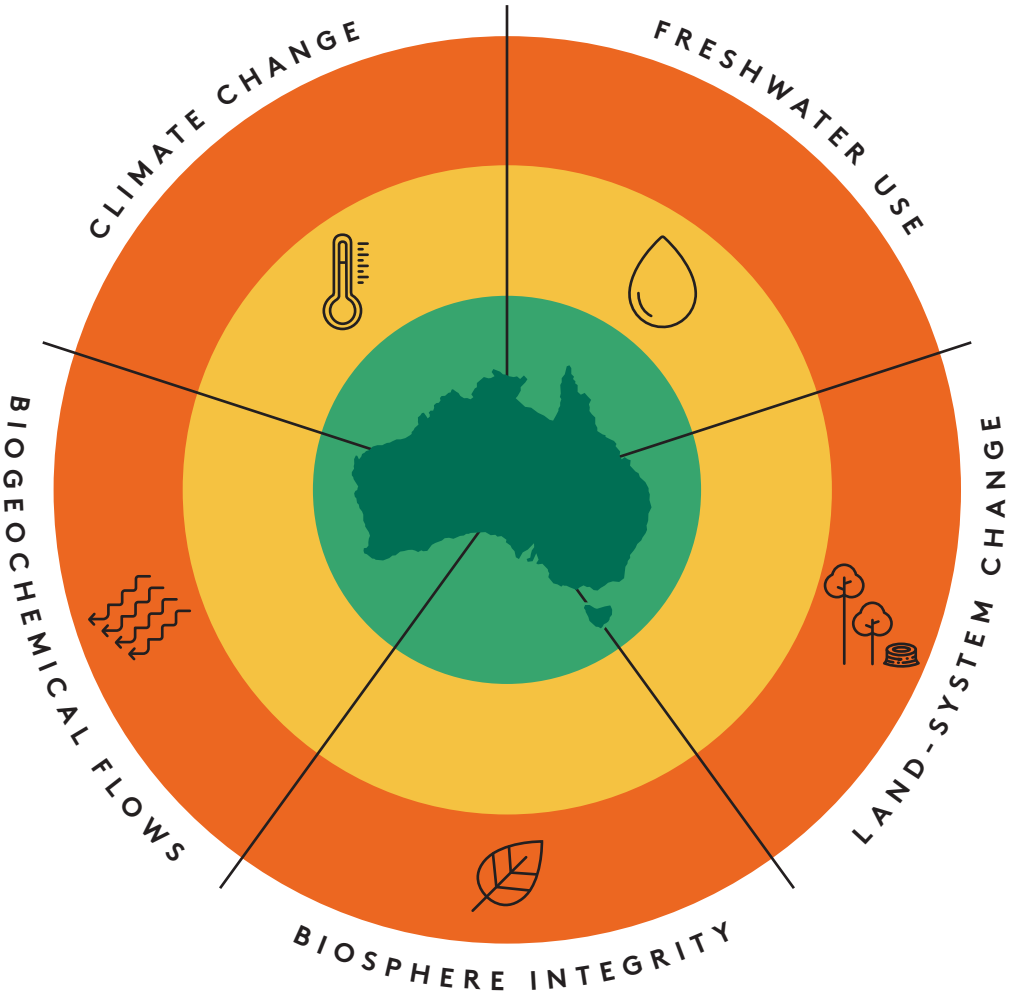
- The global planetary boundary for biosphere integrity has already been transgressed.
- The rate at which Australian mammals are becoming extinct is estimated to be 430 times higher than the extinction rate that might have occurred without intensive human activity.
- Climate change, land use and land use change have greatly reduced the overall available area for species to inhabit, with roughly 30 per cent of areas with suitable climates for species occurring on lands that are currently uninhabitable.

Biogeochemical flows – nitrogen and phosphorus



- Both the nitrogen and phosphorus biogeochemical footprints for Australia exceed an apportioned 'fair share' of the global limit.
- Australia's nitrogen and phosphorus fertiliser application practices in the land use sector are generating surplus in some key drainage divisions.
- In Australia, concentrations of nitrogen and phosphorus exceed a safe level for environmental health in 42 per cent (for nitrogen) and 55 per cent (for phosphorus) of river regions (catchments).

NATIONAL LIMITS FOR AUSTRALIA



ASSESSMENT OF NATIONAL LIMIT

Safe | **Approaching limit** | **Transgressed**

RELEVANCE TO AUSTRALIAN LAND USE SECTOR:

FRESHWATER USE

Land use contributes to water stress in some geographic locations, driving Australia towards its national freshwater limit.

LAND-SYSTEM CHANGE

The land use sector has driven substantial land conversion and is contributing to pressure on Australian land systems.

BIOSPHERE INTEGRITY

The land use sector is a key driver of Australia's biodiversity loss and extinction.

BIOGEO-CHEMICAL FLOWS

Land use is significantly contributing to interference in nitrogen and phosphorus cycles in some geographic locations, pushing Australia beyond its national limit.

CLIMATE CHANGE

Trajectory of land use sector emissions are not on track to support national limit for Australian emissions.

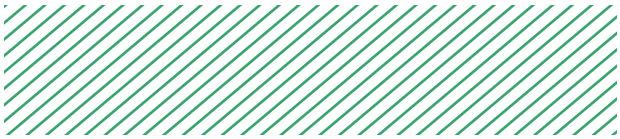
Introduction

The land use sector is increasingly included in calls for greater action to safeguard planetary health and social wellbeing. This includes leveraging the land use sector in the pursuit of the global Sustainable Development Goals and the Paris Agreement on climate change.

As many public and private sector actors move to set targets and better understand and account for their land-related impacts and the potential of mitigating actions, there is a growing impetus to better understand what 'good' looks like when it comes to sustainable land use, and a growing evidence base to support national target setting to achieve climate and broader sustainability outcomes. The urgency to act becomes even more pronounced when the latest global reports show that climate extremes are exposing millions of people to food and water insecurity, as well as slowing the growth in agricultural productivity (IPCC 2022).

In the land use sector, accounting for land-related emissions and other environmental impacts is complicated. How to set appropriate goals and limits is still being grappled with and negotiated in a range of forums; from international climate conferences to local planning processes.

Broadly, however, a sustainable land use sector can be understood as one that is operating within the planetary boundaries. The planetary boundaries are globally defined environmental thresholds or limits for a range of areas, such as climate change and biodiversity, that are critical for the functioning of the Earth's systems. Remaining within these environmental limits will enable sustainable development without compromising the health of the natural environment.



This report summarises work undertaken through the Land Use Futures program to translate five of the nine planetary boundaries to the Australian context – those that are most applicable and relevant to the land use sector. These are:

CLIMATE CHANGE

FRESHWATER USE

LAND-SYSTEM CHANGE

BIOSPHERE INTEGRITY – BIODIVERSITY LOSS AND EXTINCTION

BIOGEOCHEMICAL CYCLES – NITROGEN AND PHOSPHORUS FLOWS.

We have adapted the planetary boundaries framework to the Australian context with a view to using these boundaries and assessments in future work for Land Use Futures. It acts as a guiding framework in defining what a sustainable land use future means in the Australian context.

This work broadly defines the national thresholds that the land use sector needs to operate within, alongside other sectors, and offers a perspective on the limits and thresholds that are meaningful to the sector for each boundary at national, and sometimes smaller, scales. It indicates how Australia is tracking against key environmental variables and how the land use sector in particular is coming up against a set of limits that have consequences both at home and beyond Australia's geographical boundaries.

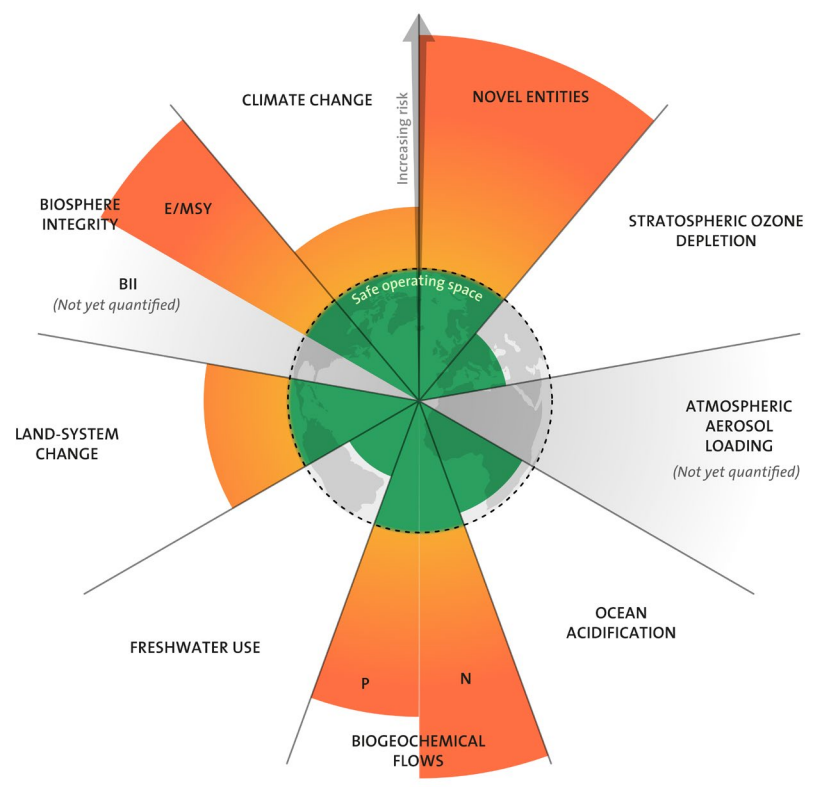
What are the planetary boundaries?

The planetary boundaries framework defines the 'safe operating space' within which humanity can continue to thrive (Stockholm Resilience Centre n.d.). The framework defines limits or thresholds for nine variables that are critical for the functioning of the Earth's systems (Rockström et al. 2009, Steffen et al. 2015). Remaining within these nine environmental limits will enable sustainable development without compromising the health of the natural environment. These variables are:

+ Climate change
+ Freshwater use
+ Land-system change
+ Biosphere integrity (biodiversity loss and extinction)
+ Biogeochemical cycles (nitrogen and phosphorus flows)
+ Ocean acidification
+ Atmospheric aerosol loading
+ Stratospheric ozone depletion
+ Novel entities.

The planetary boundaries framework is a tool to assess the impact that human activity has had on these variables and identifies tipping points beyond which detrimental feedback loops occur within and between Earth systems (Steffen et al. 2015, Lade et al. 2020). In 2015, Steffen et al. found that the global planetary boundaries for biosphere integrity and biogeochemical cycles have transgressed the zone of uncertainty (high risk), while land-system change and climate change have entered into the zone of uncertainty (increasing risk). Global freshwater use was assessed as below the global boundary (safe). (Figure 1)

FIGURE 1: Global planetary boundaries (Stockholm Resilience Centre 2022).



Adapting the planetary boundaries

The land use sector refers to the range of different actors involved in the production of food and other products derived from land use in Australia including grazing, cropping, production forestry and nature conservation.

The planetary boundaries concept was adapted for the Land Use Futures program to support our ongoing work in better understanding Australia's contribution to planetary health and the role that the land use sector can play to support a sustainable land use future.

For relevant global boundaries, we determined a national limit and assessed Australia's 'footprint' against this limit as a way of conceptualising our current impact on each boundary. This footprint represents how 'much' of the environment is needed for locally consumed goods to be produced, taking into consideration the flow of traded commodities to and from the international market. Assessing the size of this footprint gives us a sense of how Australia is impacting environmental systems from a global perspective and how we are tracking towards sustainability goals, such as nationally determined contributions under the Paris Agreement. To make this assessment we have taken a consumption-based approach (see Box 1).

For each of the five boundaries, we also considered the relevance of environmental limits to the Australian land use sector. In most cases, this analysis took a production-based approach to enable an assessment of all activities in the land use sector within Australia's territorial limits. This involved asking questions such as: what are the land requirements, resources and environmental pressures associated with agricultural commodities produced in Australia? What impact do these activities have across each of the five boundaries at a national level? And how might a transgression of these boundaries affect the land use sector?

BOX 1:

Production- and consumption-based accounting approaches

To adapt global environmental limits for application in Australia, it is important that we consider not only what we produce and consume in Australia but also the embodied emissions and resources within international trade flows.

In Australia we produce more food than we consume, exporting around 70 per cent of agricultural production (ABARES 2021a) and importing only 15 per cent of our food (ABARES 2018). Australia also has a relatively small population across a large continent, much of which is dominated by agriculture, with over 377 million hectares of agricultural land under production (ABS 2021a).

If we only consider what is either produced or consumed within Australia, we are not fully accounting for the impacts of Australia's resource use on the global environment. Without accounting for goods that we produce in Australia and export overseas, or those that are produced internationally and consumed within Australia, we are essentially misrepresenting or biassing Australia's fair share of efforts to remain within global environmental limits.

To reflect this, we have undertaken both consumption and production-based accounting methods in our analysis.

The consumption-based approach captures the embodied emissions and resources within trade flows and provides a better understanding of our 'fair share' in addressing global environmental issues. In other words, this approach captures the impact of relevant goods and services that are consumed here in Australia, including those that are imported from overseas. This approach is applied in this report mostly at the national scale to create a 'footprint' for Australia to represent how Australia is tracking around key global environmental thresholds.

This report also uses a production-based approach (often called 'territorial accounting') to assess the direct environmental pressures generated by land use activities within Australia. The production-based approach provides a local assessment of the environmental pressures on a specific boundary generated by the production of agricultural commodities within our national borders, including those generated during the production of commodities exported and consumed overseas.

A territorial approach can provide a view on whether citizens in Australia are living within the biocapacity limits of their own territory, and this can be helpful in determining what types of changes in production are necessary across different land use types in Australia. In this report, it provides an assessment of the impact of the land use sector on the Australian environment. However, the territorial approach can sometimes hide the high consumption lifestyles reliant on goods produced overseas, that we enjoy in countries like Australia and doesn't reflect the principle of equal access to our global environmental commons.

Both these approaches provide insights that are relevant for the whole supply chain, from production through to consumption. The forthcoming technical report will provide more detail on which methodologies were applied to each boundary.

The challenges of adapting the boundaries

In some cases, there were measures that were more relevant than simply 'downscaling', or directly applying the global boundary assessments to the Australian context. For example, assessing freshwater use at a national scale does not capture the substantial variation in the health and sustainability of freshwater systems across the country. In such instances, new methods have been developed to adapt the planetary boundary concept to the national scale and to draw relevance to the Australian land use sector. This includes applying both a production- and consumption-based approach to the analysis (see Box 1). The applied methods can be debated and like any analysis, have limitations which are fully explained in the forthcoming technical report.

While this report goes some way to show what environmental limits might apply in the Australian context, it is not intended to prescribe particular limits or actions for the land use sector. Setting specific thresholds for different ecosystems is challenging as they need to be set at scales that are appropriate for environmental management and decision-making.

Nevertheless, this work broadly defines the national thresholds that the land use sector needs to operate within alongside other sectors, and offers a perspective on the limits and thresholds that are meaningful to the sector for each boundary at national, and sometimes smaller, scales.

Climate change boundary

GLOBAL BOUNDARY:

Transgressed

NATIONAL LIMIT FOR AUSTRALIA:

Approaching limit

LAND USE SECTOR:

Trajectory of land use sector emissions are not on track to support the national limit for Australian emissions.

This section describes the climate change boundary and outlines that at the global and national scale of assessment, the limits for greenhouse gas emissions have either already been transgressed or are being approached. Crossing these limits will have widespread adverse impacts for nature and for people and while actions can be taken to limit warming, this can, at best, lessen rather than avoid the damages and losses projected from climate change (IPCC 2022). The land use sector has a unique role to play in managing the impacts of climate change as both a source of and sink for greenhouse gas emissions.

The global climate change boundary

The global carbon budgets that underpin a climate planetary boundary are defined as the amount of greenhouse gas emissions that can be emitted by humans into the atmosphere to stay within a specified level of global warming. If exceeded, global temperatures will become higher.

The threshold applied in the planetary boundary framework and in this report uses 1.5°C above pre-industrial levels as the limit. This aligns to the ambition of the Paris Agreement and the scientific consensus on the degree of change we need to stay within to avoid catastrophic outcomes for Earth systems as a result of climate change.

At the global scale, the planetary boundary framework measures two variables for climate change – the greenhouse gas concentration boundary and the radiative forcing boundary, which measures the change in atmospheric energy flux due to climate change, as compared to pre-industrial levels. Both have already been transgressed. This means we are not operating in a safe space for the climate, and that action is needed to reduce the level of greenhouse gases in the atmosphere.

At a global scale the trends for climate change are not on track to limit warming to 1.5°C. The land use sector is responsible for a significant portion of global greenhouse gas emissions. While commonly cited as representing 10 to 15 per cent of net global CO_2 emissions, when we consider both CO_2 and non-CO_2 gases and gross fluxes (including both sequestration and emissions), human activities on land actually account for approximately 48 per cent of all anthropogenic global greenhouse gas emissions flowing into and out of the atmosphere (Food and Land Use Coalition 2021).

If this global trend continues, the Paris Agreement targets won't be met and the world could experience catastrophic impacts from climate change. This includes not only more frequent disastrous weather events, but also the potential to cause market and political disruption and threaten food security. Importantly, the impacts of climate change will not affect all countries in the same way, with some regions such as South Asia already experiencing threats to food security as natural cycles become destabilised. The effort to curb climate change is a global one, and there is a responsibility for all nations to reduce emissions given that what happens in one country affects others.

While globally the land use sector is a significant contributor to climate change, it also holds the potential to be part of the solution. Changing how land is used and farmed to reduce land clearing and increasing efficiency in food production can help to reduce global emissions and sequester carbon.

A climate change limit for Australia

The global carbon budget was translated for Australia using a 'footprint' approach to assess Australia's fair share of global emissions to ensure the world remains within the limit of 1.5°C. While the threshold of emissions at the national scale has not yet been reached, it is quickly coming up against this limit.

Based on the current emissions trajectory, our analysis suggests that within four to nine years Australia will have emitted its total carbon budget to stay within a 1.5°C warming scenario. This carbon budget refers to the cumulative greenhouse gas emissions that can be emitted in Australia between 2021 and 2050 to limit warming below 1.5°C. The budget was calculated using assumptions from the Intergovernmental Panel on Climate Change (IPCC 2021) as well as Australian methodologies (Garnaut 2008, CCA 2014, Meinshausen et al. 2019).

Although Australia has reported annual decreases in total emissions since 2007, the current trajectory of emissions across the economy is insufficient to stay within Australia's national budget. Thus, Australia's greenhouse gas emissions need to decrease further to support the global effort to stay within the global effort to limit warming to 1.5°C.

Without this reduction in emissions, Australia will contribute to global climate change and itself experience a range of impacts which are already starting to be seen including more extreme weather, droughts, fire seasons and flooding. While significant across all parts of society and the economy, for the land use sector, climate change plays a vital role by influencing the natural cycles of other parts of the environment like water cycles, on which the sector depends.

Climate change and the Australian land use sector

Climate change is an important environmental boundary for the land use sector because the impacts of climate change, such as greater variability in rainfall, have the potential to disrupt food and fibre production. In Australia, this could affect the ability to meet domestic food demand and limit the landscape's capacity to sequester carbon. Further work in Land Use Futures will assess the potential impacts on the land use sector over time against different future scenarios. This section outlines the role of agriculture in broader land use sector emissions and highlights the role that the land use sector can play to sequester carbon.

As it does globally, the land use sector in Australia contributes to climate change by generating greenhouse gas emissions, with a high proportion coming from agriculture. In 2020 agriculture accounted for 14 per cent of Australia's national greenhouse gas emissions (Department of Industry, Science, Energy and Resources 2021a).

The largest contributor to greenhouse gas emissions from the land use sector in Australia is livestock (ClimateWorks Australia 2020), which represents about half of Australia's total methane emissions (Department of Industry, Science, Energy and Resources 2022). Livestock emissions have been declining, but this has primarily been a result of lower stock numbers due to economic or environmental circumstances rather than lower emissions per head of livestock (Department of Industry, Science, Energy and Resources 2021b).

In the Australian land use sector there are also opportunities for carbon sequestration and mitigation actions to support decarbonisation, and potentially offset emissions from other sectors. That is, the sector itself holds many of the solutions that are needed to limit climate change – both by reducing emissions and by drawing down carbon from the atmosphere. This includes activities such as landscape protection and restoration, improving agricultural practices and leveraging market opportunities for alternative proteins.

In 2020 it was reported that land use, land use change and forestry sectors produced negative emissions overall (in other words, sequestered emissions), accounting for -4.8 per cent of the national emissions profile (Department of Industry, Science, Energy and Resources 2021a). Modelled data found that environmental and carbon plantings alone could sequester 0.23 $GtCO_2$ between 2020 and 2050 (internal Climateworks Centre and Deakin University analysis, 2022). Many other land use and management changes within the land use sector, including forestry, offer the potential for further abatement, demonstrating that the land use sector has an important role to play in sequestering carbon.

Despite emissions declines in the land use sector since the 1990s, it is predicted that agriculture and land use change emissions will remain largely static through to 2030 (Department of Industry, Science, Energy and Resources 2021c) and our assessment of emissions suggests the trajectory of land use sector emissions will not be sufficient to support a national climate change limit for Australia.

To enable Australia to remain within a 1.5°C warming scenario, Australia's agricultural emissions must be reduced by 57 per cent by 2030, and by 66 per cent by 2050 from a 2020 baseline, alongside emissions reductions in other sectors of the economy (ClimateWorks Australia 2020). This would mean reducing cumulative emissions by 0.97 $GtCO_2e$ over the next 30 years. These emissions reductions were calculated to keep agricultural emissions within the national fair share budget, aligning with economy-wide net zero emissions by 2035 for Australia.

Agriculture, as a key driver of emissions in the Australian land use sector, is not currently on track to contribute to the global goal of limiting warming to 1.5°C. This follows the trends of Australian emissions as a whole. While this trend could have significant impacts on the sustainability of the land use sector, the sector can also be part of the solution.

KEY FINDINGS:

- At the global scale, the planetary boundary for climate change has been transgressed.
- At current rates of greenhouse gas emissions, within four to nine years from 2021 Australia will have exceeded its budget for how much greenhouse gas can be emitted to limit warming to 1.5 °C.
- The Australian land use sector is not reducing emissions at the pace and scale needed to help achieve the global goal of limiting warming to 1.5 °C.
- The land use sector directly contributes to greenhouse gas emissions but also holds many solutions to support climate action.

Freshwater boundary

GLOBAL BOUNDARY:

Approaching limit

NATIONAL LIMIT FOR AUSTRALIA:

Approaching limit

LAND USE SECTOR:

Land use contributes to water stress in some geographic locations, driving Australia towards its national freshwater limit.

The global freshwater boundary

Freshwater is an important indicator of planetary health. Human use of water has direct and indirect impacts on a range of issues such as biodiversity, human health, carbon sequestration and climate regulation (Rockström et al. 2009). In particular, freshwater consumption is strongly linked to the land use sector, with agriculture accounting for nearly 70 per cent of global freshwater withdrawals (FAO 2021).

Understanding the safe operating space for freshwater use is critical for the health and sustainability of the natural environment, and of people; that is, how much water can be consumed without compromising ecosystem functions, services or water flows. This is especially important for Australia as the most arid inhabited continent in the world, where the agriculture sector accounts for around 65 per cent of Australia's freshwater extraction (ABS 2021a).

At the global scale, the boundary for freshwater use is not considered to be transgressed. It is currently assessed at 2600 km^3 per year of consumptive blue water use out of a maximum of 4000 km^3 per year (bluewater is water sourced from surface or groundwater resources). However, freshwater systems are under increasing pressure, primarily due to growing food demands for the global population. Rockström et al. (2009) suggest that the remaining available freshwater that would keep us in the safe operating space might already be committed to meet future water demands.

A national freshwater limit for Australia

The global freshwater resource limit was downscaled for Australia using a 'footprint' approach to apportion Australia's 'fair share' of freshwater use. On this basis, Australia's net freshwater consumption per capita has not yet exceeded a national limit for freshwater use. However, it is approaching this limit and is under increasing pressure from human activity and changing climate conditions.

The land use sector contributes directly to the condition of Australia's inland water environments and the pressures on this system from water extraction and water resource development. In 2019–2020, 5.7 million megalitres (5.7 km^3) of water was applied to crops and pastures and 1.5 million hectares of agricultural land was irrigated, with almost half (48 per cent) of Australia's total water used for irrigation extracted from one region – the Murray-Darling Basin (ABS 2021b).

Australia's freshwater availability also faces climate challenges with a history of long periods of drought and variation in rainfall across the continent (BOM 2021a). Reduced rainfall and increased temperatures are expected to feature in many areas of Australia as the climate warms, placing greater pressure on agricultural production, while other areas are projected to have significant increases in rainfall and rainfall intensity.

Freshwater and the Australian land use sector

Being dependent on freshwater systems that are under increasing pressure has direct implications for the food and land use sectors in Australia where water use by agriculture is often driven by availability rather than demand for production. For example, water consumption by agriculture decreased by 11 per cent from 2018–19 to 2019–20 because of low water availability across a key basin (the Murray-Darling Basin) and generally dry conditions across much of the country (BOM 2021b).

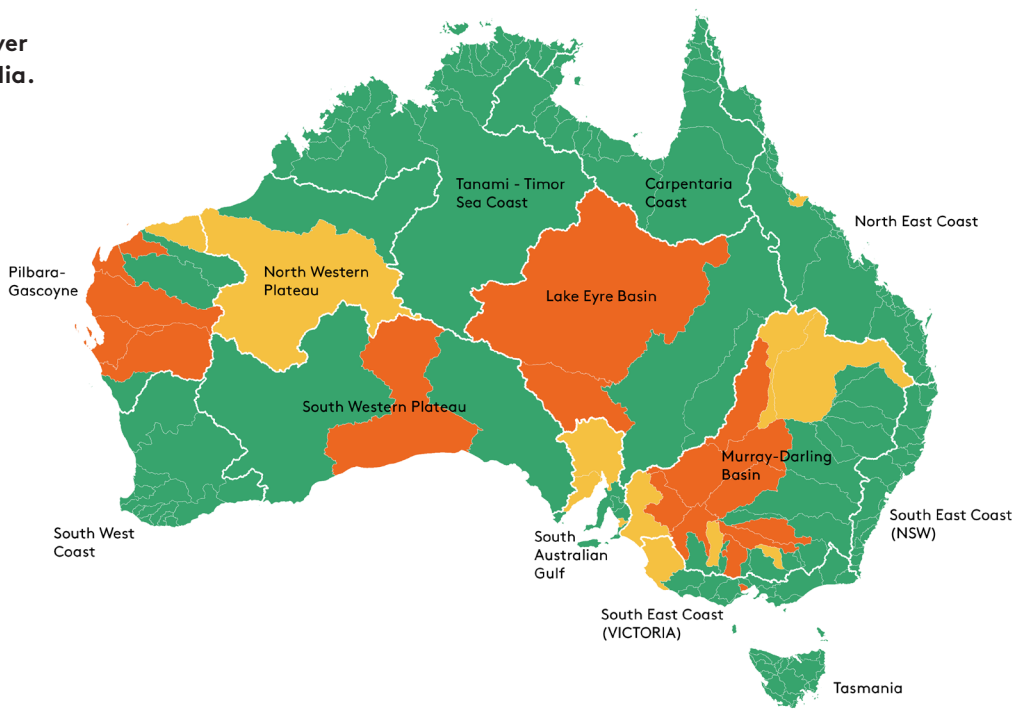
While we know broadly that agricultural land use is affecting freshwater systems, managing these impacts requires a more localised assessment to capture the true stresses on freshwater systems in Australia. This is because water resource use, management and scarcity issues are varied across Australia, with some areas experiencing more severe and frequent drought, and others experiencing extreme rain events and flooding.

In 2015, Steffen et al. proposed an additional freshwater boundary to complement the existing framework, the river-basin scale analysis. This boundary supports a more localised understanding of freshwater use and the environmental pressures this places on freshwater systems. This is the approach we have taken to considering the impacts of land use on freshwater systems in Australia.

This assessment therefore considers an environmental limit at the river-basin (catchment) scale, considering any catchment that exceeds the 40 per cent stress threshold to be beyond a safe operating space. The stress threshold measures how much water needs to remain in a river to sustain that ecosystem after some has been withdrawn for human use. If withdrawals are higher than 40 per cent of freshwater flows, the river system is considered to be stressed.

Undertaking analysis at this river-basin scale showed that, in 2020, 13 per cent of catchments across Australia were above the 40 per cent water stress threshold. These stressed water catchments correlate with high intensity and high value agriculture production zones (see Figure 2), demonstrating how the land use sector impacts on water stress in many of these regions, as well as water used for domestic or urban water supplies, and industry.

FIGURE 2: Water stressed river regions (catchments), Australia.



Orange indicates zones where water stress exceeds the regional boundary limits.

Yellow indicates water stress within the zone of uncertainty.

Green indicates within the boundary limits.

Thick white lines represent drainage division boundaries.

Thin white lines represent river region boundaries.

KEY FINDINGS:

+ At the global scale, freshwater use is currently within safe limits.
+ Australia's national freshwater use is approaching a safe limit. However, there is variability across different freshwater systems, with some exceeding the limit.
+ The land use sector is a major cause of stress in different freshwater systems across Australia, although this varies across regions.
+ 13 per cent of river regions (catchments) across Australia are under stress from water withdrawal for human activities.
+ Stressed water catchments correlate with high intensity and high value agricultural production zones, and urban and industrial zones.

Land-system change boundary

GLOBAL BOUNDARY:

Transgressed

NATIONAL LIMIT FOR AUSTRALIA:

Transgressed

LAND USE SECTOR:

The land use sector has driven substantial land conversion and is contributing to pressures on Australian land systems.

The global land-system change boundary

The land-system change boundary considers the amount of land that remains as undisturbed land (mainly forest) compared to land that has been converted for other uses.

Considering the amount of land that remains undisturbed as forest is an important marker of planetary health because forests can impact and sustain the climate and water cycles within their local regions, and can also have global influence over Earth system processes (Rockström et al. 2009, Steffen et al. 2015).

There are a range of pressures that threaten forest health and distribution including climate change and land clearing for agriculture. The primary driver of forest loss and degradation is agricultural expansion, with large-scale commercial agriculture responsible for 40 per cent of tropical deforestation between 2000 and 2010 (FAO 2020).

At the global scale, the planetary boundary for land-system change has been crossed. That is, the amount of land that has been converted from undisturbed forested land to human use, more specifically to cropland (62 per cent), has gone beyond the point of a safe operating zone into a space where the change will have far-reaching impacts for the earth's biophysical processes. The exact nature of these changes is unknown, so at the global scale we are said to be operating 'within the zone of uncertainty' for land-system change.

A national limit for land-system change in Australia

Australia's varied ecosystems are vital for supporting biodiversity, sustaining ecosystem services, and providing valuable productive, carbon, cultural, recreational and aesthetic benefits.

Australian land systems are under pressure. Forest cover in Australia has decreased from roughly 30 per cent of total land area prior to European colonisation to 17 per cent today. This level of change reflects multiple pressures on land systems which have undergone deforestation by clearing or extensive modification for agricultural, urban or industrial use. On a global list of deforestation hotspots, Australia is the only 'developed' country listed (WWF International 2021).

In this report, a safe threshold for land-system change in Australia is set as keeping disturbance due to human land uses to less than 50 per cent of the ecosystem (land area). If an ecosystem is altered or modified by

more than 50 per cent, it is considered to be an endangered ecosystem in line with the definitions used by the International Union for the Conservation of Nature.

Our analysis assessed that almost half of Australian ecosystems[1] have either crossed (23.75%) or are approaching (21.25%) the threshold beyond which they are considered endangered (Table 1). These ecosystems have primarily been converted to dryland and irrigated agriculture, plantations or other agricultural production from relatively undisturbed environments.

This level of land conversion at the national scale has implications for other markers of environmental health. For example, land clearing contributes to greenhouse gas emissions, impacts on water flows and reduces habitat, contributing to biodiversity loss.

Land-system change and the Australian land use sector

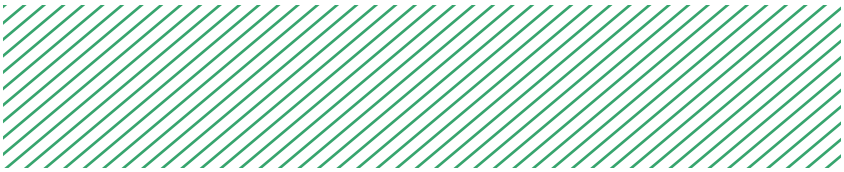
Since colonisation, the land use sector, driven by the broader food system, has played a significant role in the transformation of the Australian landscape and its natural systems, with approximately 49 per cent of Australia's land mass currently in agricultural use. This includes land modified through agricultural land management and relatively natural land use for agriculture, such as extensive grazing.

Looking specifically at the way that agriculture is impacting on land-systems in Australia, this analysis compared the land area converted for agricultural use against a threshold of 15 per cent land use change. This threshold is drawn from the planetary boundaries framework but adapted to apply to all Australian agricultural land rather than only cropland, as used in the global assessments. This was done because agricultural land occupies a more significant portion of Australia than cropland which makes up only four per cent of Australian land use.

Our analysis found that if all land use for agriculture (377 million hectares) is considered against a national threshold for land use change, Australia has transgressed it more than threefold.

This level of land-system change has resulted in cases of degradation, fragmentation and loss of habitats and biodiversity across Australia, and contributed to broader impacts across the other boundaries of climate change, biosphere integrity, biogeochemical flows and freshwater.

Changes to land management practices in Australia can play a significant role in returning to a safe operating space and can contribute to sustainability goals more generally. For example, there are many benefits from investing in nature-based climate solutions such as the protection, conservation and restoration of natural vegetation and systems. These actions have substantial potential to reduce emissions, sequester carbon and benefit from the multitude of co-benefits from ecosystem services. Retaining or restoring vegetation cools the local environment, improves moisture retention in the landscape and prevents loss of soil and nutrients via erosion. This results in increased resilience of landscapes to droughts, floods and bushfires, and promotes biodiversity, all with flow-on benefits to the sustainability of the land use sector.



1 The three ecosystem types usually considered for the land-system change planetary boundary are not dominant ecosystems for the Australian continent. For that reason, our analysis considered disturbance across all vegetation types in Australia to assess the level of ecosystem disturbance.

KEY FINDINGS

- Across various scales and metrics, the Australian land use sector is exceeding the land-system change boundary, largely due to the conversion of key climate-regulating forests to farmland.
- A primary driver of this land use change in Australia is agriculture, with approximately 49 per cent of the continent now used for agriculture.
- The area of land undergoing land use change for agriculture in Australia is more than three times greater than that which is deemed a safe level of land use conversion.
- Almost half of Australia's ecosystems have either crossed or are approaching the threshold beyond which they are considered endangered.

TABLE 1: Number of ecosystems in Australia classified as disturbed beyond the 50% disturbance threshold

INTERNATIONAL UNION FOR CONSERVATION OF NATURE (IUCN) RED LIST CATEGORY	NUMBER OF AUSTRALIAN ECOSYSTEMS
Vulnerable: greater than 50% of ecosystem disturbed	14 (17.5% of ecosystems)
Highly vulnerable: greater than 70% of ecosystem disturbed	2 (2.5% of ecosystems)
Critically endangered: greater than 90% of ecosystem disturbed	3 (3.75% of ecosystems)
Total endangered ecosystems	**19 (23.75% of ecosystems)**
Safe ecosystems	**61**
Total ecosystems	**80**

Biosphere integrity boundary – biodiversity loss and extinction

GLOBAL BOUNDARY:

Transgressed

NATIONAL LIMIT FOR AUSTRALIA:

Transgressed

LAND USE SECTOR:

The land use sector is a key driver of Australia's biodiversity loss and extinction.

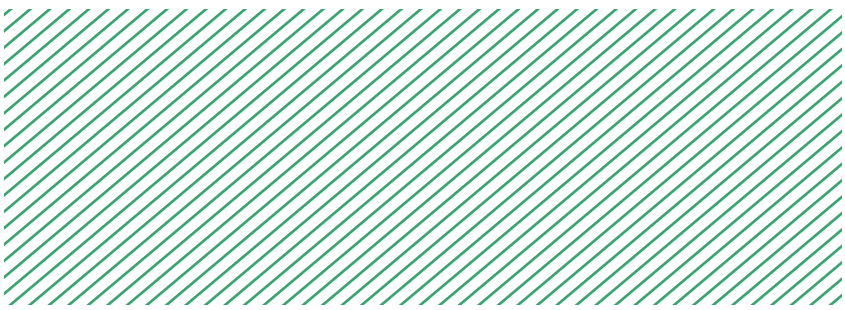
The global biosphere integrity boundary

Biodiversity plays a critical role in underpinning the stability of ecosystems and is an important marker of planetary health. It describes the variety and diversity of all life including ecosystems and genetic diversity. It is important because it provides the natural systems such as healthy soil and clean air that support life on earth.

The global biosphere integrity boundary is one way of measuring the health of species, their genetic diversity and the ecosystems they form. It refers to the limit beyond which biodiversity can no longer support ecosystem processes and resilience (Steffen et al. 2015). The planetary boundaries framework measures two elements of biodiversity to assess biosphere integrity: genetic diversity and functional diversity (biodiversity intactness). See Box 2 for more information on these measures.

On both measures of biosphere integrity, the planetary boundary has been transgressed: the number and abundance of species has declined below a level needed to retain a functioning biosphere and the extinction rate is 10 times higher than that which we would expect without the impact of human activity.

At a global scale, habitat loss is a key driver of biodiversity loss, with deforestation and land use conversion occurring primarily for agricultural use. Agriculture also impacts biodiversity through water extraction and the application of herbicides, fungicides and pesticides. As well as directly contributing to biodiversity loss, the land use sector will also be impacted if the biosphere cannot maintain genetic and functional diversity. Biodiversity loss, such as the loss of pollinators, has serious implications for crop productivity, which also impacts the economic resilience of that sector (Dudley & Alexander 2017).



BOX 2:

Measuring biodiversity at the global scale

Biodiversity can be measured at many different levels including **genetic**, **species**, **community** and **ecosystem**. The planetary boundaries draw on two different measures to assess biosphere integrity, one to determine how human impacts (land and resource use) have affected the number of **species** and individuals found in an area and another to measure **genetic** diversity, which determines the long-term ability of the biosphere to persist and adapt to changes in the environment.

The first measure, biodiversity intactness or functional diversity, assesses the average abundance of species present in an ecosystem relative to what their populations would have been in pre-industrial times. The global average biodiversity intactness value is estimated to be between 74 and 85 per cent. This is significantly below the 90 per cent average set as the safe limit to maintain ecological processes such as pollination and nutrient cycling that are vital to planetary health.

The second measure, genetic diversity, uses the extinction rate to assess genetic variation among organisms, species and populations. A higher level of genetic diversity indicates a healthy system, with greater resilience to environmental changes. The genetic diversity measure assesses how much the extinction rate differs to what might have been expected without the impact of human activities. On this measure, the global boundary for biosphere integrity has also been transgressed. It is estimated that globally we have seen 100 to 1000 extinctions per million species per year, compared to the 10 to 100 extinctions per million species per year that would have been expected without the impact of human activities.

A national limit for biodiversity integrity

Australia is known as a 'mega diverse' country. Over 20,000 species can be found on the continent, many of which are endemic (unique) to Australia. The extensive range and diversity of Australia's environment makes it important at a global scale, with between 7 and 10 per cent of all species living in Australia.

As well as being known for its extensive biodiversity, Australia is also an extinction 'hotspot' with some of the highest extinction rates of any country. It is estimated that 100 endemic species have been recognised as extinct since European colonisation in 1788, which represents 5 to 10 per cent of the world's total extinctions. Unfortunately, this figure is likely to be an underestimate (Woinarski et al. 2019).

To assess the condition of Australia's biodiversity our analysis considered two measures of biodiversity integrity at the national scale: extinction rates (to measure genetic diversity) and biodiversity intactness (to measure functional diversity). Both have been significantly transgressed.

The extinction rates vary for different species (see Table 2 below). Reptiles are estimated to have 12 times the expected extinction rate while Australian mammals are estimated to have 430 times the extinction rate that might have occurred without intensive human activity.

The extinction rates across species are significantly higher than the environmental limit of 10 extinctions per million species per year set in the planetary boundaries framework. This number of threatened species is largely caused by the cumulative impacts of land use and land use change on species abundance and biodiversity integrity, and this has occurred in a relatively short period of time since European colonisation.

We measured biodiversity intactness in the Australian context by assessing to what extent there are suitable climate areas and land use types for different species to occur as the climate (temperature and rainfall) changes. This differs from the method used in the global assessment, which is assessed against the biodiversity intactness index (Box 2)[2].

As the climate has changed over the last 30 years, there has been a four per cent decline in the total area suitable for land-based vertebrate species and a six per cent decline for plant species. It is estimated that 36 per cent of the 1356 vertebrate species and 41 per cent of the 8973 plant species have had areas with a suitable climate reduced by 10 per cent or more. This only considers loss due to climate change so the number of threatened species could be much greater when other pressures, such as land use and land use change, are considered.

Any decline in suitable climate space (from a 1990 baseline) represents a transgression of the national boundary as we have defined it for this analysis. This means that for 36 per cent of assessed vertebrate species and 41 per cent of plant species, Australia has exceeded the safe limit for biodiversity intactness.

TABLE 2: Rate of observed extinctions of Australian plants and vertebrates compared to expected rate

TAXONOMIC GROUP	DESCRIBED SPECIES	EXPECTED EXTINCTIONS, 1990–2022	OBSERVED EXTINCTIONS, 1990–2022	MAGNITUDE GREATER THAN BACKGROUND EXTINCTION RATE*
Plants	20,000	~1.23	38	45 ×
Terrestrial vertebrates	2,667	~0.7	51	78 ×
Amphibians	247	~0.06	4	66 ×
Reptiles	1,065	~0.26	3	12 ×
Birds	740	~0.18	9	51 ×
Mammals	324	~0.08	34	430 ×
Freshwater fishes	349	~0.08	1	12 x

*This number tells us how many times above the expected extinction rate the observed results are.

2 A new method for measuring functional diversity was applied to make this assessment, taking into account the more localised trends in biodiversity integrity that are important to consider in Australia because of the large size and variety of eco-regions (biomes). See forthcoming technical report for more information.

Biodiversity and the Australian land use sector

Land clearing and modification for agricultural, urban and intensive uses, as well as water extraction and exploitation of marine resources, have significantly impacted Australian biodiversity and biosphere integrity by reducing the area suitable for species to inhabit and the condition of the remaining ecosystems.

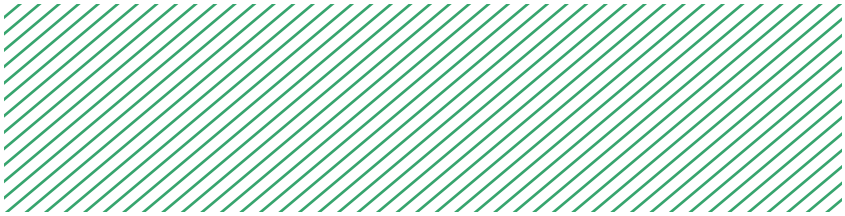
The land use sector is a key driver of biodiversity loss, through the conversion of natural habitats to intensively managed landscapes, the application of chemical fertilisers and the release of pollutants including greenhouse gases. The expansion of agricultural lands to meet demand from growing populations and changing consumption patterns is intensifying the impacts on biodiversity, amplified by impacts from transport, waste management and energy use in the food value chain.

The land use sector is dependent on the stability of ecosystems: biodiversity is critical for the production of food and fibre through processes such as pollination, pest and weed control, provision of fodder and the regulation of soil health (Brandon et al. 2008, Cardinale et al. 2012).

Understanding where species currently live and where they will be able to live in the future has important implications for land management and conservation efforts. Our analysis found that 30 per cent of areas in Australia that could provide suitable habitat for species are currently being used for other forms of land use and land management, greatly reducing the available area for species to inhabit.

Australia has already transgressed both measures of biodiversity integrity at the national scale, and climate change will further reduce the availability of suitable climate space for species. Australia's natural support systems are at breaking point and this pattern will continue if the cumulative impacts of land use and land use change are not addressed.

Despite being a key driver of biodiversity loss, the land use sector has a key role to play in enhancing biodiversity. Changes in land management practices can support and maintain biodiversity despite the perceived competition between demand for land and fibre production and other ecosystem services (Dudley & Alexander 2017). Future reports in the Land Use Futures program will explore the potential of these on-ground solutions that can, among other objectives, support biodiversity.



KEY FINDINGS

+ The global planetary boundary for biodiversity integrity has already been transgressed.
+ The rate at which Australian mammals are becoming extinct is estimated to be 430 times higher than the extinction rate that might have occurred without intensive human activity.
+ Climate change, land use and land use change have greatly reduced the overall available area for species to inhabit, with roughly 30 per cent of areas with suitable climates for species occurring on lands that are currently uninhabitable.

Biogeochemical flows boundary – nitrogen and phosphorus

GLOBAL BOUNDARY:

Transgressed

NATIONAL LIMIT FOR AUSTRALIA:

Transgressed

LAND USE SECTOR:

Land use is significantly contributing to interference in nitrogen and phosphorus cycles in some geographic locations, pushing Australia beyond environmental limits.

Global boundaries for nitrogen and phosphorus

The way that both nitrogen and phosphorus cycles through plants and animals, water, soil and the atmosphere are important planetary processes. Interference with nitrogen and phosphorus cycles occurs mostly in response to the land use sector as it works to increase yields and meet food demands for growing populations. Fertilisers containing nitrogen and phosphorus are applied globally to crops to increase yields, while nitrogen-fixing plants are grown to improve soil nitrogen for use by other plants (FAO 2001). This can cause problematic concentrations of nitrogen and phosphorus to end up in freshwater systems and coastal areas, resulting in a range of impacts including poor water quality for human use, deficiencies of oxygen in the ocean (large-scale anoxic events) and excessive plant and algal growth in freshwater (a consequence of excessive nutrient loads from fertiliser run-off).

Nitrogen also accumulates in land systems generating greenhouse gases such as nitrous oxide (Rockström et al. 2009). Nitrous oxide is nearly 300 times more active as a greenhouse gas than carbon dioxide (Clean Energy Regulator 2021) and agriculture releases about 60 per cent of Australia's nitrous oxide emissions (Department of Industry, Science, Energy and Resources 2021d).

The biogeochemical flows boundary describes the point at which interference with natural nitrogen (N) and phosphorus (P) cycles causes catastrophic environmental impacts. For both nitrogen and phosphorus, the global biogeochemical flows boundaries have been transgressed. In fact, human use of chemical fertilisers alone is considered to significantly exceed the boundary for a safe operating space for biogeochemical flows at the global scale.

The global nitrogen boundary is measured by how much nitrogen is intentionally added to the agricultural system through applying chemical fertiliser and adding nitrogen-fixing crops to the land. The threshold (62 Tg N yr^{-1}) is set to protect water quality and prevent excessive plant and algal growth which results from eutrophication of aquatic systems – that is, creating excessive nutrient richness due to fertiliser run-off. This threshold has been exceeded more than twofold, at ~150 Tg N yr^{-1}.

The phosphorus boundary is set at the global scale (11 Tg P yr^{-1}) to prevent oxygen deficiency in the ocean (large-scale anoxic events) and at the regional scale (6.2 Tg P yr^{-1}) to protect water quality and avoid excessive plant and algal growth in freshwater (eutrophication) through limiting the phosphorus flow from fertilisers to erodible soils. Both thresholds have been significantly transgressed, at approximately 22 Tg P yr^{-1} at the global scale and 14 Tg P yr^{-1} at the regional scale.

A national limit for nitrogen and phosphorus

Chemical fertiliser is widely used in Australian agriculture. In 2016–17, approximately five million tonnes of fertiliser was applied to Australian agricultural soils (ABS 2018). Assessing the impacts of this level of fertiliser use is challenging. Nevertheless, some methodologies have been adapted here to indicate ways in which the Australian land use sector is contributing to the transgression of the biogeochemical planetary boundary.

This report focuses on nitrogen and phosphorus applied as chemical fertiliser to cropland as part of agricultural practices, aligning with the planetary boundaries framework. At the national scale, we assessed the 'exceedance footprint' of both nitrogen and phosphorus (Li et al. 2019) for Australia. Both the nitrogen and phosphorus biogeochemical footprints for Australia exceed an apportioned 'fair share' of the global limits, at per capita footprints of 14.04 kg N yr^{-1} and 5.37 kg P yr^{-1}.

On average, Australia is exceeding our fair share footprint for both nitrogen and phosphorus applied as fertiliser, using 1.5 times more nitrogen and 6 times more phosphorus, even after accounting for trade flows of agricultural commodities to and from international markets.

Nitrogen and phosphorus and Australian land use

While the national limits for nitrogen and phosphorus have been exceeded, the flow-on effects of chemical fertiliser use on the landscape is varied across Australia. At a regional scale, the application of nitrogen and phosphorus as fertilisers is interfering in nitrogen and phosphorus cycles in some geographic locations, impacting the functioning of localised ecosystems.

While the factors influencing water quality are complex and can vary dramatically between different locations, water quality in Australia is generally poorer downstream of areas significantly impacted by human activities such as agriculture. For example, nutrient run-off and sedimentation in Australia has been shown to cause declines in fish populations and seagrass area in bays, increase the risk of eutrophication in estuaries and cause fish die-offs (Logan & Taffs 2013, Clark & Johnston 2016).

To assess how the land use sector is impacting on national nitrogen and phosphorus thresholds, analysis was undertaken at a river region (catchment) scale. This was done by assessing the surplus nitrogen and phosphorus flowing into the environment from cropland and pasture, to calculate the concentration of each at the catchment scale. See the technical report for more information on this methodology. This analysis provides a snapshot of the variability of water system health across Australia and demonstrates that areas under stress overlap with areas of intensive agricultural land use and industry.

Across Australia, 42 per cent of catchments were found to exceed a safe level of nitrogen and 55 per cent to exceed a safe level of phosphorus (Figure 3). Eight of the thirteen catchment areas (or drainage divisions) were found to exceed a safe level of nitrogen and nine to exceed a safe level of phosphorus. These include the Pilbara-Gascoyne and the Murray-Darling Basin, which exceed safe levels for both nitrogen and phosphorus and are both significant agricultural production zones.

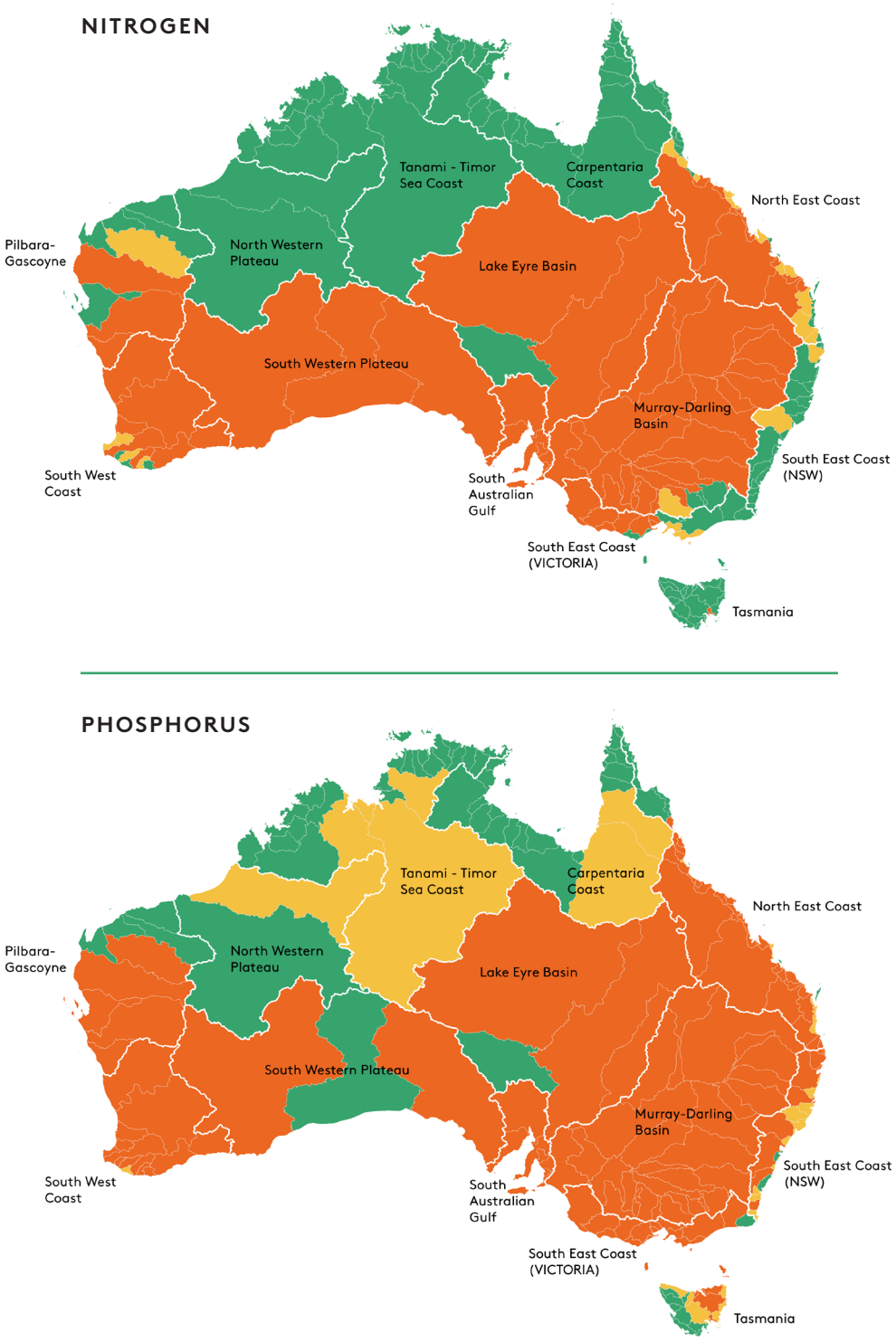
This demonstrates that Australia's nitrogen and phosphorus fertiliser application practices in the land use sector are generating surplus run-off in some key drainage divisions. This run-off has the potential to significantly alter or damage aquatic environments through eutrophication (Smith et al. 1999), and contributes to crossing of the national threshold.

As a key contributor to surplus nitrogen and phosphorus in freshwater ecosystems, the land use sector can play a significant role in addressing the impacts of agricultural run-off on water quality and on other planetary boundaries. For example, improvements in water quality at catchment and river-region scales have flow-on impacts to the biodiversity supported by those freshwater and marine ecosystems. Shifts in management practices that aim to return to a safe operating space at these scales for the biogeochemical boundary are closely linked to the land-system change boundary, with erosion due to land clearing being a strong driver of sediment and nutrient run-off (Clark & Johnston 2016).

KEY FINDINGS

+ Both the nitrogen and phosphorus biogeochemical footprints for Australia exceed an apportioned 'fair share' of the global limit.
+ Australia's nitrogen and phosphorus fertiliser application practices in the land use sector are generating surplus in some key drainage divisions.
+ In Australia, the concentrations of nitrogen and phosphorus exceed a safe level for environmental health in 42 per cent (for nitrogen) and 55 per cent (for phosphorus) of river regions (catchments).

FIGURE 3: Surplus nitrogen and phosphorus in river regions (catchments), Australia.



Orange indicates zones where nitrogen and phosphorus levels exceed the regional boundary limits.

Yellow indicates levels within the zone of uncertainty.

Green indicates within the boundary limits.

Thick white lines represent drainage division boundaries.

Thin white lines represent river region boundaries.

What we can learn from applying the planetary boundaries framework

The planetary boundaries provide a framework for considering sustainable development as it relates to the land use sector in Australia. By linking local actions and the impact of a sector to broader national and global trends, this report shows how local actions contribute to larger environmental issues and consequently, how action to redress these issues can contribute to global sustainability goals.

Systems under pressure

This analysis highlights multiple signs of stress across core environmental variables that have implications not only for Australia but also to wider global efforts to stay within environmental limits. Across the planetary boundaries of climate change, freshwater use, land-system change, biodiversity, and nitrogen and phosphorus cycles, the land use sector plays a significant role in pushing natural systems beyond their safe limits.

At the national scale, this analysis shows that Australia has transgressed limits around biodiversity protection, land-system change, and nitrogen and phosphorus flows. It is approaching national limits for climate change and freshwater use.

The land use sector is a key contributor to these environmental pressures with land clearing, freshwater use, and nitrogen and phosphorus flows corresponding to areas of high intensity and high value agricultural production zones.

Connected systems

While each planetary boundary has its own dynamics, the interactions between systems are also important as human activities in one area can impact other systems. For example, land clearing is responsible for 25 per cent of anthropogenic greenhouse gas emissions in Australia and climate change will further reduce the suitability of climate niches for species, exacerbating biodiversity loss.

The good news is that this relationship can work in reverse: action taken to address one environmental issue can have positive knock-on effects for other boundaries. For example, areas high in biodiversity are also associated with higher carbon storage potential, meaning retaining biodiversity can help mitigate climate change.

Further work in Land Use Futures will more deeply consider how land use decisions influence a range of interrelated factors and what on-ground actions can better support a range of positive environmental outcomes.

Scale matters

Defining environmental limits is complex. As this assessment highlights, it is important to consider environmental impacts at an appropriate scale to guide environmental management decisions. In the freshwater boundary, for example, understanding how much water is being used by Australia as a nation gives us a helpful benchmark about whether we are transgressing our ‘fair share’ of a global resource.

However, the variation of freshwater issues across Australia requires a more specific assessment at a catchment level to inform choices on environmental standards and limits.

This analysis is not intended to set limits and actions. Rather it illustrates the type and scale of impacts from the land use sector, to be used as a guiding framework to help define what sustainability means for the Australian land use sector. Some of the methods can be debated and we welcome dialogue and collaboration with others on how best to advance the science on setting environmental limits that will enable sustainable development without compromising the health of the natural environment.

Broadly, however, we view a sustainable land use sector as one that is operating within the planetary boundaries and contributing to efforts to meet the global Sustainable Development Goals and the Paris Agreement on climate change.

The land use sector can be part of the solution

The planetary boundaries approach provides an understanding of the direct impacts of land use activities on the environment, and also suggests that different practices and actions in this sector can directly contribute to positive environmental impacts.

The land use sector has a critical role to play in reducing emissions and sequestering carbon, along with a wide range of opportunities to enable Australia to stay within Earth system limits nationally and contribute to the global effort for sustainable development. Many solutions to improve human and planetary health can be found in the land use sector, such as waste management, conservation and restoration of natural lands, and shifts in food production.

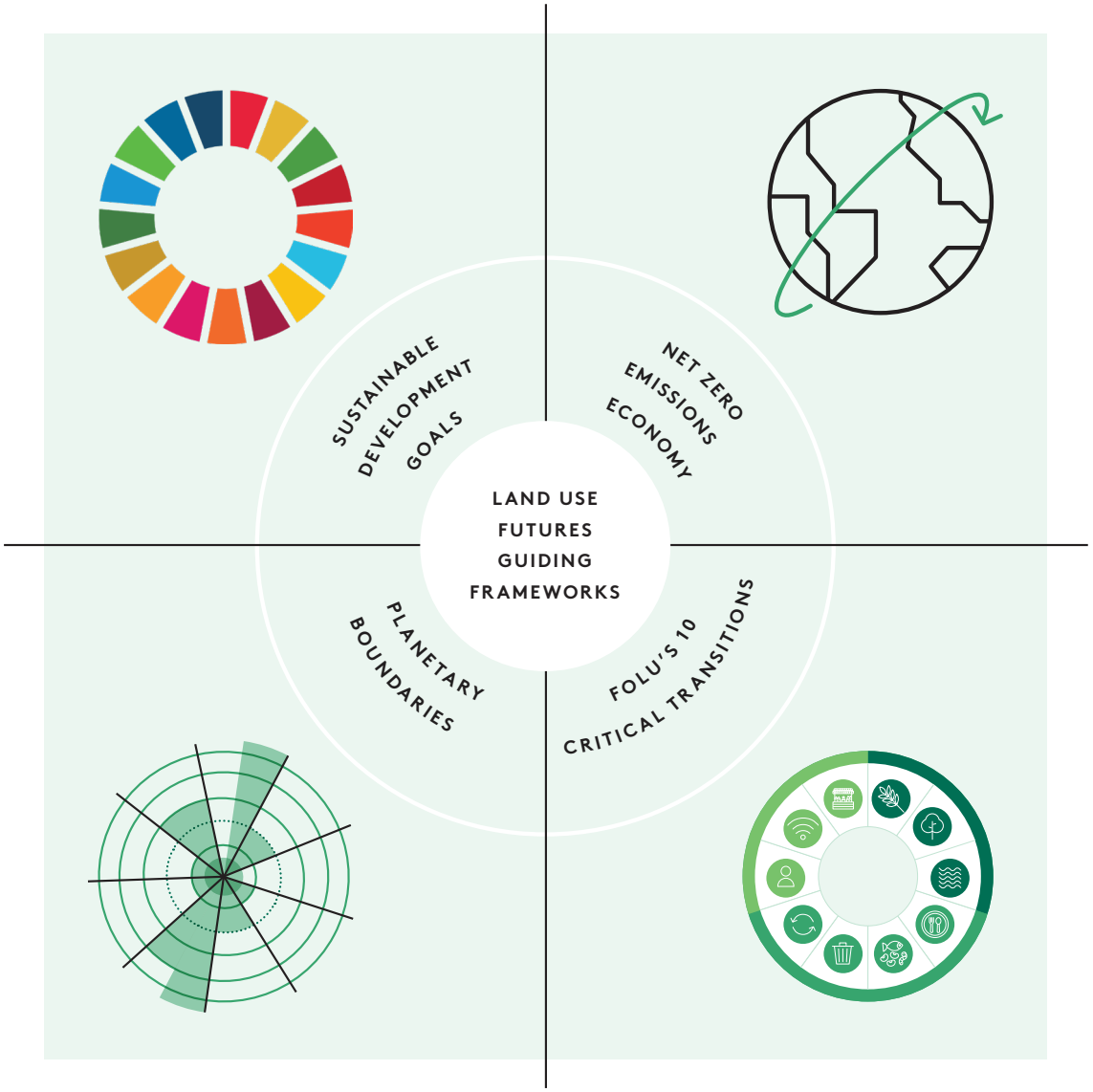
This analysis provides a sense of the size of the challenge and where action is needed. Future work in Land Use Futures will describe and quantify the most impactful solutions available to Australia and its land use sector to reduce emissions and sequester carbon and contribute to broader sustainability goals.

Next steps

The planetary boundaries framework was adapted for the Land Use Futures program to act as a guiding framework in defining what a sustainable land use future means in the Australian context. It will be used alongside other frameworks (see diagram below) as an input to developing pathways that will describe what it will take to reduce emissions and meet other sustainability goals for the Australian land use sector. This includes the global Sustainable Development Goals, global climate change goals and the Food and Land Use Coalition's (FOLU) 10 critical transitions.

The environmental limits described in this report will be used to set environmental objectives in future Land Use Futures modelling and scenario analysis. These analyses will provide insights into the overall potential of the food and land use sector to reduce emissions and sequester carbon, and explore how land use and management practices, adoption of technologies, and market and regulatory mechanisms might be used to achieve a sustainable future.

FRAMEWORKS BEING APPLIED TO THE LAND USE FUTURES PROGRAM OF WORK



Appendix: Summary of national limits for Australia

NATIONAL LIMITS FOR AUSTRALIA			
	LIMIT	**ASSESSMENT**	**RELEVANCE TO AUSTRALIAN LAND USE SECTOR**
Climate change 	2.352 $GtCO_2e$ remaining in Australia's carbon budget to remain within a 1.5 degree trajectory.	Not transgressed, but rapidly approaching the boundary: Australia has 4 to 9 years of emissions remaining to consume the entire carbon budget (i.e. remaining budget consumed by 2026).	Trajectory of land use sector emissions is not on track to support national limit for Australian emissions.
Freshwater use 	13.26 km^3yr^{-1} of freshwater use nationally.	Not transgressed, but approaching the boundary: Australia's freshwater use footprint (based on per-capita consumption within Aus) is 8.99 $km^3\ yr^{-1}$.	Land use contributes to water stress in some geographic locations, driving Australia towards its national freshwater limit. 13 per cent of river regions (catchments) across Australia are under stress from water withdrawal for human activities.
Land-system change 	Ecosystem disturbance due to human land uses less than 50 per cent.	Transgressed: 23.75 per cent of Australia's ecosystems have exceeded the 50 per cent ecosystem disturbance threshold, and a further 21.25 per cent are approaching the threshold.	The land use sector has driven substantial land conversion and is contributing to pressure on Australian land systems. If all land use for agriculture (377 million hectares) is considered against a national threshold for land use change, Australia has transgressed it more than threefold.

CONTINUED

NATIONAL LIMITS FOR AUSTRALIA			
	LIMIT	**ASSESSMENT**	**RELEVANCE TO AUSTRALIAN LAND USE SECTOR**
Biosphere integrity (biodiversity loss and extinction)	Assessment of two measures of the condition of Australia's biodiversity: + Extinction rates: greater than 10 extinctions per million species per year + Biodiversity integrity: any decline in suitable climate space from a 1990 baseline.	Transgressed: The rate at which Australian mammals are becoming extinct is estimated to be 430 times higher than the extinction rate that might have occurred without intensive human activity. It is estimated that 36 per cent of the vertebrate species and 41 per cent of the plant species have lost 10 per cent or more of areas where the climate is suitable for them to inhabit.	The land use sector is a key driver of Australia's biodiversity loss and extinction. Climate change, land use and land use change have greatly reduced the overall available area for species to inhabit, with roughly 30 per cent of suitable areas for species occurring on lands that are uninhabitable.
Bio-geochemical flows (nitrogen and phosphorus)	Exceedance of the national nitrogen (62 Tg N yr^{-1}) and phosphorus (11 Tg P yr^{-1}) biogeochemical footprint, which represents the apportioned 'fair share' of the global limit.	Transgressed: Australia is using 1.5 times more nitrogen and 6 times more phosphorus than our 'fair share' footprint.	Land use is significantly contributing to interference in nitrogen and phosphorus cycles in some geographic locations, pushing Australia beyond its national limit. In Australia, the concentration of nitrogen and phosphorus exceeds a safe level for environmental health in 42 per cent and 55 per cent of river regions (catchments) respectively.

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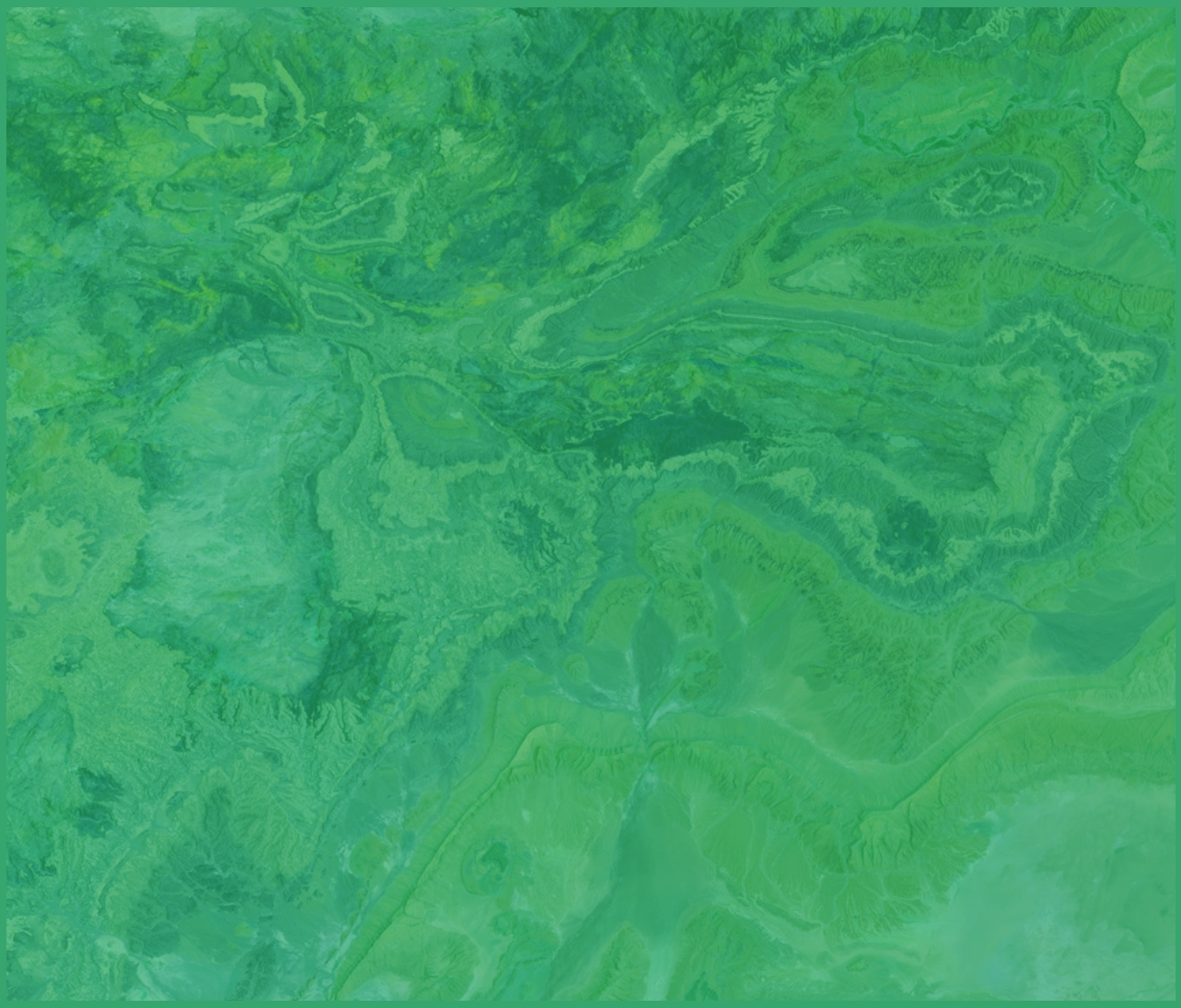

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Published by Climateworks Centre
Melbourne, Victoria, April 2022

This publication can be downloaded at:
www.climateworkscentre.org