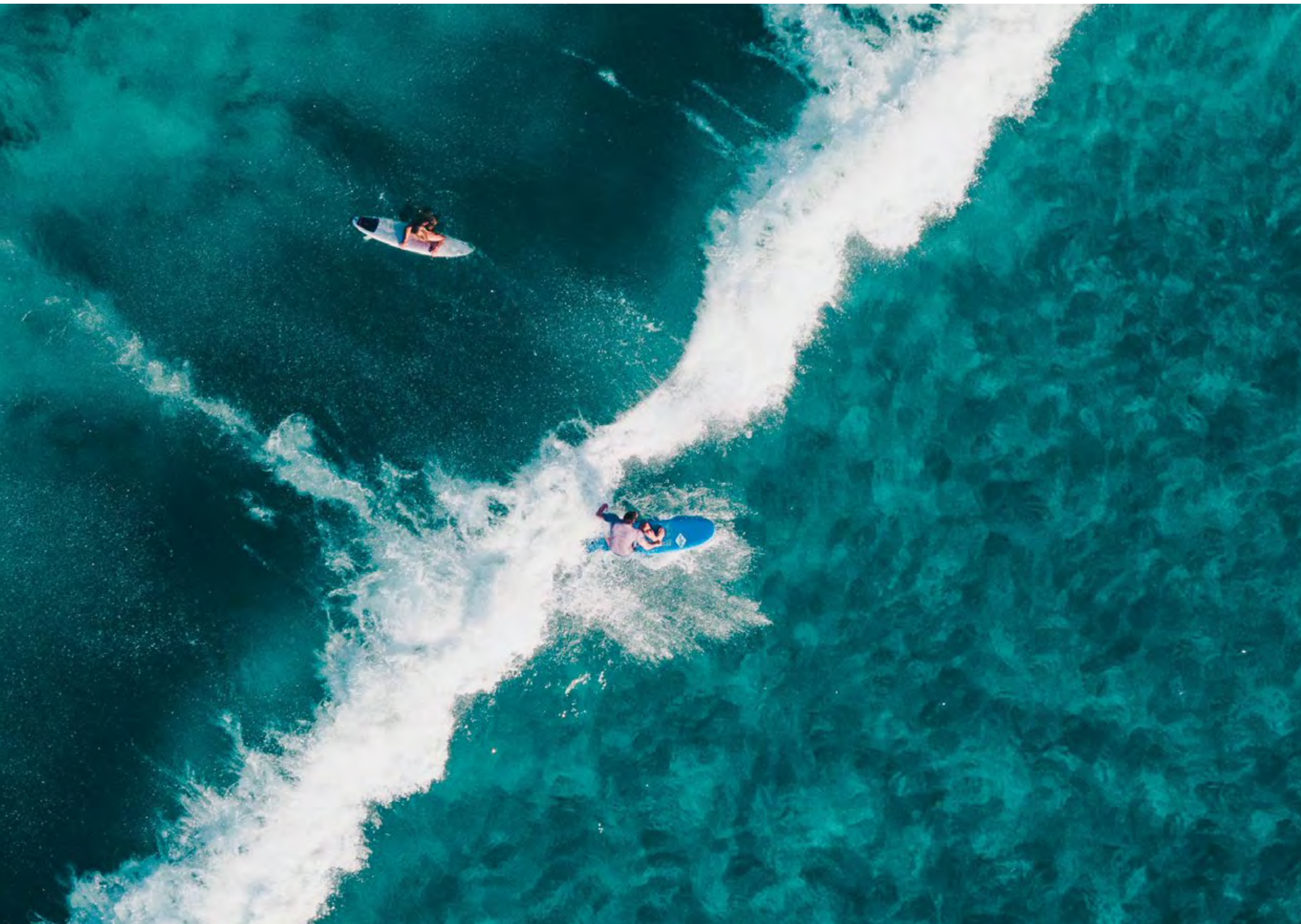
Australian National Outlook 2019

Technical Report

April 2019



Citation

Brinsmead TS, Rendall A, Baynes T, Butler C, Kelly R, Adams PD, Hayward J, Reedman L, Nolan M, Lennox J, Hennessy K, Wynn K, Ahmad ME, Marcos-Martinez R, Collins L, Lu Y, Che N, Qiu J and Kanudia A (2019) Australian National Outlook 2019: Technical report. CSIRO, Australia.

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Acknowledgments

The authors would like to thank Andrew Lenton, Brett Bryan, Cam Fletcher, Guy Barnett, James Giesecke, Janine Dixon, Javier Navarro-Garcia, and in particular Mike Grundy, Paul Graham, Stuart Whitten and David Fleming for their reviews.

In addition, the authors acknowledge and thank Michael Battaglia, Sam Bruce, John Clarke, Helen Cleugh, Simon Ferrier, James Foster, Michael Grose, Lisa Havas, David Newth, Brian Sebastian, Marcus Thatcher, Adrian Ward, and Jim West (CSIRO) as well as Stefan Frank and his colleagues at the International Institute of Applied Systems Analysis, for their input.

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1 Introduction

Author: Maryam Ahmad

In 2015, CSIRO published the results of the first Australian National Outlook (ANO) project (CSIRO, 2015). The project was a 'first of its kind' piece of integrated modelling aimed at a comprehensive exploration of the relationship between the physical economy and natural resource use in Australia. The modelling allowed ground breaking results (Schandl et al., 2015).

Soon after, CSIRO and National Australia Bank (NAB) partnered to create the second phase of the Australian National Outlook, using CSIRO's next generation integrated modelling suite to investigate the issues most pertinent to the future success of Australia's economy. Australia's business community was engaged to highlight the issues most pertinent for the future of Australia's economy. The scope of ANO 2019 was significantly broader than ANO 2015, in that there was a greater focus on economic modelling as well as a consideration of cities, infrastructure, productivity and services.

CSIRO and NAB harnessed the expertise of over 50 senior leaders (the Outlook Members) across 22 of Australia's top corporations, organisations and universities to pair with CSIRO's modelling and qualitative analysis. Outlook Members identified and prioritised a list of issues, which the CSIRO team then translated into scenarios. Once the Outlook Members group approved these scenarios, the CSIRO modelling team then modelled the issues and presented the consequent results to the Outlook Members group. The final step of the process involved the Outlook Members group working together with the CSIRO team to interpret the results into a narrative.

Figure 1.1 shows the timeline of Outlook Member workshops that were held as part of the process described above. Section 2.2 of this report describes the process that was undertaken to convert issues into scenarios. Subsequent workshops with the National Outlook members were run to explore and develop the scenarios in more detail inclusive of modelling results and to discuss interpretations and implications of these results.

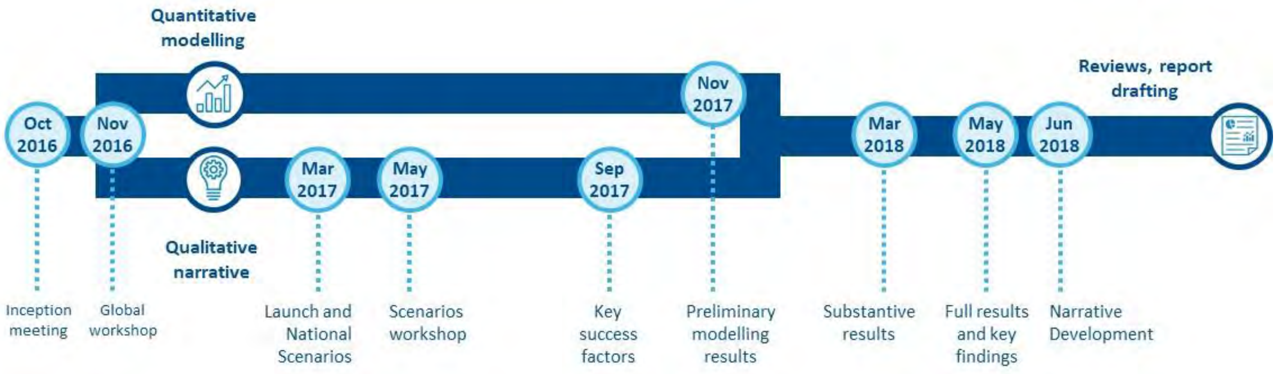


Figure 1.1 National Outlook member workshops held for the Australian National Outlook 2019

A full exploration of results and narrative interpretation can be read in the Australian National Outlook 2019 report (CSIRO and NAB, 2019). This document, the Australian National Outlook 2019 Technical report is a comprehensive peer-reviewed report that documents the technical detail underpinning the narrative report. The Australian National Outlook 2019 report discusses results under two scenarios: *Slow Decline* and *Outlook Vision*. The *Slow Decline* scenario was characterised by Outlook members as Australia drifting and underachieving relative to its potential, with the *Outlook Vision* representing more positive alternative futures. This report goes into further detail by reporting results for the *Outlook Vision* under two different global contexts: *Thriving Australia* under a fractious global context and *Green and Gold* under a more harmonious global context. It should be noted that both scenarios fall under the *Outlook Vision*. Chapter 2 of this report describes these scenarios in further detail.

The issues and results discussed in this project fall within four domains (Figure 1.2): Global context (Chapter 3); Productivity and Services (Chapter 4); Cities and Infrastructure (Chapter 5); and Natural Resources and Energy (Chapters 6 through 8).

The second half of this report describes the integrated modelling suite, including details of how the models connect with each other (Chapter 9) followed by a description of each of the models used in the project (Chapters 10 through 16). See Figure 9.1 for an overview of the models, and Figures 9.2 and 9.3 for an overview of the interactions between the models. The Appendix of this report provides further details about the integration of the models.

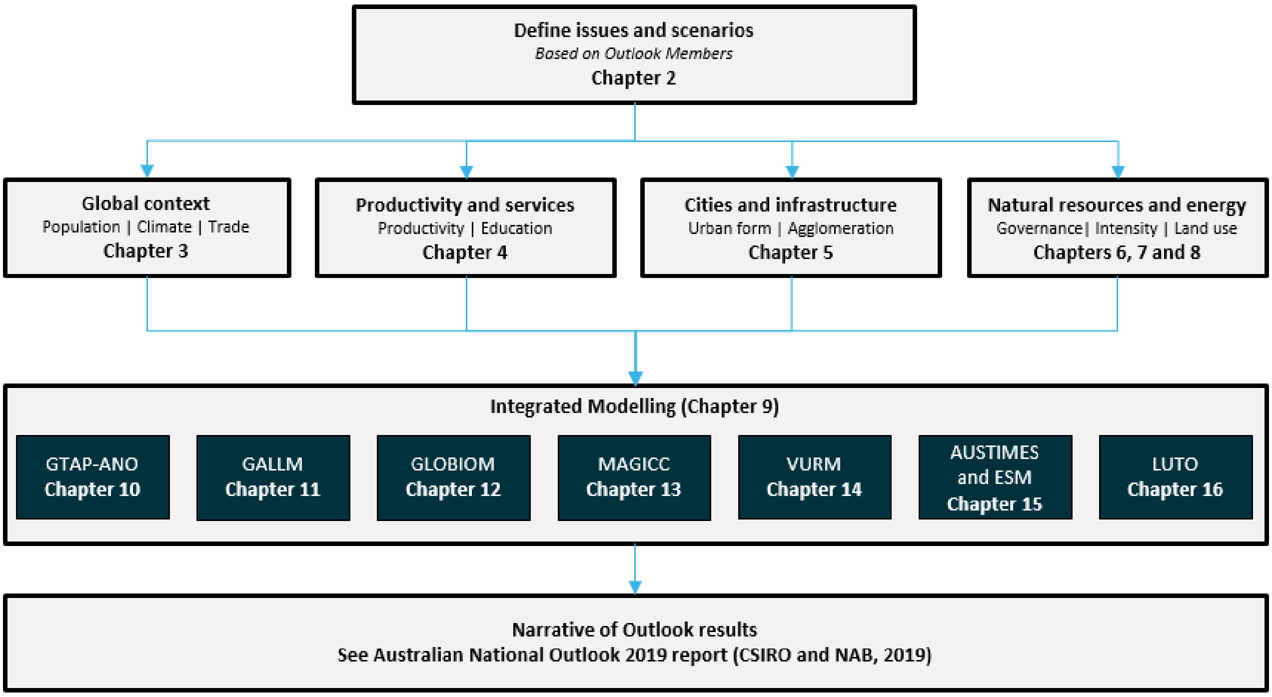


Figure 1.2 Domains and models used in the Australian National Outlook 2019

1.1 References

CSIRO and NAB (2019) Australian National Outlook. CSIRO, Australia.

CSIRO (2015) Australian National Outlook 2015: economic activity, resource use, environmental performance and living standards, 1970–2050. CSIRO, Australia.

Schandl et al. (2015) Australia is ‘free to choose’ economic growth and falling environmental pressures, Nature DOI 10.1038/nature16065.

2 Scenarios

Authors: Thomas Brinsmead and Maryam Ahmad

2.1 Introduction

The core framework for quantitative analysis in both the Australian National Outlook 2015 and the Australian National Outlook 2019 is integrated modelling across multiple key domains, and across multiple future scenario possibilities. Scenarios are a useful antidote to the common human habit of planning for what we perceive as the 'most likely' future, or a future that looks much like the present. They are not predictions of the future, instead they provide evidence-based narratives to help explore the future and the choices we face. More specifically, they help us examine assumptions, explore the implications of uncertain future trends, and can help decision makers recognise, prepare for, and respond more effectively to change (Wilkinson and Kupers, 2013).

Quantitative scenario exploration is a now standard framework (see Shoemaker, 1995 or Van Asselt, 2015; for early descriptions of the Shell scenario methodology exemplified by Shell, 2017; see Schwartz, 1991) used for futures planning, and a methodology in which CSIRO is experienced (CSIRO 2016, CSIRO and Energy Networks Australia, 2017; Graham and Bartley, 2013; Hajkowicz et al., 2012). The Australian National Outlook (ANO) 2019 is a scenario planning investigation and constructive exploration project to examine future possibilities for a selected subset of Australia's circumstances. It was designed to expose alternative possible futures and stimulate public discussion about the choices open to us as a nation. What strategies are required to more reliably realise valuable futures as characterised by the *Outlook Vision*:

- access to high quality of life with even better opportunities for future generations, supported by prosperous and globally competitive industries,
- inclusive and enabling communities, with strong public and civic institutions, and
- sustainable enjoyment of natural endowments?

As a an integration process, the ANO 2019 has comprised a dynamic investigative interaction between the aspirations and concerns for the nation of Outlook members, and analysis-based exploration of what might be achievable given contemporary understanding of biophysical, technological and economic constraints and, to some extent, social constraints. The primary purpose of this technical report is to provide a description of the models, tools and background processes that produced the detailed quantitative analysis underpinning many of the detailed observations and insights based on broader analysis and presented in the companion ANO 2019 summary report (CSIRO and NAB, 2019). Essentially, the ANO 2019 contrasts two alternative plausible national scenarios for Australia in 2060, *Slow Decline* and the *Outlook Vision* (see Figure 2.1). From an integrated modelling perspective these two scenarios are more complex, and developed from multiple scenarios and issues (an issue is an explicitly identified feature of interest, an initially motivating primary subject of analysis) They were developed and refined through an extensive consultative process (as described in the following section) and are based on a combination of quantitative and qualitative future settings.

Note that while the Australian National Outlook 2019 report discusses results under two scenarios: *Slow Decline* and *Outlook Vision*, this report goes into further detail by reporting results for the *Outlook Vision* under two different global contexts: *Thriving Australia* under a fractious global context and *Green and Gold* under a more harmonious global context. It should be noted that both scenarios fall under the *Outlook Vision*. Chapter 2 of this report describes these scenarios in further detail.

This chapter describes those scenarios and how they were developed. Section 2.2 provides a brief description of the consultative process that developed the scenario content and Section 2.3 provides the overall structural framework that characterises a scenario description for quantitative modelling. Sections 2.4 and 2.5 provide additional details of respectively, three selected core scenarios and an additional five 'sensitivity' scenarios. The final Section 0 provides specific quantitative details of how the scenarios are connected to the modelling analysis.

Slow Decline	**Outlook Vision**
In *Slow Decline*, Australia drifts into the future. Economic growth, investment and education outcomes are all relatively weak. Australia's economy is increasingly vulnerable to external shocks. Total factor productivity growth remains well below the global frontier and relatively low wage growth. Australia's cities sprawl outwards, making it more difficult for people in the outer suburbs to access jobs, education and services. Housing affordability remains a major concern. This deepens social divisions and polarisation. Trust in institutions remains low. Although energy policy issues are resolved, the low-emissions energy transition is stymied by a lack of global cooperation on climate change. Both energy and agricultural productivity remain relatively low.	In the Outlook Vision, Australia reaches its full potential. Economic growth remains strong and inclusive as Australian companies use technology to move productivity towards the global frontier and create new globally competitive, export-facing industries. Improved educational outcomes give Australians the skills they need to compete in this technology-enabled workforce. Australia's cities are dynamic and diverse global centres with higher-density populations, a diverse range of affordable housing options and easy access to high-quality jobs, recreation, education and other services. Australia successfully transitions its energy system, with high reliability and affordability and lower emissions. If the world cooperates to limit climate change to 2°C, Australia can go even further and reach 'net zero' emissions by 2050, driven by significant shifts in land use to carbon plantings.

Figure 2.1 Core national scenarios developed in ANO 2019

2.2 Consultative process for setting scenarios

The workflow of the ANO 2019 was directed by a group of over 50 business, industry and academic leaders affiliated with over 24 organisations, corporations and institutions (for a list of Outlook members, see CSIRO and NAB (2019)). Individuals were invited into the group following a protocol to foster diversity within the group – most notably, youth delegates.

This group (the Outlook Members) set the frameworks for an investigation of Australia’s future using CSIRO’s integrated quantitative modelling capability as well as qualitative expert analysis. A crucial component of this – the first step of the work – was setting the scenarios described in this chapter.

Over the life of the project, the Outlook Members group met face-to-face nine times (eight workshops and a project inception event) as detailed in Table 2.1, in addition to other minor meetings. In early workshops, participants prioritised the global and national issues they thought were most important to Australia’s future success. This started with a broad environment scan that initially identified well over 100 issues, and ultimately settled on 13 national issues across three main topical areas. It should be noted that it was not practical to cover every possible issue facing Australia. A number of issues, such as tax policy, are not explicitly included in this report. Furthermore, while climate change mitigation effort (reducing greenhouse gas emissions) have been incorporated in national results, the costs and benefits of adaptation have limited representation and are generally underestimated due to the complexity of the modelling involved. This is not because these topics aren’t important, but because they were either beyond scope of the project or because they have, in some cases, been addressed thoroughly elsewhere. As members joined the Group during the course of the project, not all members had the opportunity to attend every workshop, particularly the earlier ones. From time to time members also attended telephonic briefings and participated in telephonic sessions to make decisions regarding the direction of the work. In the case of scenario setting, members also participated in an online survey.

Table 2.1 List of Outlook Member workshops

DATE	EVENT
6 October 2016	Project inception meeting
30 November 2016	Workshop 1: Global workshop
15 March 2017	Workshop 2: Launch and National Scenarios
10 May 2017	Workshop 3: Scenario workshop
19 September 2017	Workshop 4: Key Success Factors
22 November 2017	Workshop 5: Preliminary modelling results
1 March 2018	Workshop 6: Substantive results
9 May 2018	Workshop 7: Full results and key findings
21 and 22 June 2018	Workshop 8: Narrative Development

While the inception meeting dealt with identifying the scope and focus of the project, the following workshops quickly turned to defining scenarios. During Workshop 1 (November 2016), participants identified seven major global influences for exploration. The influences that were identified included: technology and new business models; demography; geopolitics; climate; inequality, locational disadvantage, social cohesion; access to capital (and technology); education and skills.

The project team processed these influences to define two initial global scenarios and two further optional scenarios that were then circulated to Outlook Members for their feedback. A synthesis of the feedback received was circulated to Members for discussion prior to Workshop 2 (March 2017).

The group agreed to adopt the two initial global scenarios in Workshop 2 and, having explored the global context domain in Workshop 1, went on to identify national issues (including risks and opportunities). This activity occurred with workshop participants grouped into three domains: Productivity and Services, Cities and Infrastructure, and Natural Resources and Energy. An overview of this discussion was then documented and circulated back to the group after the workshop.

There were two additional activities in April 2017, between Workshop 2 and Workshop 3: a meeting to refine national issues and a background presentation on scenarios. The purpose of the meeting was to check and clarify the description of the national issues to ensure that there was consensus among the group. The team then proceeded to translate these issues into the national scenarios.

The background presentation on the development and use of scenarios was led by Shell and delivered by Jeremy Bentham (Vice President, Global business Environment, Shell International). This proved to be popular with Outlook Members as it helped contextualise the use of scenario planning and its power as a decision-making technique.

The purpose of Workshop 3 (May 2017) was to present the progress made on the national scenarios to the Outlook Members and spark a discussion regarding their suitability.

There were two telephonic sessions following Workshop 3: one on the 24 of May to discuss the Zero Draft Broad Vision for Australia (an overarching statement of the group's shared vision) and one on the 5 of June to discuss the proposed national scenarios. Complete proposed scenario descriptions were then circulated to the group on the 21 of June followed by an online survey to give members an opportunity to vote on these proposed scenarios. Members were able to vote one of three ways: (i) Yes, I support, (ii) Yes, I support, with the exception of the comments provided immediately below, and (iii) No, I do not support.

The feedback received via the survey was then used to finalise the scenarios. The finalised global and national scenario descriptions were then circulated back to the members on the 10 of July and the project team shifted their focus to quantitative and qualitative analysis.

The following section outlines the structure of the scenarios, the underlying issues used to construct the scenarios, and the process used to parameterise and translate those issues for modelling and analysis.

2.3 Scenario structure

For scenario analysis in ANO 2019, three distinct core scenarios were defined.A *Slow Decline* scenario is characterised by the outlook members with Australia drifting and underachieving relative to its potential with settings similar to those existing today.Two other scenarios with generally enhanced settings were defined, a *Thriving Australia* scenario albeit with a more fractious global context and a *Green and Gold* scenario under a more cooperative global context. In ANO 2019 (CSIRO and NAB 2019) the *Thriving Australia* and *Green and Gold* scenarios are referred to collectively as the *Outlook Vision*.

The scenarios are structured across four main domains: the Global Context, Productivity and Services; Cities and Infrastructure and Natural Resources and Energy. They were used to help focus and structure participant engagement and cover both global and national cross-cutting issues, as well as interactions within and between each domain. The issues covered within these domains are seen in Figure 2.2. The categorisation of issues of concern into domains is pragmatically motivated and supports intellectual division of labour. In practice, a single domain addresses issues that are more closely related. Ideally, domains are defined such that significant interactions among them are less complex than those within them.

Each of the issues are further explored through specific settings, and it is the unique combination of the settings for each issue that make up a scenario. For example, the Agricultural Productivity issue within Natural Resources and Energy domain is explored using two settings: one where agricultural productivity is consistent with recent historical trends (‘recent trend’) and another where productivity is higher than the historical trend (‘improved’). For the core scenarios, *Slow Decline* considers a ‘recent trend’ setting, whereas *Thriving Australia* and *Green and Gold* both consider the ‘improved’ setting. The mapping of issues and settings can be seen in Figure 2.3 and a qualitative summary of each setting can be seen in the next section (Scenario Structure: Elements, Section 2.4).

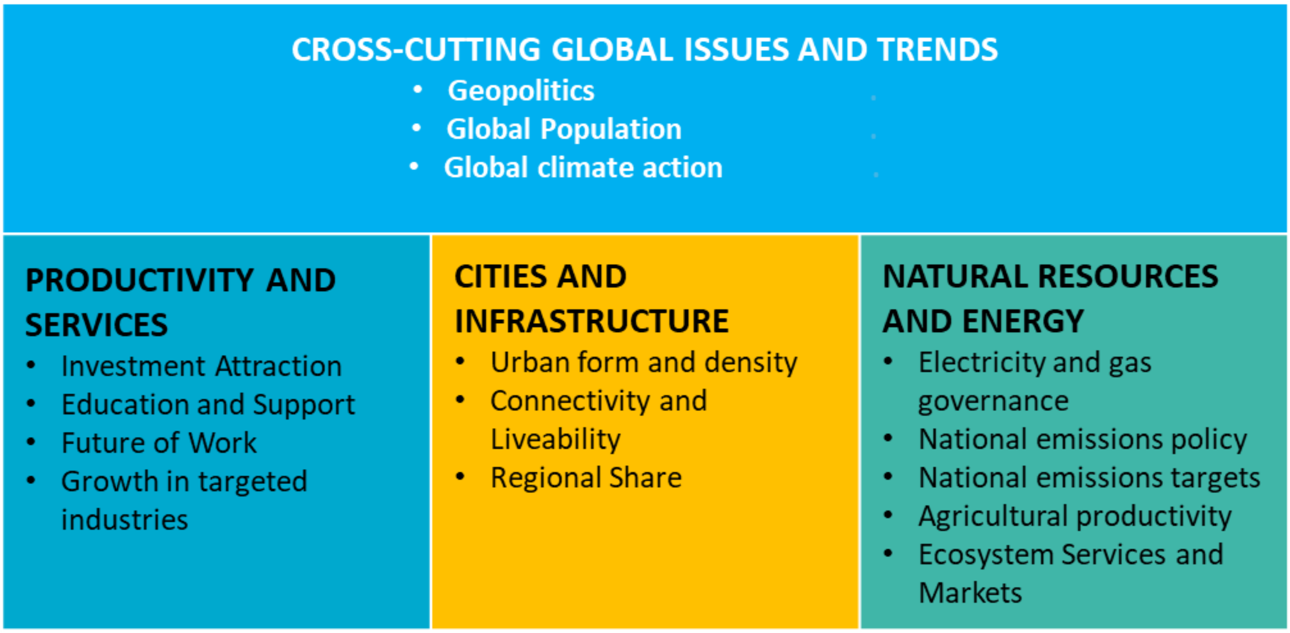
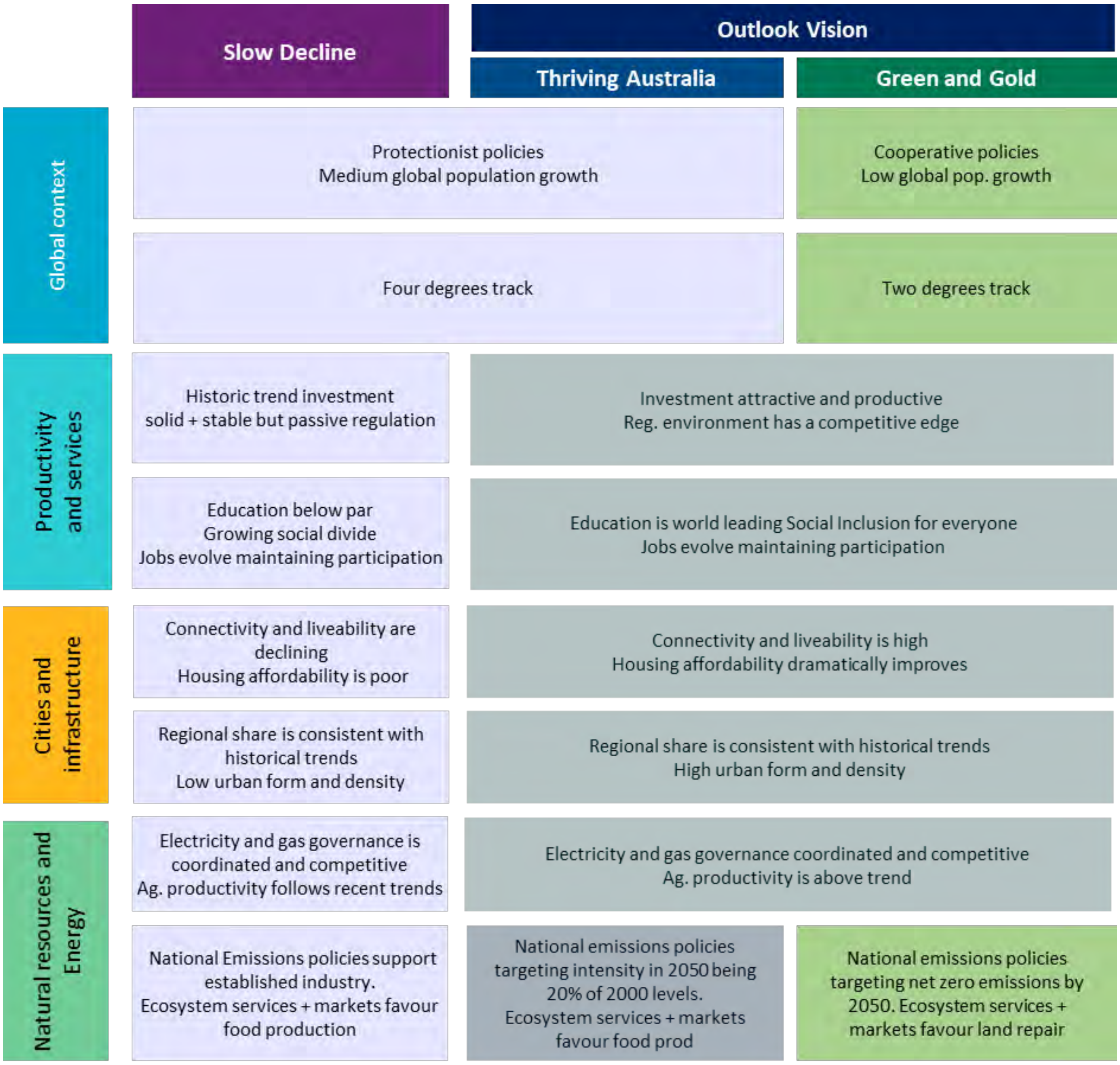


Figure 2.2 Domains (broad categories to classify issues) and issues (feature of interest or concern, see text)

In addition to the three core scenarios analysed, additional selected “sensitivity case” scenarios were also constructed, in order to evaluate the significance of a small number of critically important modelling assumptions. These “sensitivity case” scenarios are each similar to one of the core scenarios, with identical assumptions on all but a few settings of particular interest. When comparing between core scenarios it is typically difficult to identify which particular differences in assumptions are responsible for different outcomes; the “sensitivity case” scenarios allow the impacts of the selected assumptions to be isolated, by comparing results to the corresponding core scenario. The sensitivity scenarios are described below after the core scenarios.



<table>
<tr><th rowspan="2"></th><th rowspan="2">Slow Decline</th><th colspan="2">Outlook Vision</th></tr>
<tr><th>Thriving Australia</th><th>Green and Gold</th></tr>
<tr><td rowspan="2">Global context</td><td colspan="2">Protectionist policies
Medium global population growth</td><td>Cooperative policies
Low global pop. growth</td></tr>
<tr><td colspan="2">Four degrees track</td><td>Two degrees track</td></tr>
<tr><td rowspan="2">Productivity and services</td><td>Historic trend investment
solid + stable but passive regulation</td><td colspan="2">Investment attractive and productive
Reg. environment has a competitive edge</td></tr>
<tr><td>Education below par
Growing social divide
Jobs evolve maintaining participation</td><td colspan="2">Education is world leading Social Inclusion for everyone
Jobs evolve maintaining participation</td></tr>
<tr><td rowspan="2">Cities and infrastructure</td><td>Connectivity and liveability are declining
Housing affordability is poor</td><td colspan="2">Connectivity and liveability is high
Housing affordability dramatically improves</td></tr>
<tr><td>Regional share is consistent with historical trends
Low urban form and density</td><td colspan="2">Regional share is consistent with historical trends
High urban form and density</td></tr>
<tr><td rowspan="2">Natural resources and Energy</td><td>Electricity and gas governance is coordinated and competitive
Ag. productivity follows recent trends</td><td colspan="2">Electricity and gas governance coordinated and competitive
Ag. productivity is above trend</td></tr>
<tr><td>National Emissions policies support established industry.
Ecosystem services + markets favour food production</td><td>National emissions policies targeting intensity in 2050 being 20% of 2000 levels.
Ecosystem services + markets favour food prod</td><td>National emissions policies targeting net zero emissions by 2050. Ecosystem services + markets favour land repair</td></tr>
</table>

Figure 2.3 Mapping Issues to Scenarios

Scenario construction (as opposed to scenario analysis) involves the identification of particularly influential assumptions about future conditions, from which other consequences of relevance may be derived by logical analysis. In general, a scenario definition can be characterised as a collection of scenario elements that are essentially causally independent (either in principle or in practice), each comprising the identification of some significant aspect of the future and a characterisation of the condition or state of that aspect. While the condition or state of each aspect is specified for any given scenario definition there is, in principle, a counterfactual possibility that it might be different. Particular scenarios of interest are those that are intended to showcase groupings of outcomes that are, in the judgement of the members, more likely to co-exist, or have mutually reinforcing elements. It is from these more coherent scenarios, that “core” and “sensitivity” scenarios are selected for detailed modelling analysis.

There are in principle any number of future possibilities that could be used as a basis for the construction of potentially insightful scenarios. It is a challenge to find a set of useful particular scenarios from this enormous range of possibilities. In practice, the ANO processes reduced this range by developing a broad “scenario space” from which to select particular scenario definitions.

A process of successive refinement narrowed the scenario space in order to make the scenario selection and definition decision process more tractable.

2.4 Scenario Structure: Elements

The following section provides a summary of the issues across the four domains, as well as a qualitative description for each issue settings adopted for the three core scenarios, for those issues that are explored with different settings in the modelling suite, either across three core scenarios or additional sensitivity scenarios. This is summarised in Table 2.2. Note that the setting of some issues, such as Education and Support and Future of Work is identical across the three core scenarios; alternative settings may be instead explored as a sensitivity (see Section 2.5). Note also that some issues were addressed either only as quantitative modelling results rather than model assumptions, or not represented in the modelling suite at at all and so addressed by ANO 2019 qualitatively only. These issues do not appear in Table 2.2 (or later in Table 2.7). However, as part of the scenario construction process, though they were associated with qualitatively distinct settings, and their descriptions as included domain by domain in tables in following Sections 2.4.1-0.

Table 2.2 Core scenario definitions

ISSUE	*SLOW DECLINE*	*OUTLOOK VISION*	
		THRIVING AUSTRALIA	*GREEN AND GOLD*
Geopolitics	Protectionist	Protectionist	Cooperative
Population	Central projection	Central Projection	Lower Growth
Climate Action	Four Degrees Track	Four Degrees Track	Two Degrees Track
Investment Attraction	Historical Trends	Strong	Strong
Education and Support	World Leading	World Leading	World Leading
Future of Work	Jobs Evolve	Jobs Evolve	Jobs Evolve
Growth in targeted industries (Boosts)	Low growth	Strong growth	Strong growth
Urban Form and Density	Low Density	High Density	High Density
Connectivity & Liveability	Declining connectivity	High connectivity	High connectivity
Regional Share	Trend	Trend	Trend
Electricity and Gas Governance	Coordinated and Competitive	Coordinated and Competitive	Coordinated and Competitive
National Emissions Policy	Support established industries	Low carbon transition	Low carbon transition
National Emissions Targets	*Slow Decline* targets	*Thriving Australia* targets	*Green and Gold* targets
Agricultural Productivity	Trend	Improved	Improved
Ecosystem Services & Markets	Favour Food Production	Favour Food Production	Landscape repair

2.4.1 Global Context

The Global Context domain explores four issues. Unlike the other three domains, all issues were grouped under one of two contexts: a factious global context and a more cooperative global context.

In qualitative terms, the fractious global context called *Nation First* explored a world that drifts toward protectionism. Under this context, barriers to freetrade remain in place, global average income growth is weak and climate policy is ineffectual, putting the world on track to a 4°C rise by 2100 (see Section 3.4.2.3 in Chapter 3 for more details). At the same time, population grows in line with central estimates, with continuing strong growth in demand for global minerals. The cooperative global context called *Working Together* explores a world where improvements in trade and macroeconomic reform results in stronger global economic growth, including in high income countries. Climate action puts the world on track to 2°C or lower by 2100 and population growth is at low end of projections, resulting in slower growth in construction and an earlier peak in global minerals demand. Table 2.3 outlines the specific issues and settings used for these two global contexts. Note that not all settings are associated with alternative modelling input assumptions. Some, such as Global Minerals Demand, are interpreted as a result from the modelling suite rather than a scenario assumption setting. Others, such as 'regulatory environment' or 'social inclusion' in the Productivity and Services domain (see Table 2.4), are not differentiated across scenarios in the modelling, but addressed only qualitatively – details of whether and how each issue is addressed in the quantitative modelling can be found in Section 0.

Table 2.3 Settings under each issue for the *Nation First* and *Working Together* global contexts

Issue	Setting	
	Nation First (Factious global context)	***Working Together*** (Cooperative global context)
Geopolitics	**Protectionist**. Nationalism and protectionist rhetoric stall trade liberalisation and economic cooperation. Weak economic growth in high income countries [to 2030] results in below trend growth in average global incomes.	**Cooperative**. Improved cooperation across G20 nations reduces trade barriers and promotes effective macroeconomic management, with a return to stronger [above trend] per capita economic growth in high income countries as well as the BRIIC economies.
Population	**Central projection**. Population grows in line with central estimates, increasing by 36% from 2010 to 9.4 billion in 2060, with a 19% increase in Asia.	**Lower growth**. Population growth is at the low end of official projections, increasing 22% from 2010 to 8.4 billion in 2060, with a 5% increase in Asia.
Global Minerals Demand	**Grows strongly**. Rising population and incomes see continuing strong demand for metals, construction materials, and other minerals products, particularly in Asia.	**Peaks early**. A more rapid demographic transition and slower population growth in Asia, and around the world, sees slower growth in construction and associated demand for metals and minerals.
Global Climate Action	**Four degrees track**. Paris climate commitments are met to 2030, but the pledge and review process fails to deliver action to 2050 consistent with 2°C, instead putting the world on track to 4°C by 2100.	**Two degrees track**. Paris climate commitments are met or exceeded to 2030, with accelerating action by all major nations putting the world on track to no more than 2°C, or lower if 'negative emissions' technologies are deployed after 2060.

2.4.2 Productivity and Services

The Productivity and Services domain explores five issues. While all feature in the three national scenarios, the Future of Work issue is held constant across all three core national scenarios using the 'jobs evolve' setting. The related 'automation destroys jobs' Future of Work setting, has been captured within a scenario sensitivity (see Section 2.5). The Regulatory Environment issue was not addressed in within the modelling suite, although a favourable regulatory environment could be regarded as a factor that enhances investment attraction and encourages the likelihood of the 'strong' Investment Attraction setting. Social Inclusion is also addressed quantitatively in only a limited fashion in ANO 2019, though see Chapter 4 for some qualitative discussion.

Table 2.4 Settings under each issue covered by Productivity and Services

Issue	Setting	
Investment Attraction	**Historical trends.** Investment and productivity continue in line with recent decades. Capital available for productive investment remains constrained, and household investment continues to emphasise real estate. Australia continues to attract and retain global talent that complements the domestic workforce.	**Strong.** Improved business performance and other changes see Australia attract more foreign and domestic institutional investment. Productivity increases relative to existing trends. Household investment shifts from real estate to more productive assets. Australia continues to attract and retain global talent that complements the domestic workforce.
Regulatory Environment	**Solid and stable, but passive**. Regulation is stable, but often imposes unwarranted costs, stifles innovation, and favours incumbent industries and enterprises. Base case public expenditure on services reflects the impacts of population ageing.	**Competitive edge**. Regulation shifts to a collaborative partnership approach with industry that promotes innovation and competitiveness, and gives specific attention to achieving desired policy outcomes as effectively as possible. This actively supports entrepreneurs and business to grow enterprises and industries serving global markets. Public expenditure on services meets or exceeds base case levels.
Education and Support	**Below par.** Australian education outcomes remain mediocre relative to OECD standards, with a corresponding low growth trend in labour productivity. Meanwhile, education and productivity in Asian neighbours continues to improve.	**World leading.** Australia invests in early year policies, education and training, transition to work, and re-skilling and redeployment to meet evolving needs. [Australian outcomes are in the top 25% of OECD nations.] This greatly improves skills and participation outcomes, and significantly reduces inequality and multiple forms of disadvantage. Inequality falls, labour productivity to 2030 increases substantially faster than the long term trend.
Social Inclusion	**Growing divides.** Disadvantage, poverty and inequality become further entrenched. Market incomes diverge. Access to quality health and social services is restricted for those on lower incomes. Australian social, geographic, and intergenerational stratification increases. Social divisions deepen and politics becomes more polarised.	**Everyone is included.** Disadvantage, poverty and inequality decline. Strong investments in health and early childhood, and adequate and appropriate transfers, help to break intergenerational disadvantage and give all Australians a real chance to thrive. Social cohesion and mobility improves, with broad participation in civic life.
Future of Work	**Automation destroys jobs.** Technology displaces existing jobs faster than new jobs can be created and filled. Effective participation falls substantially, reflecting both underemployment and structural unemployment.	**Jobs evolve.** Participation is stable, as technology drives shifts across sectors and skills. Employment trends continue, with a gradual decline in average weekly hours as part-time work increases.

2.4.3 Cities and Infrastructure

The Cities and Infrastructure domain explores five issues. For all scenarios, population was held constant. The Regional Share setting is held constant across all three core national scenarios using the 'trend' setting. The related 'shift to regions' setting has been captured within a scenario sensitivity (see Section 2.5). Housing Affordability was not addressed within the modelling suite, though there is some discussion in Chapter 5.

Table 2.5 Settings taken for each issue under Cities and Infrastructure

Issue	Setting	
Population	Australia’s population increases by 72% to 2060, to reach 41 million people, driven by net inward migration of 240,000 people per year. People aged 65 and over rise from 15% to 25% of the population. Consumption patterns are consistent with ageing of the population, particularly for health and related services.	
Regional Share	**Trend.** The distribution across cities and towns is consistent with historical trends (and ABS projections). Australia’s four largest cities grow 95% to house 27 million people by 2060, lifting their share of total population from 58% to 66%. In 2060, Melbourne and Sydney are each home to 8 million, while Perth and Brisbane are 5 million – similar to Sydney and Melbourne today. Outside the major cities, population grows by only 40%, with population and services consolidating into cities and larger towns as and smaller towns shrink.	**Shift to regions.** In contrast to historical trends, by 2060 the population living outside Australia’s major cities doubles to 20 million, around six million more than current projections. A game-changing shift sees Australia create 10-12 new mid-size cities, each housing 250,000 to 350,000 people, offering access to greenspace and recreation opportunities that are not available in the major cities. The major city population increases by only 52% to 21 million, and their share of total population falls from 58% to 51%.
Urban Form and Density	**Low density.** The area of major cities continues to expand, increasing by more than 60% as population increases 95%, with resulting modest increase in overall density to accommodate increased population. Neighbourhood design reinforces use of private vehicles, contributing to poor health (such as obesity) and social isolation.	**High density.** Population growth is accommodated with little or no increase in area. Cities create world-class high-density precincts, rather than a uniform population spread. In *metro style*, the density of major cities increases by 80-90%, while in *stronger regions* density increases by 40-45% by 2060. Neighbourhood design encourages walking and active transport, contributing to improve health and stronger social capital and networks.
Connectivity and Liveability	**Declining.** Urban expansion is poorly managed, with increased travel times and congestion, and lower economic productivity. Regional population consolidates into regional centres. Connectivity declines both within and between cities and towns.	**High.** Effective planning, investment and engagement deliver ’30 minute cities’ offering an attractive mix of jobs, services and recreation. Cities and regions are complementary and well-connected, helping businesses and research institutions compete for global talent.
Housing Affordability	**Poor:** Market settings continue to favour housing over other forms of investment. Housing remains unaffordable and high cost high relative to other countries.	**Improves dramatically:** Market and institutional settings change to favour other forms of investment over housing, so that dwelling prices and rental costs rise more slowly than wages.

2.4.4 Natural Resources and Energy

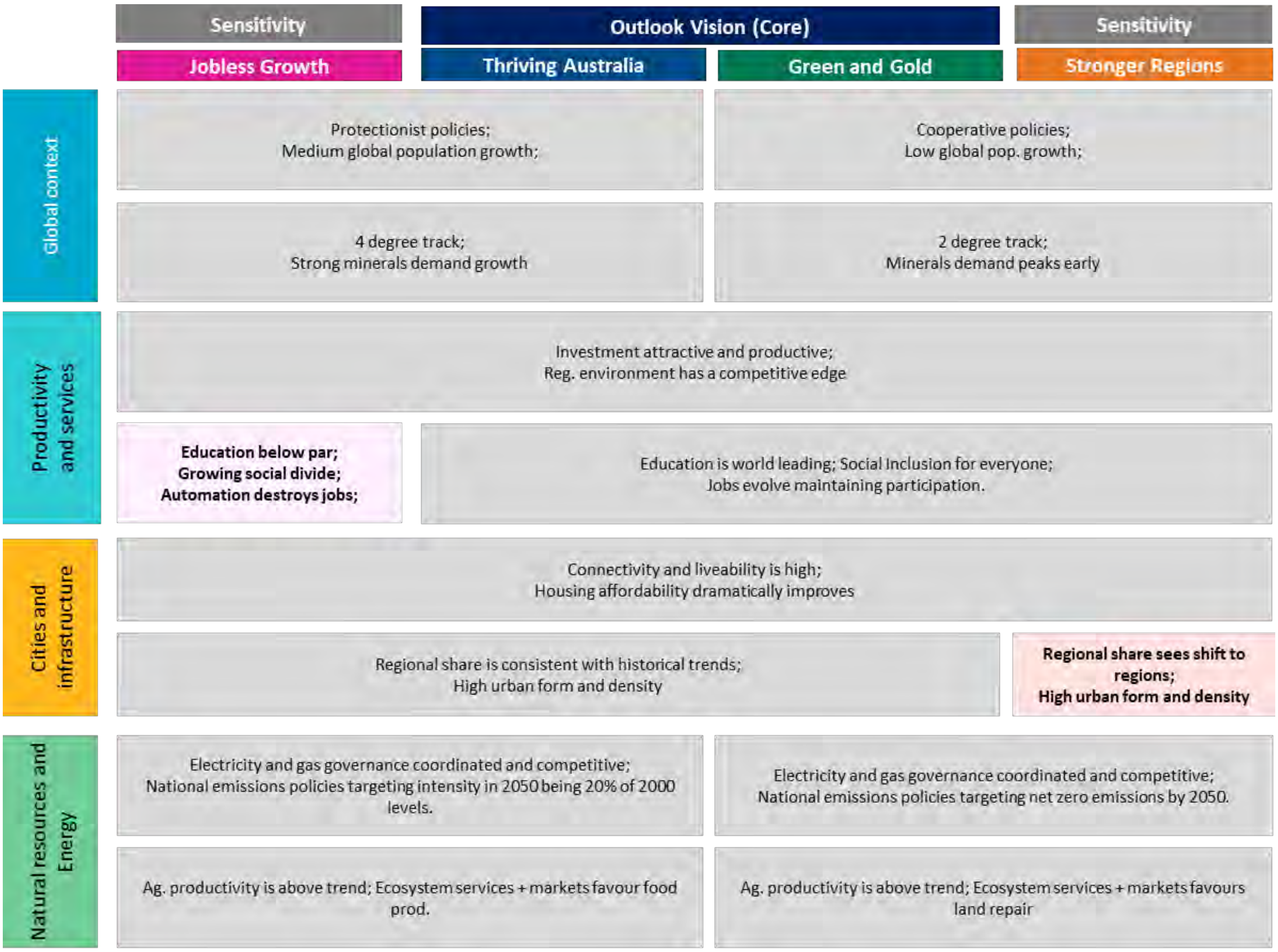
Table 2.6 Settings taken for each issue under Natural Resources and Energy

Issue	*Setting*		
Electricity and Gas Governance	**Improved but uncertain.** Uncertainty about electricity policy settings continues to 2030, making it difficult to secure private investment in new capacity. *Ad hoc* government actions address energy security and reliability, but poor coordination and low investor confidence increase costs and prices. Uptake of electric vehicles is relatively slow. Domestic gas prices increase to parity with global prices by 2025.	**Coordinated and competitive.** Collaborative policies transform the electricity system. Settings evolve in an orderly way, ensuring investor confidence and delivering clean, affordable and reliable energy, along with improved demand management and more efficient network utilisation. Key electricity sector policies include a Clean Energy Target (CET) from 2020 to 2035, and the introduction of more comprehensive emissions reduction incentives and policies no later than 2030. For new capacity, investor confidence is higher (and thus risk premiums are lower) where national emissions policies support low carbon transition. Electric vehicles account for 40% of private road transport by 2050 and improve electricity network efficiency. [Well-coordinated policy delivers globally competitive gas and electricity prices for energy intensive industries, across all global contexts.]	
National Emission Policies	**Support established industries.** Policy supports established industries, including through taxpayers bearing some or all of the cost of achieving emissions reductions. In some cases Australian greenhouse gas emissions reduction targets are less stringent than other high income nations.	**Low carbon transition.** Policy supports emission reductions across the economy. While transitional assistance is provided, producers and consumers bear the cost of achieving emissions reductions. Policies include stronger and more ambitious support for energy efficiency, particularly for building and vehicles. Australian greenhouse gas emissions reduction targets are calibrated to global action.	
National Emissions	***Slow decline* targets** Australian emissions intensity is reduced to 40% of 2000 levels by 2050.	***Thriving Australia* targets** Australian emissions intensity is reduced to 20% of 2000 levels by 2050.	***Green and Gold* targets** Australian emissions intensity is reduced to net-zero by 2050.
Agricultural Productivity	**Recent trend.** Agricultural productivity (value and output volume per hectare) is consistent with historical trends.	**Improved.** Agricultural productivity is higher than historical trend, supported by whole-of-sector innovation and targeting new high-value market niches.	
Ecosystem Services and Markets	**Declining condition.** (not modelled) Farm management and institutional settings see continuing declines in the condition and resilience of 'public good' natural assets, including ecosystems and biodiversity, river health, and soils in some locations. Policy settings do not provide incentives for carbon sequestration or re-establishing native habitat through land sector plantings. The timing and extent of implications for the resilience and productivity of agricultural systems are unclear.	**Favour food production.** Farm management and institutional settings maintain production values, while the condition and resilience of 'public good' natural assets continues to decline (including ecosystems and biodiversity, river health, and soils in some locations). This sets the stage for Australia strengthening its reputation for healthy and well-regulated food in key export markets – but not to establish a national reputation as a sustainable and environmentally friendly producer.	**Landscape repair.** Farm management and institutional settings support repair of past degradation of landscapes, improving the condition and resilience of ecosystems and biodiversity, river health, and soils. This sets the stage for Australia strengthening its reputation for sustainable and healthy food in key export markets.

The Natural Resources and Energy domain explores five issues. The targets for the National Emissions issue arise from the interactions between the Electricity and Gas Governance and National Emissions Policies issues (below) and the Global Context domain (see 1.3.1). Each of the three core national scenarios has its own National Emissions setting, the name of the setting taken from the national scenario name. Each of the five issues in this domain was able to be represented with quantitatively distinct settings in the ANO 2019 modelling suite.

2.5 Scenario sensitivities

A traditional approach to scenario planning often considers numerous combinations of issue settings across a range of extremes. While this approach facilitates the development of diverse scenarios and multiple pathways (a critical element of scenario planning), it can fail plausibility and can oversimplify the complex relationships between events; unless effort is made to ensure that the issue settings are mutually consistent. Given this and the breadth of the issues identified within the ANO, we did not apply this approach across the three national scenarios. However, to incorporate additional divergent thinking into the process, two scenario sensitivities were considered: *Jobless Growth* and *Stronger Regions*.



<table>
<tr><th></th><th>Sensitivity</th><th colspan="2">Outlook Vision (Core)</th><th>Sensitivity</th></tr>
<tr><th></th><th>Jobless Growth</th><th>Thriving Australia</th><th>Green and Gold</th><th>Stronger Regions</th></tr>
<tr><td rowspan="2">Global context</td><td colspan="2">Protectionist policies;
Medium global population growth;</td><td colspan="2">Cooperative policies;
Low global pop. growth;</td></tr>
<tr><td colspan="2">4 degree track;
Strong minerals demand growth</td><td colspan="2">2 degree track;
Minerals demand peaks early</td></tr>
<tr><td rowspan="2">Productivity and services</td><td colspan="4">Investment attractive and productive;
Reg. environment has a competitive edge</td></tr>
<tr><td>**Education below par;
Growing social divide;
Automation destroys jobs;**</td><td colspan="3">Education is world leading; Social Inclusion for everyone;
Jobs evolve maintaining participation.</td></tr>
<tr><td rowspan="2">Cities and infrastructure</td><td colspan="4">Connectivity and liveability is high;
Housing affordability dramatically improves</td></tr>
<tr><td colspan="3">Regional share is consistent with historical trends;
High urban form and density</td><td>**Regional share sees shift to regions;
High urban form and density**</td></tr>
<tr><td rowspan="2">Natural resources and Energy</td><td colspan="2">Electricity and gas governance coordinated and competitive;
National emissions policies targeting intensity in 2050 being 20% of 2000 levels.</td><td colspan="2">Electricity and gas governance coordinated and competitive;
National emissions policies targeting net zero emissions by 2050.</td></tr>
<tr><td colspan="2">Ag. productivity is above trend; Ecosystem services + markets favour food prod.</td><td colspan="2">Ag. productivity is above trend; Ecosystem services + markets favours land repair</td></tr>
</table>

Figure 2.4 Mapping of issues to national scenarios

Jobless Growth is a variation to the *Thriving Australia* scenario and explores the implications of strong technology adoption across industries with the Australian workforce and education system failing to keep up. *Stronger Regions* is a variation to the *Green and Gold* scenario and explores the implications related to new ‘quarter million’ well connected satellite cities. The mapping of issues in relation to the national scenarios are outlined in Figure 2.4.

While the implications of automation and development of regional satellite cities could plausibly occur under many national scenarios, this use of scenario sensitivities allowed exploration of the implications of these issues or a single issue. A sensitivity case scenario for each of these factors was constructed by varying a core scenario only for issue settings related to either automation or regional economic development, holding all other issue settings as for the comparison core scenario.

Additional ANO 2019 modelling was undertaken to explore other issues of specific interest within particular domains. These can be interpreted as scenario sensitivities and are listed in Table 2.7. For each sensitivity scenario in Table 2.7, the settings for all issues except that in the 'Sensitivity Issue' column are identical to the corresponding 'Base Scenario'. The sensitivity issue takes on the setting described in the 'New Setting' column. For example, the *Jobless Growth* scenario has settings identical to the core scenario *Slow Decline* in Table 2.2, except for the 'Future of Work' sensitivity issue in the Productivity and Services domain (see Table 2.4). Instead of the Future of Work issue corresponding to the 'jobs evolve' setting, it is instead the 'automation destroys jobs' setting, described qualitatively in Table 2.4. How these settings are interpreted within the modelling suite is described in the following section.

Table 2.7 Sensitivity scenarios definition

SENSITIVITY SCENARIO	BASE SCENARIO	SENSITIVITY ISSUE	NEW SETTING
Jobless Growth	*Slow Decline*	Future of Work (Productivity and Services)	Automation destroys jobs (from 'jobs evolve')
Human Capital sensitivity	*Slow Decline*	Education and Support (Productivity and Services)	Below par (from 'world leading')
Regional Growth	*Thriving Australia*	Regional Share (Cities and Infrastructure)	Shift to regions (from 'trend')
Climate Impacts	All three core scenarios	Agricultural climate impacts (Natural Resources and Energy)	Drought simulation (from 'trend' annual climate impacts)
Policy Uncertainty	*Slow Decline*	Electricity and Gas Governance (Natural Resources and Energy)	Improved but uncertain (from 'coordinated and competitive')

2.6 Parameterisation and translation

In order to estimate quantitative impacts of the various settings that characterise each scenario, a modelling assumption interpretation is needed. Interpretation requires selecting particular model structural parameters to vary by issue setting (parametrisation), as well as specifying the particular (usually quantitative) value (or values) that those parameters should take under each setting (translation). For example, the Agricultural productivity issue is parametrised in both the economic model (VURM, see Chapter 9) and the land-use model (LUTO). In the economic model, it is parametrised as a component factor of Total Factor Productivity in the Crops sector, the Livestock sector and the Forestry & Logs sector. In the land-use model, it is parametrised as per unit of land use productivity change of each broadacre crop represented, intensive livestock and carbon plantings. For the ‘Recent Trend’ setting, it is translated as an arithmetic constant growth per annum in the productivity index of 1.25 per annum starting from 100 in 2018 for the agricultural sectors and 0.5 per annum for forestry (reaching 152.5 and 121.0 in 2060). For the ‘Improved’ setting, the productivity index growth rates are 3.0 and 1.0 per annum for agriculture and forestry respectively, reaching 226.0 and 142.0 in 2060.

Each issue that is represented in the quantitative modelling is associated with at least one parameter, usually more, and each setting is associated with a particular translation – a value - for each issue. Ideally, the parametrisations and translations are designed so that each setting can be varied independently. When this is not the case for an existing model parametrisation, it is often possible to create a model pre-processing step that will accommodate independent issue translation.

Parametrisation and translation are processes undertaken by model and domain experts. The choice of parametrisation should take into account the qualitative description of each issue and their settings, and the reason the issue is of interest. Ideally, consideration should also be given to the sensitivity of the key model reporting parameters that represent proxy indicators for the issues at stake. For example, reporting parameters relevant to the agricultural productivity issue include but are not limited to: statistics on total agricultural production, calories of food produced, farm profitability, agricultural export production, land area occupied by carbon forestry, and emissions abatement quantity from the forestry sector. These are also proxy indicators for (respectively) the strength of the Australian agricultural industry, contribution to feeding the human population, rural economic health, international competitiveness of agriculture, extent of change to the landscape and contribution to mitigation of global greenhouse gas emissions.

Translation requires domain expertise about what represents a reasonable range of values consistent with the settings description. This may be based on:

- projections from published literature
- estimates based on other modelling and analysis
- guidance provided by clients or
- best guesses based on such considerations as: existing values, recent trends and historical variation of the parameter or proxy analogues.

If a give issue is reasonably well understood, parametrisation and translation may be a matter of retaining existing, well-tested, features of the models in the suite (such as a carbon emissions price in the national electricity generation sector), or consulting a well-established data source (such as United Nations global population projections). If a given issue is not well understood, parametrisation, but particularly translation, can involve a significant quantity of additional investigation, from literature review to consulting expert opinion to quantitative analysis, including experimentation using existing or redeveloped models.

The following section describes how each issue is parametrised and translated into the quantitative modelling analysis, for each domain.

2.6.1 Global Context Issues

Globally significant issues initially identified as being of interest included Geopolitics, Population, Climate Action, Global Minerals demand, Consumption patterns and Work Trends. It was decided that work trend changes – the possibility of more automation and the deployment of artificial intelligence would be considered explicitly only in the national analysis, and consumption patterns were also not parametrised in the global models. It was decided that demand for materials (minerals) would be investigated only as an output of the global modelling analysis, rather than imposing differences in assumptions between the two Global scenarios: *Nation First* and *Working Together*. Table 2.8 shows broadly how each global issue was represented in the quantitative analysis and Table 2.9 shows in more detail how parametrised issues were translated in each of their possible settings.

Table 2.8 Global issues – relevant models

ISSUE	MODELS WITH ASSUMPTIONS DIRECTLY AFFECTED	MODELS WITH RELEVANT RESULTS	ADDITIONAL ANALYSIS OUTSIDE MODEL SUITE
Geopolitics	GTAP-ANO	GTAP-ANO	No
Population	GTAP-ANO, GALLMT	GTAP-ANO	No
Climate Action	GTAP-ANO, GALLME, GALLMT, GLOBIOM-emulator, MAGICC (Indirectly: VURM, ESM, AUS-TIMES, LUTO)	GTAP-ANO, GALLME, GALLMT, GLOBIOM-emulator, MAGICC (Indirectly: all)	No
Minerals Demand	None	GTAP-ANO	No
Consumption Patterns	None	None	No
Work Trends	None	None	No

The Geopolitics setting is characterised by two alternatives: 'protectionist' and 'cooperative', which are represented in the quantitative global modelling directly through the global economic model GTAP-ANO. Each setting is aligned to a particular Shared Socioeconomic Pathway (SSP) global economic scenario from the international research community (Riahi et al. 2017), with the protectionist setting corresponding to the "middle of the road" SSP scenario SSP2 (O'Neill et al. 2014) and the cooperative setting corresponding to the more optimistic "low adaptation and mitigation challenge" SSP scenario, SSP1, with higher economic growth. This is represented in the global economic model by targeting of GDP growth when calibrating the model parameters, a process that essentially corresponds to aligning the total factor productivity growth parameters of the model to those implied in the Shared Socioeconomic Pathway source data (Fouré, Bénassy-

Quéré, and Fontagné 2013). In addition, global barriers to free trade are assumed to reduce to half their initial levels (data from sources described in Aguiar et al. (2016)) over the decade between 2020 and 2030 in the cooperative setting, in contrast to the protectionist setting, where they are assumed to remain unchanged.

There are only two alternative global population projections. The ‘central projection’ corresponding to SSP2, has relatively high population growth to 9.4 billion in 2060 consistent with central projections by the United Nations. The ‘lower growth’ population projection corresponding to SSP1, has population reaching only 8.4 billion in 2060, consistent with some of the United Nations low population scenarios. For detailed regional trajectories, the data source used for population was Fouré et al. (2013). The labour force data from this database was used directly in the global economic model, and the population projections used where ever a *per capita* calculation is required (such as GDP per capita which is used to project transport demand in the global transport model).

Table 2.9 Global issues parametrisation and translation

ISSUE	PARAMETRISATION	SETTING	TRANSLATION
Geopolitics	Total Factor Productivity Growth	Protectionist	Consistent with Shared Socio-economic Pathway 2 (Middle of the Road) data from CEPII, approx. 1.4%pa globally
	(GTAP-ANO)	Cooperative	Consistent with SSP1 (Low adaptation challenge), approx. 1.8%pa globally
	Trade Barriers	Protectionist	From 2011 trade barriers in GTAP 9 database Unchanged to 2060
	(GTAP-ANO)	Cooperative	Trade barriers reducing from 100% to 50% of starting values between 2020 and 2030
Population	GTAP-ANO Labour force, Regional populations for per-cap calcs	Central Projection	Consistent with SSP2 data from CEPII, with global population increasing to 9.4 billion by 2060
		Lower Growth	Consistent with SSP2 data from CEPII, with global population increasing to 8.4 billion by 2060
Climate Action	CO_2 and non-CO_2 emissions price	Four Degrees Track	Converging across regions from 2025 to $40/t in 2040, followed by 1% growth to 2060, similar to RCP6.0 carbon price projections by IPCC
	(All global models except MAGICC)	Two Degrees Track	Converging across regions to $20/t in 2020, followed by 5% growth to 2060, similar to RCP2.6
	Policy/technology driven emissions intensity reduction	Four Degrees Track	Emissions price driven only Fossil fuel to liquids capacity installation: allowed
		Two Degrees Track	CO_2 ex-electricity generation, transport: 0.5% pa non-CO_2 ex-electricity generation, transport: 2.0% pa N_2O electricity generation, transport 2010-2020: 2.0% pa N_2O electricity generation 2020-2050: 1.5% pa N_2O transport 2020-2050: 0.5% pa Fossil fuel to liquids capacity installation: disallowed

Climate action settings are a significant quantitative modelling driver, represented primarily as an emissions price trajectory. An emissions price is applied in almost all of the global models, to both CO_2 and non-CO_2 greenhouse emissions in the global economic model, and to combustion emissions (CO_2) in the global transport model GALLMT and the global electricity generation model GALLME. An emissions price is applied to both CO_2 and non-CO_2 greenhouse emissions in GLOBIOM, which provides the data source for the global land-use sector projections for ANO 2019 that are extracted from the GLOBIOM emulator. The same emissions price is applied to both CO_2 and non-CO_2 greenhouse emissions in CO_2-equivalent units. The two climate action settings are a 'four degrees track' and a 'two degrees track', referring to the expected increase in global average temperatures by 2100. Prices are based on those in scenarios reported by the IPCC in Clarke et al. (2014, Chapter 6, p450). The 'four degrees track' setting has global emissions prices converging from their current levels (that vary by region) to a globally uniform price of \$40/t-CO_2-eq (53.25 AUD 2015) in 2045 starting from \$15/t-CO_2-eq (19.96 AUD 2015) in 2025, and then growing by 1% to a little below \$50/t-CO_2-eq (61.81 AUD 2015) in 2060. In the 'two degrees track' however, globally uniform convergence takes place more quickly to \$20/t-CO_2-eq (26.62 AUD 2015) by 2020 with a 5% growth thereafter to a little above \$200/t-CO_2-eq (273.80 AUD 2015) by 2060.

Emissions intensity improvements that are not motivated by a price on emissions are also assumed and vary by climate action setting. They are not applied in the 'four degrees track' setting, but they range from 0.5%-2.0% in the 'two degrees track' setting for N_2O emissions for all sectors and CO_2, CH_4 and F-gases for economic activity excluding transport and electricity generation. Further details can be found in Chapter 3.

2.6.2 Productivity and Services Issues

Issues relevant to the Productivity and Services domain were initially identified as Investment Attraction, Education and Support, the Future of Work, Social Inclusion, Growth in Targeted Industries and Regulatory Environment (see Table 2.4).

Table 2.10 Productivity and Services issues: relevant models

ISSUE	MODELS WITH ASSUMPTIONS DIRECTLY AFFECTED	MODELS WITH RELEVANT RESULTS	ADDITIONAL ANALYSIS OUTSIDE MODEL SUITE
Investment Attraction	VURM	VURM	No
Education and Support	VURM	VURM	**Yes**
Future of Work	VURM	VURM	**Yes**
Growth in Targeted Industries (boosts)	VURM	VURM	**Yes**
Social Inclusion	None	VURM	**Yes**
Regulatory Environment	None	None	No

In the ANO 2019 modelling, Investment Attraction settings are represented by differences in GDP growth and the trajectories of the ratio of total factor productivity (TFP) to capital (see Chapter 4 for details). An 'historical trends' setting had GDP growth averaging 2.09%pa to 2060. For a 'strong' Investment Attraction setting, a higher GDP growth of 2.81% was used to endogenously determine the ratio of total factor productivity to capital, and then this endogenously calculated trajectory is used as an exogenous translation for this setting.

Where the Future of Work issue is concerned with the prospect of increasing automation in the workplace and the potential for an adverse impact on opportunities for employment, this is represented in the modelled natural rate of unemployment. For the less pessimistic view that ‘jobs evolve’, the natural unemployment rate is based on historical data, but for a sensitivity setting where ‘automation destroys jobs’ a higher natural rate of unemployment of 10% is assumed, with an exogenous unemployment rate that peaks at 20%.

The assumed unemployment rate is also varied for the Education and Support issue. This reflects the importance of having human capital that is matched to improved use of technology that drives labour productivity and the opportunities for employment. The ‘world leading’ setting is again the more optimistic view that the natural unemployment rate continues along historical lines, whereas a ‘below par’ setting has a natural unemployment rate at 7%, with a peak in unemployment of as much as 10%.

Growth in specific industries is permitted in those that are considered to have capacity for substantial above-trend growth, which are represented in the national economic model as “instrument” sectors whose ratio of total factor productivity to capital is permitted to be endogenous to meet a targeted GDP growth rate. Other “non-instrument” economic sectors are those that are considered unlikely to exhibit significant gains (see Chapter 4).

Social Inclusion is not represented as an input to the modelling, although one proxy indicator is the Gini coefficient (see the ANO 2019 report (CSIRO and NAB, 2019)), for which an estimate is produced from the occupational income distributions and unemployment rates that are reported as results from the national modelling. Finally, Regulatory Environment is not directly addressed in the modelling, although could be considered to have a similar parametrisation to Investment Attraction, with a ‘solid and stable, but passive’ setting for industry regulation being qualitatively associated with ‘historical trends’ Investment Attraction and a Regulatory Environment offering a ‘competitive edge’ associated with ‘strong’ Investment Attraction.

Table 2.11 Productivity and Services issues - parametrisation and translation

ISSUE	PARAMETRISATION	SETTING	TRANSLATION
Investment Attraction	Average GDP growth to 2060	Historical Trends	2.09%
		Strong	2.81%, or endogenous
	Total Factor Productivity to Capital ratios in instrument sectors	Historical Trends	Endogenous
		Strong	Endogenous, or fixed corresponding to 2.81% GDP growth
Education and Support	Natural unemployment rate	Below Par	7% equilibrium with 10% peak
		World Leading	Endogenously modelled
Future of Work	Natural unemployment rate	Automation Destroys Jobs	10% equilibrium, with 20% peak
		Jobs Evolve	Endogenously modelled
Industry Boosts	Sectoral characterisation as instrument or non-instrument	Trend only growth potential	Non-instrument
		Above Trend Growth potential	Instrument
Social Inclusion	Unemployment and income distribution by occupation	All	Gini coefficient estimate

2.6.3 Cities and Infrastructure Issues

Issues relevant to the Cities and Infrastructure domain were initially identified as Population (growth and spatial distribution), Urban Form and Density, Connectivity and Liveability, regional share and housing affordability (see Table 2.12 for the relevant models and Table 2.13 for how the settings are interpreted in each model). During the analysis process there was a decision to investigate two additional issues: Public Infrastructure, and Autonomous Vehicles. Both Housing Affordability and Autonomous Vehicles are treated qualitatively, with no specific influence on the national modelling suite intended to represent different settings. Public Infrastructure is addressed by estimating projections of expenditure, which is represented as growing in line with GDP, so this issue is treated as a result from the modelling suite rather than an assumed setting.

Table 2.12 Cities and Infrastructure issues – relevant models

ISSUE	MODELS WITH ASSUMPTIONS DIRECTLY AFFECTED	MODELS WITH RELEVANT RESULTS	ADDITIONAL ANALYSIS OUTSIDE MODEL SUITE
Population	VURM	VURM	**Yes**
Urban Form and Density	VURM, AUS-TIMES	VURM, AUS-TIMES	**Yes**
Connectivity and Liveability	VURM, AUS-TIMES	VURM, AUS-TIMES	**Yes**
Regional Share	VURM, AUS-TIMES	VURM, AUS-TIMES	**Yes**
Public Infrastructure	None	VURM	**Yes**
Housing Affordability	None	None	No
Autonomous Vehicles	None	None	No

Projections of total national population are identical across scenarios, and based on Australian Bureau of Statistics central projections (Series B). These are used to determine the labour force settings in the national economic model, VURM. The distribution of population across space however, does vary by setting. In particular, the settings for the Urban Form and Density issue determine the spatial distribution of population within capital city areas and surrounds, and the regional share settings affect the projections of the proportion of the population in regional urban centres rather than within the surrounds of capital cities. Each of these settings affects aggregate personal transport tasks requirements. Population density also affects the potential for transport tasks to be conveniently delivered by public transport.

The Connectivity and Liveability settings affect projections of the fraction of local areas that are attractive travel destinations for the populace (commercial, hospital and educational uses of land for jobs and services) and affects transport mode choices. The more that desired travel destinations are local, the more transport tasks are likely to be delivered by active transport modes (walking or cycling) and public transport. So, via their impact on the spatial distribution of population, the three issues: Urban Form and Density, Connectivity and Liveability and Regional Share, combine to determine (in addition to other drivers such as fuel prices and income) the private road transport task requirement that is represented in both the national economic model, VURM, and the transport model AUS-TIMES.

Table 2.13 Cities and Infrastructure issues parametrisation and translation

ISSUE	PARAMETRISATION	SETTING	TRANSLATION
Population	Labour force in VURM	All	Consistent with 72% population increase
Urban Form and Density		Low Density	Population (and density) increase in capital cities occurs primarily in inner city centres and outer suburbs. Higher personal transport distances requirements.
		High Density	Population (and density) increase in capital cities occurs primarily in inner and inner-mid suburbs. Lower personal transport distances requirements.
Connectivity and Liveability	Personal transport mode choice	Declining	Lower destination fraction of local areas leading to greater personal trip proportion by private road vehicle and greater road transport demand
		High	Higher destination fraction, greater active and public transport modes, lower road transport demand.
Regional Share	Urban versus regional population distribution	Trend	Share of national population living in 8 state capital cities rises from 67% in 2016 to 73% in 2060
		Shift to regions	Capital cities share of population falls to 61% in 2060
	Transport task requirements	Trend	Greater personal transport task requirements in capital cities, lower in regional centres. Lower in total
		Shift to regions	Higher total personal transport task requirements
	Labour Productivity	Trend	Greater range of labour productivity change across occupations due to greater disparity between urban and regional areas, with higher average improvement nationally See Table 5.9 (Chapter 5).
		Shift to regions	Less range in labour productivity change across occupations due to less disparity between urban and regional areas, with lower national average improvement See Table 5.10 of Chapter 5

Regional Share settings also affect projected labour productivity changes due to economic agglomeration. Data show that income distributions tend to vary by the size of the local population, with income distributions tending to be more polarised, but higher on average, in urban areas with larger populations (see Chapter 5). Larger populations also tend to be associated with higher incomes for higher paid occupations and lower incomes for lower paid occupations than are found in smaller populations. The effect of slightly lower populations in capital city areas and higher populations in regional urban centres is to decrease average incomes in the capital city areas and increase them in the regional urban centres. The net effect is a decrease in overall incomes. This is represented in the national economic modelling as a difference in labour productivity by occupation (distribution of income within occupation is not explicitly modelled, though this is addressed in the social inclusion issue for Productivity and Services), but the magnitude of difference in productivity by scenario due to agglomeration effects (less than 10% over the period from 2016 to 2060) is relatively small compared to the change in average income due to projected ongoing economic growth.

2.6.4 Natural Resources and Energy Issues

The Natural Resources and Energy issues initially identified included Electricity and Gas Governance, National Emissions Policy, National Emissions Targets, Agricultural Productivity and Ecosystem Services and Markets (Table 2.14). During the analysis it was recognised that residential energy efficiency has an important impact on outcomes in this domain, and so this was included as an issue associated with National Emissions Policy and National Emissions Targets. In addition, it was possible to conduct a Climate Impacts sensitivity analysis based on assumed plausible impacts of climate change, for example, the adverse productivity impacts of prolonged drought, enabling some modelling analysis. Finally, in order to investigate the potential of a hydrogen export industry, this issue (Hydrogen Industry) was considered as a sensitivity using the results of modelling analysis, plus a number of additional assumptions. For details see Chapter 6, Chapter 7 and Chapter 8.

Table 2.14 Natural Resources and Energy issues – relevant models

ISSUE	MODELS WITH ASSUMPTIONS DIRECTLY AFFECTED	MODELS WITH RELEVANT RESULTS	ADDITIONAL ANALYSIS OUTSIDE MODEL SUITE
Electricity and Gas Governance	VURM, ESM, AUS-TIMES	VURM, ESM, AUS-TIMES	No
National Emissions Policy	VURM, ESM, AUS-TIMES	VURM, ESM, AUS-TIMES	No
National Emissions Targets	ESM, AUS-TIMES	ESM, AUS-TIMES	No
Agricultural Productivity	VURM, LUTO	VURM, LUTO	No
Ecosystem Services and Markets	VURM, LUTO	VURM, LUTO	**Yes**
Climate Impacts	LUTO	LUTO	**Yes**
Hydrogen Industry	None	VURM, ESM, AUS-TIMES	**Yes**

2.6.4.1 Energy Issues

The details of how energy issues were translated in the ANO 2019 quantitative modelling appears in Table 2.15. The Electricity and Gas Governance issue is primarily influenced by a price on greenhouse emissions in all national scenarios (except an ‘energy policy uncertainty’ sensitivity scenario). An emissions price is applied to all sectors of the economy, including the national economic model: VURM, the electricity generation and transport models: ESM and AUS-TIMES, and the land-use model: LUTO. The emissions price corresponds to the price from the Global Context setting (converted into Australia dollars). Additional parameters for the Electricity and Gas Governance issue include the range of years for which the electricity sector is assumed to meet emissions targets consistent with Australia’s commitments in the United Nations Framework Convention on Climate Change (UNFCCC 2015) Paris Agreement as implemented in the electricity generation model. In all national scenarios these apply from 2020, but for the ‘improved but uncertain’ setting they apply only until 2030, and in the ‘coordinated and competitive’ setting, they apply until as late as 2035.

The required return on capital investment in the electricity industry in the 'coordinated and competitive' setting is a standard real commercial rate of 7%. In the 'improved but uncertain' setting, with additional risk associated particularly with investment in fossil fuel generation technology, the required return is as in Jacobs (2017), increasing to 8% for renewables, 9% for combined cycle gas generation and 12% for coal generation. Only gas peaking plant is associated with the lower required return of 7%.

Table 2.15 Energy issues parametrisation and translation

ISSUE	PARAMETRISATION	SETTING	TRANSLATION
Electricity and Gas Governance	CO_2 / non-CO_2 emissions price	Four Degree Track	As for global
		Two Degree Track	As for global
	Year range that electricity sector achieves Paris commitments	Improved but uncertain	2020-2030: Emissions from electricity generation below a trajectory decreasing linearly by year to 26% below 2005 levels in 2030.
		Coordinated and competitive	2020-2035 Emissions from electricity generation below a trajectory decreasing linearly by year to 26% below 2005 levels in 2030, and towards zero in 2050 between 2030 and 2035.
	Required return on generation investment	Improved but uncertain	Higher, reflecting uncertainty, 7% for gas peak, 8% for renewables, 9% for combined cycle gas, 12% for coal
		Coordinated and competitive	7%, lower representing certainty
National Emissions Policy	Electricity Generation Emissions	Support established industries	
		Low carbon transition	
	Industrial Energy Use	Support established industries	High efficiency
		Low carbon transition	High fuel switching from gas to electricity and high efficiency
	Household Energy Use	Support established industries	Moderate switching from gas to electricity and high efficiency
		Low carbon transition	High fuel switching and high efficiency
National Emissions Targets	Electricity Generation Emissions Intensity Scheme 2050 Target and start year	*Slow Decline* Targets	60% reduction on 2000 levels From 2035
		Thriving Australia Targets	80% reduction, from 2030

Under all national scenarios, it is assumed that the domestic price of gas, which is currently below global prices, converges to global parity within the next five years.

National Emissions Policy settings for residential, commercial and industrial sector energy use is associated with parameters representing fuel switching (from gas to electricity), the uptake of energy efficiency technology, and emissions intensity improvements in crop and livestock production.

For energy use in residential and commercial buildings, fuel switching and uptake of energy efficiency technology in the 'low carbon transition' settings is consistent with the high efficiency scenario assumptions in ASBEC (2016). Energy efficiency for 'support established industries' settings are also consistent with ASBEC (2016), although the efficiency of fuel switching is constrained by current best practice technology to reflect lower global action on decarbonisation.

In industrial sectors, 'support established industries' and 'low carbon transition' assumes high energy efficiency consistent with (ClimateWorks Australia et al., 2014). Fuel switching in 'support established industries' is driven by cost trade-offs in VURM. In 'low carbon transition', high rates of switching from fossil fuels to electricity is assumed consistent with ClimateWorks Australia et al. (2014)

While non-CO_2 emissions pricing is implemented in the national economic model via a marginal abatement cost curve mechanism (see Chapter 14), the resulting emissions intensity improvements are implemented only approximately in the land-use model. There, instead of a representing a marginal abatement cost curve in detail, improvements in emissions intensity in crops and livestock production are imposed as a constant annual percentage improvement in a way that approximately matches the magnitude improvement realised by the marginal abatement cost curve method in the national economic scenario. This corresponds to 3.0% pa for the low carbon transition setting and only 1% pa for the setting that supports established industries.

An emissions intensity scheme is implemented in the later years in all national scenarios (again except an energy policy uncertainty sensitivity scenario). This is a market based mechanism that is based on an emissions abatement target that becomes increasingly stringent over time to an end-point target emissions intensity in 2050. Electricity generators whose emissions intensity is greater than the annually varying target are required to purchase emissions permits at the going market rate to account for the excess, while generators whose intensity is lower than the target may sell emissions permits corresponding to their remaining credits.

The three national scenarios, *Slow Decline*, *Thriving Australia* and *Green and Gold* have targets in 2050 that are each increasingly ambitious. In *Slow Decline* the 2050 emissions target is a 60% reduction on 2000 levels, in *Thriving Australia* is it an 80% emissions reduction target, and in *Green and Gold* there is a 2050 emissions target in the electricity sector of zero. The start year for the Emissions Intensity Scheme is also brought forward in each subsequent national scenario, where the start year is, respectively, 2035, 2030 and 2025.

The potential for exports of hydrogen representing a new Australian export industry consistent with a 'low carbon transition' setting is not implemented directly with the modelling analysis. Instead quantitative analysis is undertaken by parametrising a proportion of the gas export market that switches from natural gas to hydrogen produced from renewable electricity. Under the default setting, the Australian gas export industry remains primarily natural gas. By way of estimating indicative economic potential, a 'low carbon transition' setting has hydrogen exports growing from the time it reaches price parity with LNG in about 2040 (see Section 6.5.3 in Chapter 6), reaching 14% the energy gas market by 2060. This results in an additional requirement for investment in (e.g. remote) renewable electricity generation of up to 260TWh pa by 2060, plus corresponding hydrogen production facilities, instead of LNG production capacity. This represents approximately 60% additional electricity generation.

2.6.4.2 Land use Issues

Agricultural productivity growth assumptions also vary by setting (Table 2.16). In all settings, the productivity index on a per unit land area basis is assumed to grow from an initial level of 100 by a constant (linear) improvement over time. In the 'recent trends' setting, the rate of improvement for agriculture (crops and livestock) productivity index is assumed to be 1.25 index points pa, reaching 153.7 by 2060. The corresponding annual improvement in forestry is assumed to be 0.5 pa, reaching 120 by 2060. In an 'improved' productivity setting, it is assumed that accelerated research and development in primary industries is able to lift productivity growth in agriculture and forestry by respectively 3.0 and 1.0 index points per year, so that the productivity index that starts at 100 in 2020 is 229 and 143 in 2060. The 'recent' and 'above trend' productivity paths provide a lower and upper bound for which the future is expected to be positioned (see Chapters 16 and 7 for details). These improvements are applied in both the economic model and the land use model.

Table 2.16 Land-use and climate impacts issues parametrisation and translation

ISSUE	PARAMETRISATION	SETTING	TRANSLATION
Agricultural Productivity	Crops & Livestock Productivity	Recent trend	Grows from 100 in 2018 at constant 1.25 pa
		Improved	3.0 pa
	Forestry Sector Productivity	Recent trend	0.5 pa
		Improved	1.0 pa
Ecosystem Services/ Markets	Payments to Landowners for carbon and biodiversity	Declining condition	No payments available
		Favour food production	Carbon planting payments with 33.3% biodiversity levy for monoculture (mixed species) at emissions prices exceeding AUD30 (60)/t
		Landscape repair	Payments for carbon plantings with 33.3% biodiversity levy
	Proportion of profitable carbon and biodiversity plantings land converted	Declining condition	NA
		Favour food production	50%
		Land-scape repair	100%
Climate Impacts on Agriculture	Agricultural sector productivity	Trend annual climate impacts	Climate projections consistent with four alternative global climate models
		Drought simulation	Climate impacts simulated by productivity change in 2036-2049 of 1996-2009 drought
Additional Climate Change Impacts	Total GDP and sectoral impact	Four degrees track	
		Two degrees track	

The ecosystem services and markets issue is parametrised primarily by whether payments are made available to landowners for carbon and biodiversity plantings. In the 'declining condition' setting they are not, so there is no incentive for land holders to move out of agriculture into forestry (note that this setting was not modelled for ANO 2019, after it was determined that limited carbon plantings were present even in the more attractive 'favour food production'). In the 'favour food production' settings payments are available to landowners for carbon plantings at CO_2 emissions prices, and monoculture plantings are levied at 33.3% when the carbon price exceeds \$AUD30/t-CO_2-eq and mixed species plantings are levied when the carbon price exceeds \$AUD60/t-CO_2-eq, the revenue raised funding biodiversity value improvements. However, under this setting, due to lack of policy clarity, only 50% of the land that could be profitably converted does so. Although this setting was not explored within the core scenarios for ANO 2019, it can be implemented in the land use modelling as a constraint.

For ANO 2019, however, results show that the relevant national scenarios featuring these settings (*Slow Decline* and *Thriving Australia*) did not enjoy sufficiently high carbon sequestration prices to motivate significant quantities of carbon plantings, even without a policy uncertainty motivated land-use change constraint. On the other hand, though not part of the ANO 2019 project, it would be possible to explore this setting under a higher carbon price.

Finally, in the 'landscape repair' setting, which was implemented in the *Green and Gold* scenario, payments are available to landowners for carbon plantings at CO_2 emissions prices, and monoculture and mixed species plantings again attract a 33.3% carbon sequestration income levy (at carbon prices of \$AUD30/t-CO_2-eq and \$AUD60/t-CO_2-eq respectively) in order to promote biodiversity values. Under this setting 100% of the land that could be profitably converted does so, though subject to a social lag as explained in Chapter 16 (Section 16.3.4). Climate change impacts are explored in a sensitivity scenario using the land-use model, LUTO, only. Under the default settings, climate projections are deemed to not have any effect on trend productivity growth but have annual impacts due to modelled variations in temperature and rainfall. However, under a 'drought simulation' setting, the productivity of the agricultural sector is modified by (an additional decline of) 0.24% per annum to reflect historical drought conditions from 1996-2009 for the projected period from 2036-2049. This is not a prediction of the impacts of climate change, but rather a sensitivity exploration of the type of climate and agricultural outcome for Australia that might be more likely under a warming planet.

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3 Global context

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3.1 Introduction

In the Australian National Outlook (ANO) 2019, the purpose of the global scenarios is to set the context for the Australian experience, which is the core focus of the study. There are significant ongoing global developments that will inevitably change the economic and environmental conditions which Australia will face into the future, and any foresighting exercise that is concerned with nationally significant matters must consider those aspects of the international environment that are likely to have the most impact. Among these changes is the prospective significant growth in presently important Australian trading partners such as China and countries in South-East Asia, as they transition from being low-income to medium-income nations and represent an increasing share of the global economy, as well as the rapid potential economic growth of India and the nations of Africa.

Recurrent concerns about global food security (FAO, 2009; UNCCD, 2017; FAO et al., 2018; Rockefeller Foundation, 1951) have been maintained by economic and population growth, together with increasing pressures on land suitable for agricultural production, including the potential negative impacts of climate change in some regions, as well as a recent slowdown in yield increases. Given Australia's role as an exporter of agricultural commodities, and the continuing trend in international trade in food products, these global population, land-use and climate issues are of likely continued significance to Australia's national interests. Similarly, changes in global energy markets have an impact on Australia's long term economic and social wellbeing. This is not only because as a developed economy, Australia consumes domestically a considerable proportion of global energy resources, but also because Australia's energy resources play a significant, and likely continuing, role in supply the global demand for energy and materials resources. This remains true even as concerns about global sustainability motivate international political actions that could significantly change the opportunities and threats to national interests.

In order to address how some of these global trends could affect the national outlook for Australia, the ANO 2019 project included the development of (nationally relevant) global scenarios, including analysis performed by a suite of simplified quantitative models of global scale land-use, economic, energy sector, and climate.

3.2 Summary qualitative settings

Exploration of key drivers and issues relevant to the global context for Australia's future identified a range of initially three qualitative scenarios, differing primarily across international cooperation on trade and climate change action and expectations of economic growth. This was later narrowed down to two scenarios for quantitative analysis.

A slightly less optimistic global scenario named *Nation First* has the world drifting towards protectionist trade policies. Although there is no major breakdown in international trade, global economic growth is weak, limiting growth in global incomes. This is particularly the case in high income nations. Population and economic growth in Asia remains relatively strong. International cooperation on climate action falters, resulting in continued increase in greenhouse gas emissions and leading to a 4^{o} C rise in mean global surface temperatures by 2100 relative to pre-industrial levels. Global population growth is in line with central projections, with continuing strong growth in demand for materials including minerals and fossil fuels.

A slightly more optimistic global outlook named *Working Together* envisages stronger international cooperation on both trade and macroeconomic reform. This results in stronger global economic growth in high income countries as well as mid-income regions. Global cooperation on climate action results in a lower greenhouse gas emissions trajectory, leading to a 2^{o} C or lower increase in global temperatures by 2100. Demand for carbon credits increases, particularly in the land sector. As the costs of renewable energy options fall, so too does the use of fossil fuels. The Asian middle class expands, but global population growth is at the lower end of projections, leading to slower growth in construction and an earlier peak in material consumption and global minerals demand.

A global 'Dystopia' scenario was also developed but was not modelled quantitatively. This scenario was characterised by the less internationally cooperative environment of *Nation First*, with relatively higher population growth, greenhouse gas emissions and global demand for materials and fossil fuel. However in addition to generally lower global economic growth, technology develops in such a way that the gains of growth are not broadly shared, as automation displaces labour, limiting opportunities for a large proportion of the global population to earn high wages. Quantitative modelling of the potential for automation to adversely affect job opportunities and to increase inequality was developed as one of the national scenarios. (The global scenario arguably shows some qualitative similarity to scenario SSP4 of Riahi et al. (2017).)

Table 3.1 Settings under each issue for the *Nation First* and *Working Together* global contexts

Issue	Setting	
	Nation First **(Factious global context)**	***Working Together*** **(Cooperative global context)**
Geopolitics	**Protectionist** Protectionist rhetoric stalls economic cooperation. Weak economic growth in high income countries to 2030.	**Cooperative**. Improved cooperation across G20 nations promotes macroeconomic growth in both high income and BRIIC countries.
Population	**Central projection** Population increases by 36% from 2010 to 9.4 billion in 2060, with a 19% increase in Asia.	**Lower growth** Population increasing only 22% from 2010 to 8.4 billion in 2060, with a 5% increase in Asia.
Global Climate Action	**Four degrees track** Paris climate commitments are met to 2030, but lacklustre action to 2050 puts the world on track to 4°C by 2100.	**Two degrees track** Paris climate commitments are met to 2030, with accelerating action by major nations putting the world on track to no more than 2°C warming (or lower with 'negative emissions' technologies after 2060).

In order to more specifically characterise the various alternative global context scenarios, and in accordance with the Australian National Outlook scenario framework (Chapter 2), a handful of key scenario *issues* were identified with which to distinguish the scenarios and to assist in connecting them to quantitative analysis. For the Global Context, six key issues were identified, namely Geopolitics, Global Population, Global Minerals Demand, Global Climate Action, Global Work Trends and Consumption Patterns. Each of these issues is described below for each of the two modelled scenarios *Nation First* and *Working Together* in further qualitative detail, expanding on the summary descriptions above. Table 3.1 summarises the issue settings for each of the two core global scenarios.

In practice, the identification of key drivers, their grouping into issues, the development of distinct issue settings and consolidation into scenario qualitative summaries is a process of concurrent and iterative development among each of these elements, somewhat described in Chapters 2 and 9.

3.3 Global Issues and settings

The Table 3.2 shows various settings for the global issues, and how they are interpreted within the global modelling suite. In principle, a scenario can be defined by independently selecting a setting for each issue. For the global scenarios, the *Nation First* scenario is associated with a 'protectionist' setting for Geopolitics, a 'central projection' for Global Population, and a 'four degrees track' for Global Climate Action. The *Working Together* scenario is associated with a 'cooperative' setting for Geopolitics, 'lower growth' for Global Population and a 'two degrees track' for Global Climate Action.

Table 3.2 Global issue settings

ISSUE	PARAMETRISATION	SETTING	TRANSLATION
Geopolitics	Total Factor Productivity Growth	Protectionist	Consistent with Shared Socio-economic Pathway 2 (Middle of the Road) data from CEPII, approx. 1.4%pa globally
		Cooperative	Consistent with SSP1 (Low adaptation challenge), approx. 1.8%pa globally
	Trade Barriers	Protectionist	From 2011 trade barriers in GTAP 9 database unchanged to 2060
		Cooperative	Trade barriers reducing from 100% to 50% of starting values between 2020 and 2030
Global Population	GTAP-ANO Labour force, Regional populations for per-cap calcs	Central projection	Consistent with SSP2 data from CEPII, with global population increasing to 9.4 billion by 2060
		Lower growth	Consistent with SSP2 data from CEPII, with global population increasing to 8.4 billion by 2060
Global Climate Action	CO_2 and non-CO_2 emissions price	Four degrees track	Converging across regions from 2025 to $40/t in 2040, followed by 1% growth to 2060, similar to RCP6.0 carbon price projections by IPCC
	(All global models except MAGICC)	Two degrees track	Converging across regions to $20/t in 2020, followed by 5% growth to 2060, similar to RCP2.6
	Policy/technology driven emissions intensity reduction	Four degrees track	Emissions price driven only Fossil fuel to liquids capacity installation: allowed
		Two degrees track	CO_2 ex-electricity generation, transport: 0.5% pa non-CO_2 ex-electricity generation, transport: 2.0% pa N_2O electricity generation, transport 2010-2020: 2.0% pa N_2O electricity generation 2020-2050: 1.5% pa N_2O transport 2020-2050: 0.5% pa Fossil fuel to liquids capacity installation: disallowed

Each of the three core national scenarios, *Slow Decline*, *Thriving Australia* and *Green and Gold*, as well as the national sensitivity analysis scenarios, had a global context defined by either the *Nation First* or the *Working Together* global scenario. Table 3.3 shows the global scenario settings for each national scenario, with further detail provided in Chapter 2.

Table 3.3 National scenarios global context

NATIONAL SCENARIO	GLOBAL SCENARIO SETTING
Slow Decline	*Nation First*
Jobless Growth	*Nation First*
Human Capital sensitivity	*Nation First*
Thriving Australia	*Nation First*
Green and Gold	*Working Together*
Regional Growth	*Working Together*
Climate Impacts	Both
Policy Uncertainty	*Nation First*

Note that while the Australian National Outlook 2019 report discusses results under two scenarios: *Slow Decline* and *Outlook Vision*, this report goes into further detail by reporting results for the *Outlook Vision* under two different global contexts: *Thriving Australia* under a fractious global context and *Green and Gold* under a more harmonious global context. It should be noted that both scenarios fall under the *Outlook Vision*. Chapter 2 of this report describes these scenarios in further detail.

3.3.1 Geopolitics

Two contrasting international geopolitical futures are considered, differing in the extent of international cooperation on trade and macroeconomic management. These settings differentially impact general economic development globally, with corresponding impact on Australia's opportunities for access to global export markets and for Australian consumers to purchase high quality and competitively priced goods and services from overseas.

In a 'protectionist' international geopolitical setting, nationalism and protectionist rhetoric from world leaders is assumed to stall progress on international trade liberalisation and economic cooperation. The resulting relatively weak economic growth, especially in high income countries flow through to below trend growth in average global incomes to 2030. The *Nation First* global scenario is characterised by this geopolitical setting.

The contrasting 'cooperative' geopolitical environment with improved trade cooperation across G20 nations is assumed to not only reduce barriers to international trade, but also to promote macroeconomic management policies (Khan, Nsouli and Wong 2002) that result in returns to stronger (above trend) economic growth in high income countries as well as Brazil, Russia, India, Indonesia and China. The *Working Together* global scenario is associated with 'Cooperative' geopolitics.

In the ANO 2019 global modelling suite, the 'protectionist' setting is represented by maintaining current levels of trade protections while in the 'cooperative' geopolitical setting they are reduced by 50% phased in linearly between the years 2020 and 2030. Initial levels of protection are derived from the GTAP 9 database (Aguiar, Narayanan and McDougall 2016). These data include the effects of tariffs, subsidies and domestic agricultural support. However, the effects of various other "non-tariff barriers" to trade are not captured.

For total factor productivity assumptions, ANO 2019 modelling was guided by the Shared Socioeconomic Pathway (SSP) framework (Riahi et al. 2017). The 'protectionist' eopolitical setting of *Nation First* is associated with SSP2 assumptions about economic development (the 'middle of the road'), the SSP scenario that is also associated with the 'central projection' Global Population setting (see Section 3.3.2). The 'cooperative' geopolitical setting, on the other hand, is associated with SSP1, consistently with the "low adaptation challenge" aspect of that SSP, as favourable economic growth allows resources to be made available to build social resilience to climate impacts. This SSP is also consistent with the 'lower growth' Global Population setting, due to its "low mitigation challenge" aspect, under lower population pressures a smaller magnitude of net emissions reductions is warranted. The particular choice of total factor productivity trajectories consistent with the guiding SSPs, was applied directly to only the economic model GTAP-ANO, however, this had follow-on implications for demand for energy and transport services in "downstream" models GALLME, GALLMT, all of which had follow-on impacts to greenhouse emissions in MAGICC.

3.3.2 Global population

Population growth is a significant factor influencing global futures, as a strong driver of both economic activity and global environmental pressure. The demographics of a nation's population determines to a large extent its available labour force, and its material needs for food, water, shelter, sanitation, energy and infrastructure, and hence its demand for resources.

Under a 'central projection' for Global Population associated with *Nation First*, there is an increase from 6.9 billion persons in 2010 to 9.4 billion by 2060, a growth of 36%, while the population of Asia increases by 19%. Under a 'lower growth' Global Population setting associated with the *Working Together* global scenario, the increase to 2060 is only 22% to 8.4 billion persons, with a 5% increase in Asia.

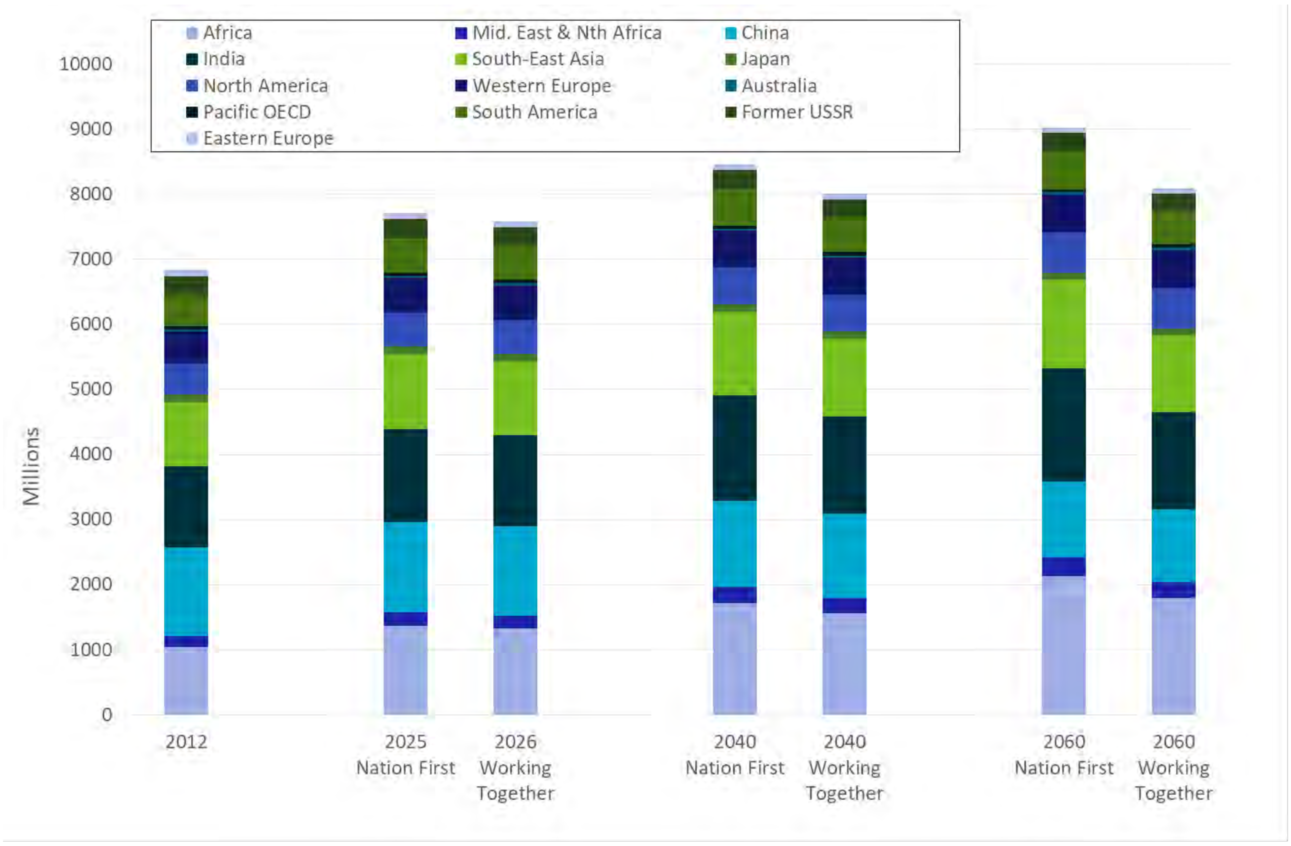

Figure 3.1 Global Population by scenario

Source: Fouré et al. (2013)

For ANO 2019, the 'central projection' Global Population is similar to the United Nations central projections, and match projections by the International Institute for Applied Systems Analysis (IIASA) for Shared Socioeconomic Pathway 2 (SSP2, see O'Neill et al. 2014 and Riahi et al. 2017). The 'lower growth' setting was quantified by matching the IIASA projections for SSP1, which is similar to low United Nations global population projections. These population data inform the ANO 2019 global economic model GTAP-ANO, where they are instrumental in defining the available labour force. They also inform the demand for transport services applied in the ANO global transport model GALLMT, which is a function of both population and average income (GDP per capita) in each represented region. The regions in the global economic model are taken from those in the global transport and electricity models GALLME and GALLMT (Hayward et al. 2017 and

Hayward and Graham 2013) which are based on those defined in Table 1 of Schafer and Victor (2000). See also Table 12.2 in Chapter 12. Projections for population, labour supply and real GDP by region for SSP2 and SSP1 are taken from the Centre d'Etudes Prospectives et d'Informations (CEPII) 'EconMap' database (see Fouré et al 2013 for the projection methodology).

3.3.3 Global climate action

Anthropogenic emissions of greenhouse gases have significant potential to impact the ability of the Earth system to support conditions favourable to human wellbeing (Steffen et al. 2018). Efforts to mitigate the rate of emissions into the atmosphere could represent a change to the nature (Bataille et al. 2018) and sectoral distribution (Tol, Pacala and Socolow 2008) of global economic activity, and the longer term consequences of atmospheric greenhouse gas concentrations could affect the planetary climate system with potentially large impacts on global human health, food production systems, ecosystems, infrastructure requirements, material living standards and global GDP (IPCC 2018, especially Summary for Policymakers, B5, C2). Action to mitigate the rate of emissions at the global scale requires international cooperation, the extent of which could profoundly affect the options available to Australian at a national scale (see Chapter 8 for details). This issue was hence selected for investigation as part of the global scenarios definitions.

Under a 'four degrees track' setting on global climate action, it is assumed that United Nations Framework Convention on Climate Change (UNFCC 2018) Paris Agreement commitments are met to 2030. From 2030 to 2050 however, weaker international cooperation leads to waning commitment to global action. The pledge and review process fails to deliver action consistent with limiting the increase in global temperatures to less than two degrees relative to the pre-industrial level. As a result, the planet is on track to an increase of four degrees by 2100 (IPCC, 2018; Rogelj et al., 2016). This higher emission global setting is associated with the *Nation First* global scenario.

A lower emission global setting is assumed for the *Working Together* global scenario. The 'two degrees track', again referring to targeted limits on the increase in global temperatures since the pre-industrial era, has UNFCC Paris Agreement commitments met or exceeded to 2030. Beyond 2030, accelerating action by all major nations puts the earth system on track to no more than two degrees increase at 2100, opening the possibility of even less severe climate change if 'negative emissions' technologies are deployed after 2060 (IPCC, 2018).

For ANO 2019, the global climate action setting was differentiated in GNOME.3 by both a price on greenhouse gas emissions applied worldwide across various regions, and different assumptions about technological development driving total factor productivity associated with the Geopolitical setting (Section 3.3.1). In addition, greenhouse gas emissions abatement driven by factors other than an emissions price are stronger in the 'two degrees track' setting. The Intergovernmental Panel on Climate Change (IPCC) scenarios for emissions, called Representative Concentration Pathways (RPCs) (IPCC 2014, see p57), were used in ANO 2019 as guidance for specific quantitative assumptions on greenhouse gas emissions price and other greenhouse emissions related factors. In particular, RCP 6.0 was used to guide many of the quantitative settings for the 'four degrees track' setting, and RCP2.6 was used to guide quantitative scenario assumptions for the 'two degrees track'.

A price on greenhouse gas emissions, guided by associated RCPs, is applied to each of the four socioeconomic GNOME.3 models, the global land use model (the GLOBIOM emulator), global economic model GTAP-ANO, the global electricity model GALLME and the global transport model GALLMT. Details of the construction of the greenhouse gas emissions price for the two alternative Global Climate Action settings appear in Section 3.4.2.3. Additional emissions intensity improvements are applied to non-CO_2 emissions from GTAP-ANO, and N_2O emissions associated with GALLME and GALLMT. These assumptions are also guided by the relative ambitions of the two alternative climate action settings. Furthermore, data provided to the simplified climate change model, MAGICC, as projections for greenhouse emissions not represented by the four socioeconomic GNOME3 models are also taken from RCP6.0 and RCP2.6 (IPCC 2014).

The economic cost of direct impacts associated with climate change has not been included in the modelling. The 'two degree track' would have lower impacts than the 'four degree track'. The IPCC (2018) Reasons for Concern illustrate the impacts of different levels of global warming for people, economies and ecosystems across a range of sectors and regions.

The economic costs and benefits of adaptation have not been included in the modelling. Adaptation builds resilience to climate change risks and takes advantage of climate change opportunities. It includes actions such as building sea walls, using drought-tolerant and heat-tolerant crops, improving building insulation, developing better energy/transport/water infrastructure, revising land-zoning and building-codes, enhancing early-warning systems for extreme weather, and improving education about risk management.

3.3.4 Global minerals demand

Demand for minerals and other materials is a broad environmental sustainability indicator (Efthimiou et al. 2017) addressing concerns about the depletion of finite planetary resources, and the environmental impact associated with resource extraction industries (UNEP 2016 and Schandl et al. 2017). While the demand for materials is associated with improvement in consumer living standards, the continued exploitation of new material resources also has undesirable impacts (ibid.). In ANO 2015, particular attention was given to the potential to reduce materials demand by both the realisation of technical efficiencies in resource usage, as well as the shifting of consumer preferences from material products to more experiential services. After the consultative process described in Section 2.2 of Chapter 2, these factors ended up being of less interest for ANO 2019, than other priorities, and so technical efficiencies were not explored as part of the global scenario settings. Consequently the projected material demands are higher than they would be had some of the more favourable technical efficiency potentials explored in ANO 2015 also been applied to ANO 2019 scenarios.

Under a setting where Global Minerals Demand 'grows strongly', a rising global population and income provides support for continuing strong demand for metals, construction materials and other minerals products, particularly in Asia. Where Global Minerals Demand 'peaks early' there is expected to be a slower growth in construction and associated demand for metals and minerals owing to slower population growth, particularly in Asia, due to a more rapid demographic transition.

Global Minerals Demand is treated as an output reporting parameter of the ANO global modelling suite, GNOME.3, in particular from the global economic model GTAP-ANO, driven primarily by assumptions about global population and those driving global GDP. In accordance with the qualitative scenario definitions described in Chapter 2, the *Nation First* global scenario is assumed to be associated with the Global Minerals Demand setting 'grows strongly' and the *Working Together* global scenario is assumed to correspond to 'peaks early'. It will be seen in Section 3.5.4 however that, without the imposition of additional assumptions about material intensity (Efthimiou et al. 2017) improvements, the global modelling results for *Working Together* do not demonstrate this expected correspondence.

3.3.5 Global consumption and production patterns

In ANO 2015 consideration was given to exploring differences in patterns of consumption, particularly demand for services and 'experiential' goods relative to material goods, driven by changes in consumer preferences, perhaps expressed as cultural change, or influenced by public policy decisions such as the treatment of material waste or policies promoting recycling or public transport. This can potentially have a significant influence on the global demand for natural material and energy resources. Exploring this issue was of less interest for ANO 2019 clients, however, and it was decided that all consumption should be assumed to be similarly consistent with rising income per capita patterns over time, and that the value of construction activity across distinct global scenarios would simply reflect differences in population. There are no distinct settings directly representing exogenous differences in the material intensity of consumer preferences or the material and energy intensity differences in production technology. Only indirectly caused differences arising from different settings on global climate action and varying effort at greenhouse gas emissions mitigation have been represented.

3.3.6 Global work trends

Technological change and its impact on the future of work is likely to have significant implications on global economic productivity, the quality of life of the general population as both a workforce and as consumers. It will also potentially have significant implications nation by nation on political institutions that influence the nature of the relationship between labour and economic capital., However it was decided that the modelling tools and expertise available was unsuitable to analysing the complexities of this issue at the global scale, and it would be more feasible to consider the issue only within the national scenarios analysis, as a sensitivity scenario.

3.4 Quantitative modelling settings

3.4.1 Global Model Framework

Although Australia is a globally open economy, it is a relatively small global player across most industries, although this is not true for some minerals such as iron ore and some agricultural commodities. It is therefore reasonable to assume that the results of modelling of different national scenarios at the national Australian scale are not required for the settings of the global model which represents distinct economic sectors at only a highly aggregated scale. Rather, the global projections influence the national projections, but not vice versa.

Similar considerations inform the integration of the global sectoral models. The primary drivers of the global modelling suite, including those that impact significantly on more than one of the global models (see Table 2.8 in Chapter 2), include:

- economic (total factor) productivity assumptions
- population projection based labour force and consumer population assumptions
- fossil fuel prices
- international efforts towards greenhouse gas emissions abatement and
- openness of global trade conditions.

It is global economic growth that is assumed in our modelled relationships, to drive the demand for energy including electricity, and growth in incomes that makes both personal and freight transport more affordable, motivating demand for transport fuels. Although in reality there is an extent to which technological and physical resources properties of the energy sector of the global economy influences economic outcomes via prices, this is a second order effect that is not represented in the global suite. Similarly, our modelled relationships show the Earth climate system being significantly influenced by emissions from human economic activity. Although in reality there is likely to be significant direct impacts of climate change on the global economy, particularly human land-use, this relationship is also not quantitatively well understood (Rosen 2016) and so it was not represented within the ANO 2019 global model suite. Instead, it is discussed qualitatively in Chapter 8.

3.4.2 Issue Parametrisation

3.4.2.1 Background assumptions: energy prices

Projections for the baseline world prices of oil, gas and coal are derived from a combination of projections from the (United States) Energy Information Administration (EIA) and the (European) International Energy Agency. These energy prices were used in the baseline (calibration) of the global economic model, GTAPE-ANO, with no greenhouse emissions prices, and then allowed to become endogenous to the simulations. As sensitivity of global scenarios to global energy prices was not highlighted as being of particular interest to the ANO 2019 members, this was not explored, and instead a single particular setting for energy prices was selected.

Specifically, base case oil price projections were based on the reference case oil price series (Brent spot price) from the 2017 Annual Energy Outlook, (Energy Information Administration, 2017), and extrapolated beyond 2040. For global gas and coal price projections, relative prices of gas and coal prices to oil prices from the 2017 World Energy Outlook (IEA 2017) were applied to the extrapolated oil prices series from IEA 2017.

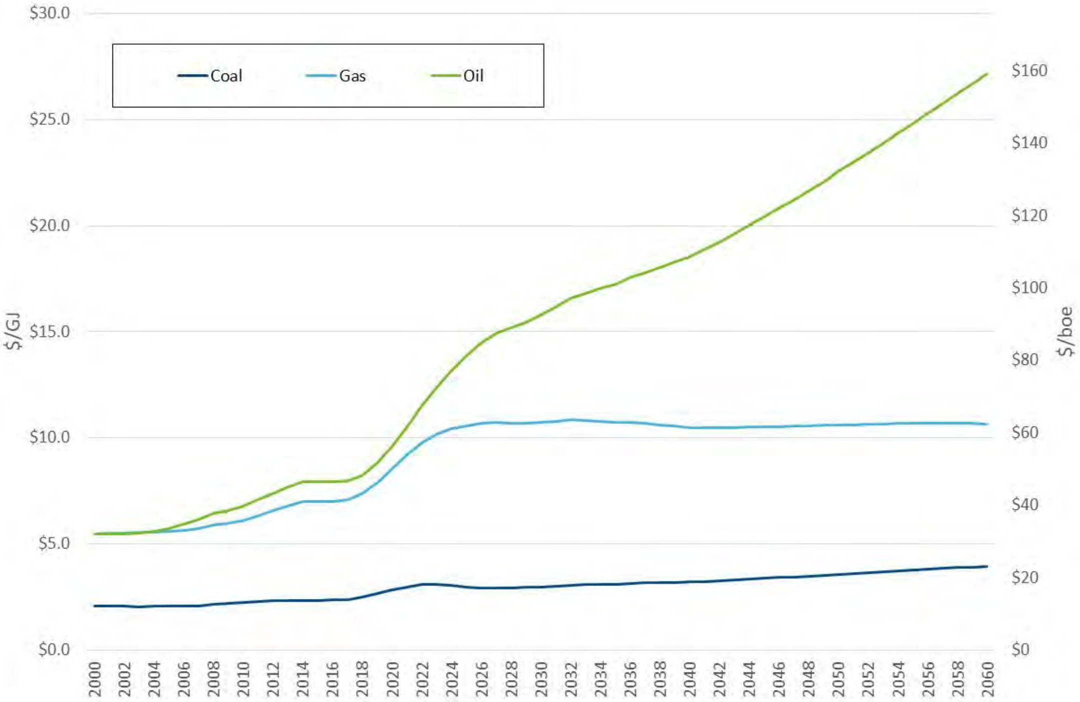

Figure 3.2 Baseline fossil fuel price trajectories

Source: EIA 2017, IEA 2017 and CSIRO calculations

Beyond 2056, the IEA oil price projections were extrapolated at the constant dollar growth rate from 2055-2056, which is an extrapolation choice that limits projected growth over the long term time horizon relative to a constant percentage growth rate. In the medium term from 2040 to 2056, the oil price projections were allowed to grow more quickly than linearly, and instead extrapolated at a constant percentage, selected as the average percentage growth rate from 2020 and 2040.

For the gas and coal price projections, we calculated the ratio of gas (Japanese import prices) to oil and coal to oil price projections from the 2017 World Energy Outlook Current Policies scenario (IEA 2017), which were given at 2016, 2025 and 2040. These ratios were interpolated at constant growth rates from 2016-2025, and from 2025-2040, and again extrapolated from 2040-2056 at the average percentage growth rate from 2025-2040, and beyond 2056 at the constant dollar growth rate of 2055-56. These energy price relativities for gas and coal derived from IEA data were applied to our oil price projections extrapolated from EIA data. Finally, the resulting fossil fuel price series was smoothed across the time range from 2010-2020 in order to subdue the impact of historical price volatility, given that the CGE simulations are quite sensitive to inter-annual growth rate variability. The resulting endogenous primary energy prices are quite similar to the baseline prices and reported in Section 3.5.2.2.

3.4.2.2 Global economic productivity assumptions

The differences in economic growth assumptions in the two global scenarios are quantified by calibrating regional productivity assumptions in the global economic model GTAP-ANO, to match GDP projections for the corresponding shared socioeconomic pathways in a baseline calibration condition with no carbon price. The *Nation First* and *Working Together* ANO 2019 scenarios total factor productivity assumptions correspond to SSP2 and SSP1 respectively. Indicative comparisons of these total factor productivity assumptions are provided in Figure 3.3 and Table 3.4based on national TFP factors provided in the CEPII dataset (Fouré et al 2012, 2013).

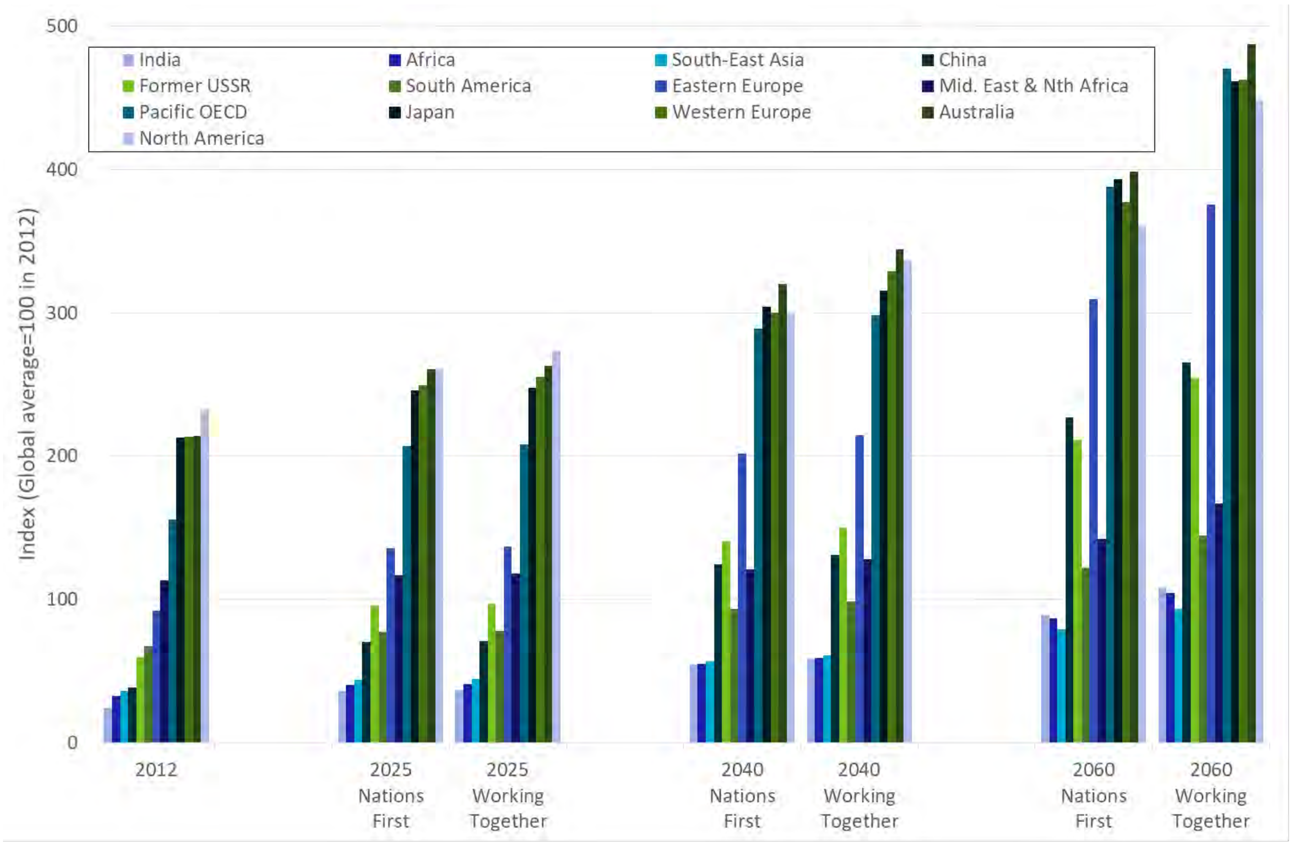

Figure 3.3 Regional average Total Factor Productivity index (global average in 2012=100)

Source: Fouré et al (2012, 2013) and CSIRO calculations

Figure 3.3 and Table 3.4 show that the greatest assumed growth in TFP over the projection period is in China, with the lowest growth in the Middle East & North Africa. Lower income regions such as India, Africa and Eastern Europe are projected to have higher growth than already wealthier OECD regions such as Western Europe, Japan and North America, with South America a relative laggard. Australia has the highest assumed projected TFP on the basis of the Fouré et al (2012, 2013) dataset in 2060 under both global growth scenarios, from its 2012 position of second to North America. The differences in total factor productivity between the two scenarios are modest compared to both the projected growth over time, and the differences among regions.

In order to develop the regionally weighted average TFP index shown here, a weight W corresponding to production factor inputs in a standard Cobb-Douglas/Solow model of production, $W = K^{\alpha}L^{1-\alpha}$, with capital stock K, labour force L and production elasticity of substitution α was applied to each country in the region (See Table 3.4). The time series was rescaled so that the global weighted average scaled TFP is 100 in 2012.

Table 3.4 Average Total Factor Productivity Growth 2012-2060, by region

	NATION FIRST	*WORKING TOGETHER*
India	2.71%	3.12%
Africa	2.08%	2.47%
South-East Asia	1.65%	2.00%
China	3.76%	4.10%
Former USSR	2.66%	3.06%
South America	1.25%	1.60%
Eastern Europe	2.56%	2.97%
Mid. East & Nth Africa	0.47%	0.81%
Pacific OECD	1.92%	2.33%
Japan	1.29%	1.63%
Western Europe	1.19%	1.63%
Australia	1.30%	1.72%
North America	0.92%	1.38%
Global average	1.79%	1.38%

Source: Fouré et al (2012, 2013) and CSIRO calculations

3.4.2.3 Global climate action

Global climate action in the ANO 2019 global (and national) modelling suite is parametrised by a regional greenhouse gas emissions price applied to all economic activity in the global economic model GTAP-ANO, to both CO_2 and non-CO_2 emissions (see Chapter 10). The same CO_2 emissions carbon price trajectory is provided to the GLOBIOM emulator, which interpolates GLOBIOM scenario simulations in which the carbon price is applied to non-CO_2 emissions, including agriculture. It is also applied to CO_2 emissions modelled in the global electricity and transport models GALLME and GALLMT (but not to N_2O emissions from combustion in those two sectors, as they are not explicitly modelled).

The regional prices applied to greenhouse gas emissions assumed in the near term is based on International Energy Agency (2016), Ecofys (2013), World Bank and Ecofys (2014, 2015) and World Bank et al. (2016) and other sources (See Table 3.5). In the long term they are consistent with the *Nation First* and *Working Together* global scenario qualitative characterisations, which are intended to represent global greenhouse gas emissions outcomes similar to RCP6.0 and RCP2.6.

For the ‘four degrees track’, carbon prices are represented as converging across regions from 2025 to \$40/t-CO_2-eq in 2040 before continuing to increase at a constant 1.0%pa growth rate. In the ‘two degrees track’ global scenario, the international community is assumed to agree to apply a uniform carbon price of \$20/t from much earlier, in 2020, increasing constantly at 5.0% thereafter. The initial regionally uniform price and growth rates are based on data presented in Clarke et al. (2014, Chapter 6, p450). See Figure 3.4 and Figure 3.5 for a comparison of the assumed greenhouse gas emissions prices in each of the two global scenarios.

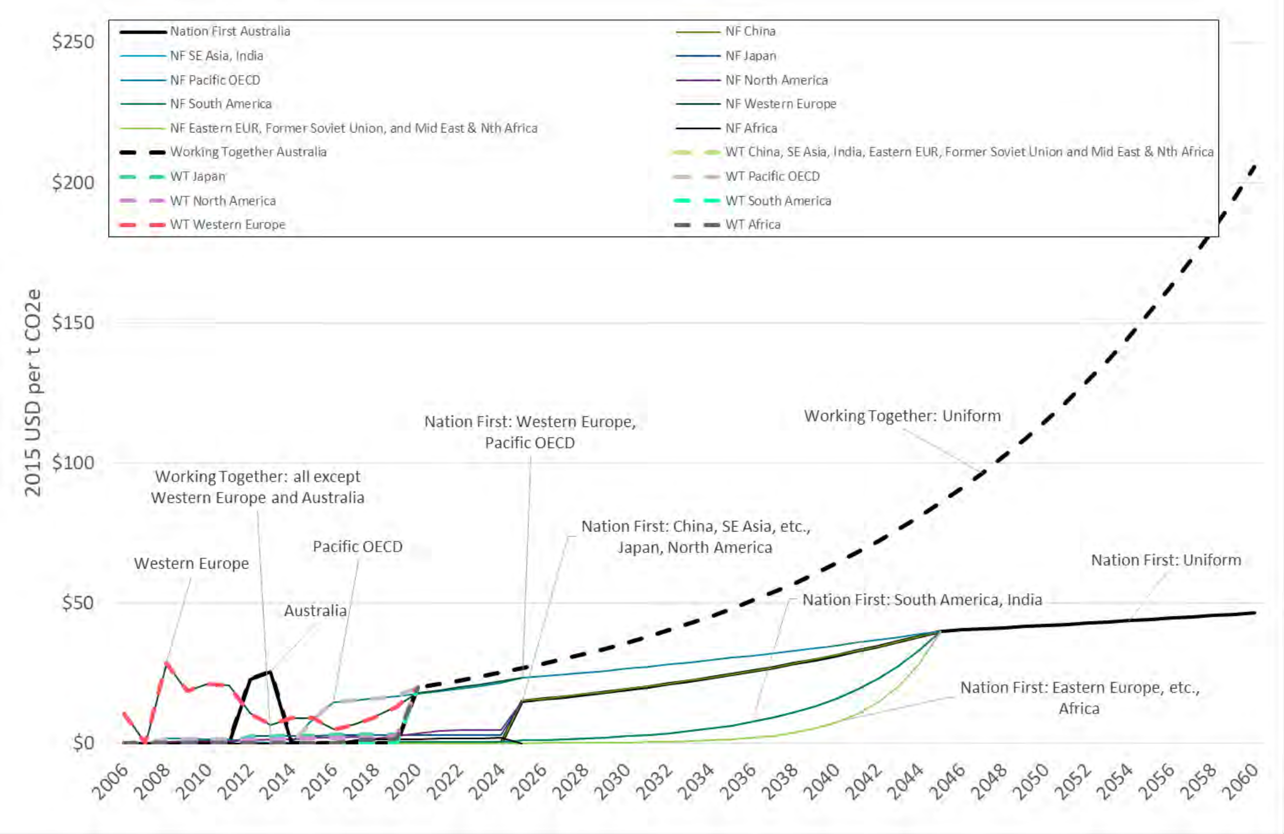

Figure 3.4 Carbon price trajectories, Four degrees track and Two degrees track comparison. trajectories, Vertical axis title and units

Source: see Table 3.5

Athough the price of greenhouse gas emissions is set exogenously to the ANO 2019 global modelling suite, including GTAP-ANO, the resulting global suite projections were checked for qualitative consistency with the descriptions of the selected ANO 2019 Global Scenarios. The outcome was a mixed success, as described below in Section 3.5.3 and in more detail in the Chapter 13. For the four degrees track setting, global emissions projections did somewhat match the intended qualitative scenario description. However for the two degrees track setting, projected global greenhouse gas emissions to 2060 exceeded those represented in selected comparison benchmark scenarios that do remain below two degrees warming to 2100. Even assuming that global emissions are able to reduce post-2060 more closely towards those in the benchmark scenario, the corresponding climate impacts exceed those targeted in the qualitative description.

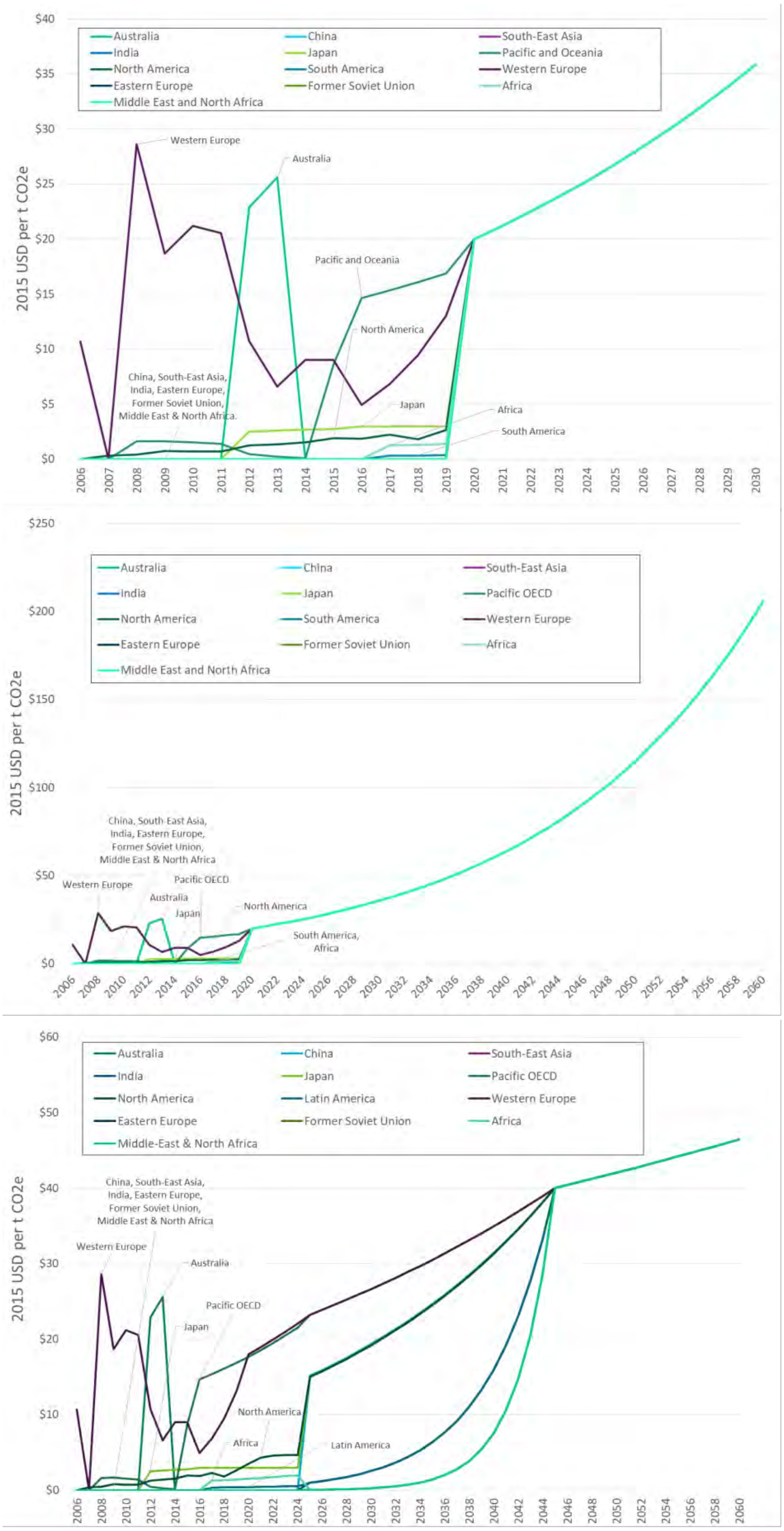

Figure 3.5 Carbon price trajectories, by scenario. Top: Four degrees track, Middle: Two degrees track, Bottom: two degrees track – near term

Source: see Table 3.5

Table 3.5 Data sources for historical and near term CO_2 emissions prices by region

COUNTRY	SOURCE
Argentina, Chile, Uruguay	Fouré and Fontagne (2016)
Canada	Ecofys (2013), World Bank and Ecofys (2014, 2015), World Bank et al. (2016) Government of Canada (2016) Environment and Climate Change Canada (2017) Board of Governors of the Federal Reserve System (US) (2017)
China **South Africa**	IEA (2016)
EU member countries; **United Kingdom**	IEA (2016), Ecofys (2013, p4), World Bank and Ecofys (2014, p56) Helm (2012) United States Bureau of Labor Statistics (2017)
Japan	World Bank et al. (2016, p14)
Mexico	World Bank et al. (2016, p14, p49)
New Zealand	World Bank and Ecofys (2014, 2015), World Bank et al. (2016) New Zealand Ministry for the Environment (2018) Reserve Bank of New Zealand (2017) Theecanmole (2016) United States Bureau of Labor Statistics (2017)
USA	World Bank and Ecofys (2014, 2015), World Bank et al. (2016) United States Environmental Protection Agency (2017)

3.4.2.4 Barriers to free trade

Indicative magnitudes of barriers to free trade in the GTAP 9 database (Aguiar, Narayanan and McDougall 2016), and represented in the global economic model, GTAP-ANO, are shown in Figure 3.6 and Figure 3.7. Import tariffs include ordinary import duty (TFRV) and the export tax equivalent (MFRV) of the multi-fibre arrangement quota premium (MFA), applied to China only, and assigned to the importing region. Domestic input subsidies are the absolute value of the ‘net intermediate input subsidies (ISEP)’ (domestic) and import subsidies are the absolute value of ISEP (imported). Production subsidies are the magnitude of ‘net ordinary output subsidies’ (OSEP). Figure 3.6 shows these magnitudes by traded commodity, as a percentage of global 2012 GDP, and Figure 3.7 shows these magnitudes by region, as a percentage of regional 2012 GDP. The GTAP database parameters VRRV (export subsidy equivalent of voluntary export restraints) and PURV (export tax equivalent of price undertaking) set to zero in the model, and FBEP (factor based subsidies) are not shown.

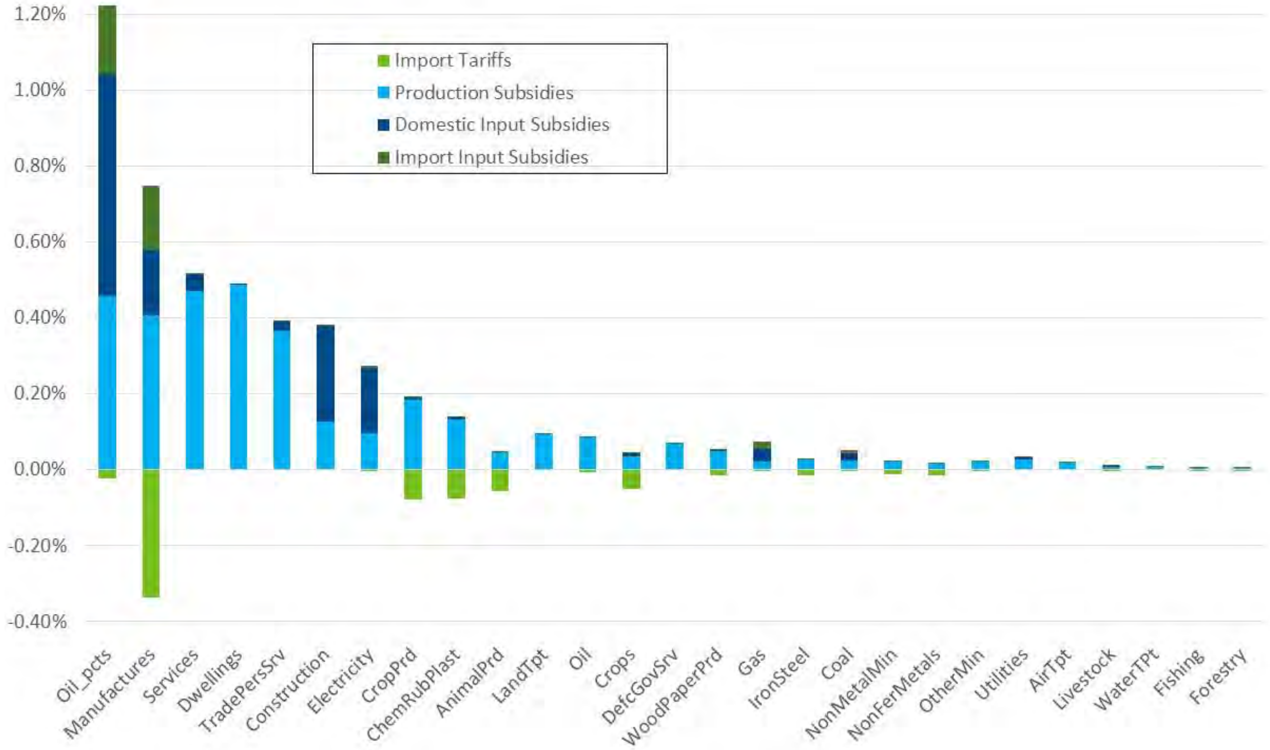

Figure 3.6 Size of modelled initial year barriers to free trade, % of global GDP, Upper chart, by industry

Source: GTAP9 database (see Aguiar, Narayanan and McDougall 2016)

It can be seen that, by value, most of the barriers to free trade are implemented as subsidies rather than tariffs, and primarily as production (output) subsidies. Oil products, manufactures, construction and electricity are subject to the highest production subsidies, with manufactures subject to the highest import tariffs, followed by crop products and chemicals, rubber & plastics. The relative magnitude of barriers to free trade is of the order of 3-10% of regional GDP, with Eastern Europe and India subject to the higher percentages, and the Middle-east & North Africa, and South-East Asia at the lower end of the scale. Eastern European subsidies are primarily production subsidies, with the subsidies in India also applied to input factors. Australian barriers to free trade are of median magnitude relative to GDP.

Trade barriers in the *Nation First* scenario are assumed to remain at their current levels, and in the *Working Together* global scenario are assumed to decline uniformly to 50% of their current levels over the period between 2020-2030 (see Figure 3.8), reflecting the assumed improved international cooperation in this scenario.

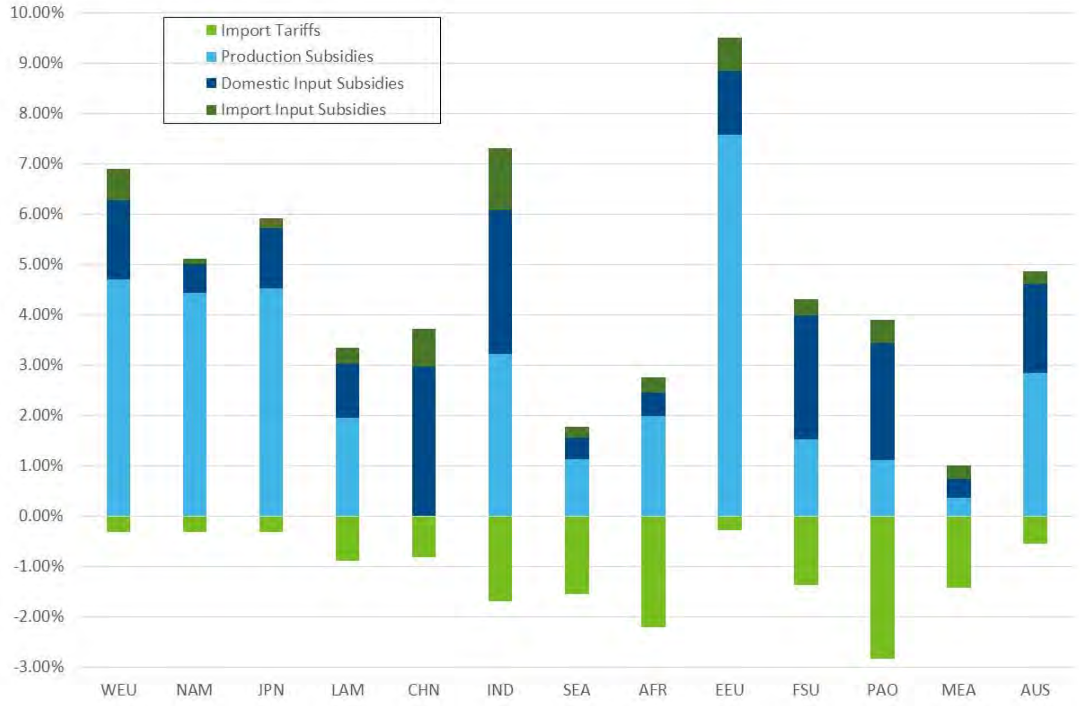

Figure 3.7 Size of modelled initial year barriers to free trade, % of regional GDP, by region

Source: GTAP9 database (see Aguiar, Narayanan and McDougall 2016).

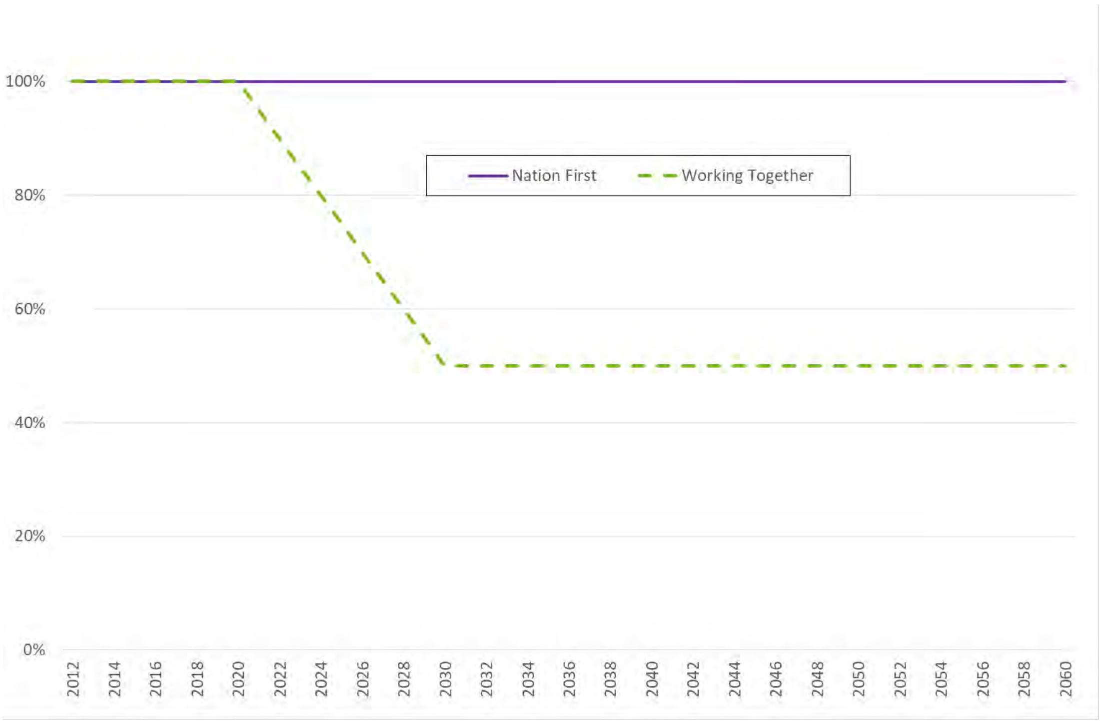

Figure 3.8 Scaling factor applied to trade barrier projections, by global scenario

Source: CSIRO

3.5 Quantitative modelling results

3.5.1 Economic growth

The comparative economic growth projections from GTAP-ANO between the *Nation First* and *Working Together* scenarios are consistent with the assumptions in the Shared Socioeconomic Pathways, with higher GDP in the *Working Together* setting. Since the population growth is assumed to be lower in the *Working Together* scenario, the difference between the two global scenarios in per capita GDP is even greater (see Figure 3.10 for results in both real 2015 USD, and in purchasing power parity). Note that these reported GDP results are based on growth rates modelled by GTAP-ANO applied to base year (2012) data and purchasing power parity factors derived from Fouré et al (2012, 2013).

The projected economic growth, with the assumed greenhouse gas emissions trajectories in each global scenario, is slightly lower than the calibration baseline assuming no emissions price.

While it is expected that an emission price alone will slightly reduce projected economic growth, this excludes any assessment of the costs and benefits of the direct impacts of climate change with and without adaptation. International studies have shown that a 4°C Track with adaptation could lead to a global GDP loss of 1%–3% by 2030–2060. For a 2°C Track without adaptation, the global GDP loss would be reduced to 0.5%–1.6% by 2050–60, or lower if there is also effective adaptation. Global warming of 5°C without adaptation could lead to a global GDP loss of more than 10% by 2100 (Stern 2006, Mercer 2011, OECD 2015). The dampening effect of the emissions price on economic output appears to be less significant than the differences in productivity assumed between the two global scenarios, despite the countervailing population growth assumptions.

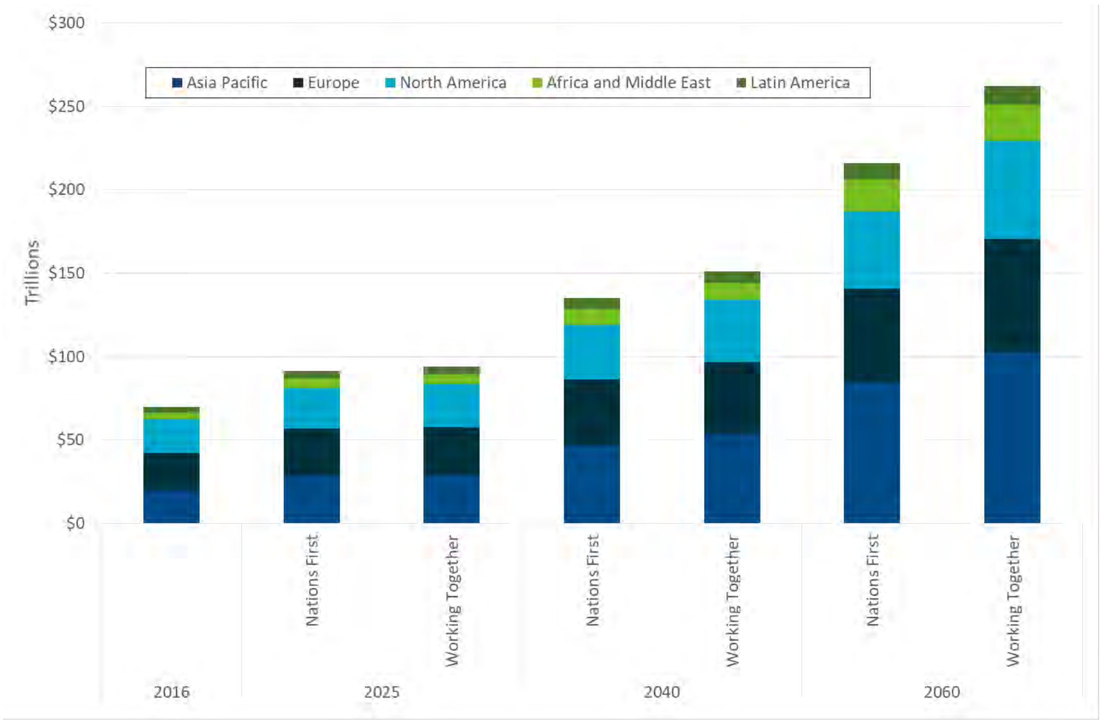

Figure 3.9 Global GDP projections by broader region, purchasing power parity (2015)

Source: Centre d'Etudes Prospectives et d'Informations, Fouré et al (2012, 2013) and CSIRO modelling

Figure 3.10 Global GDP projections by region and scenario: baseline calibration versus simulated result. Top: 2015 USD, Below: Purchasing Power Parity (2015)

Source: Centre d'Etudes Prospectives et d'Informations, Fouré et al (2012, 2013) and CSIRO modelling

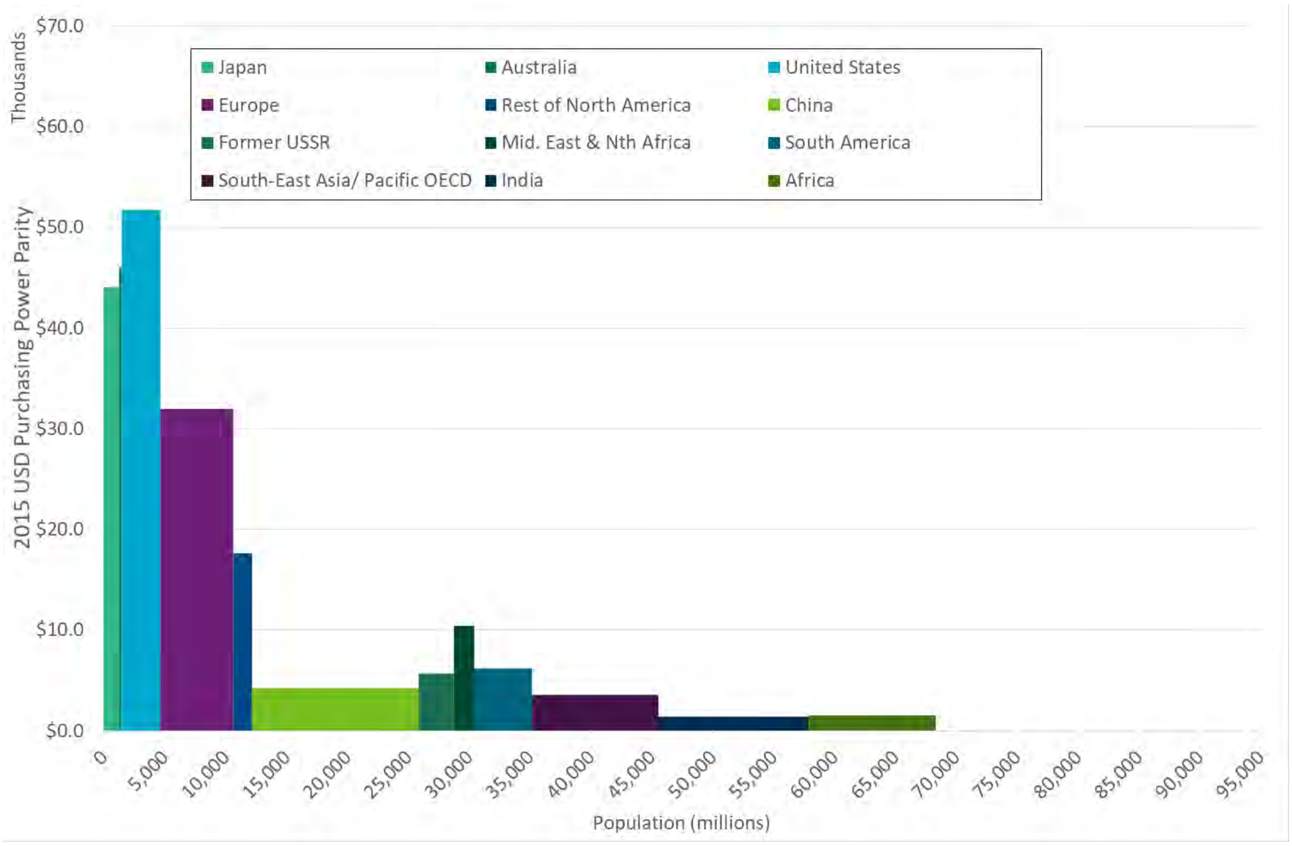

Figure 3.11 Gross Domestic Product per capita (in 2015 purchasing power parity equivalent) and population by region and scenario - 2012.

Source: Centre d'Etudes Prospectives et d'Informations, Fouré et al (2012, 2013) and CSIRO modelling

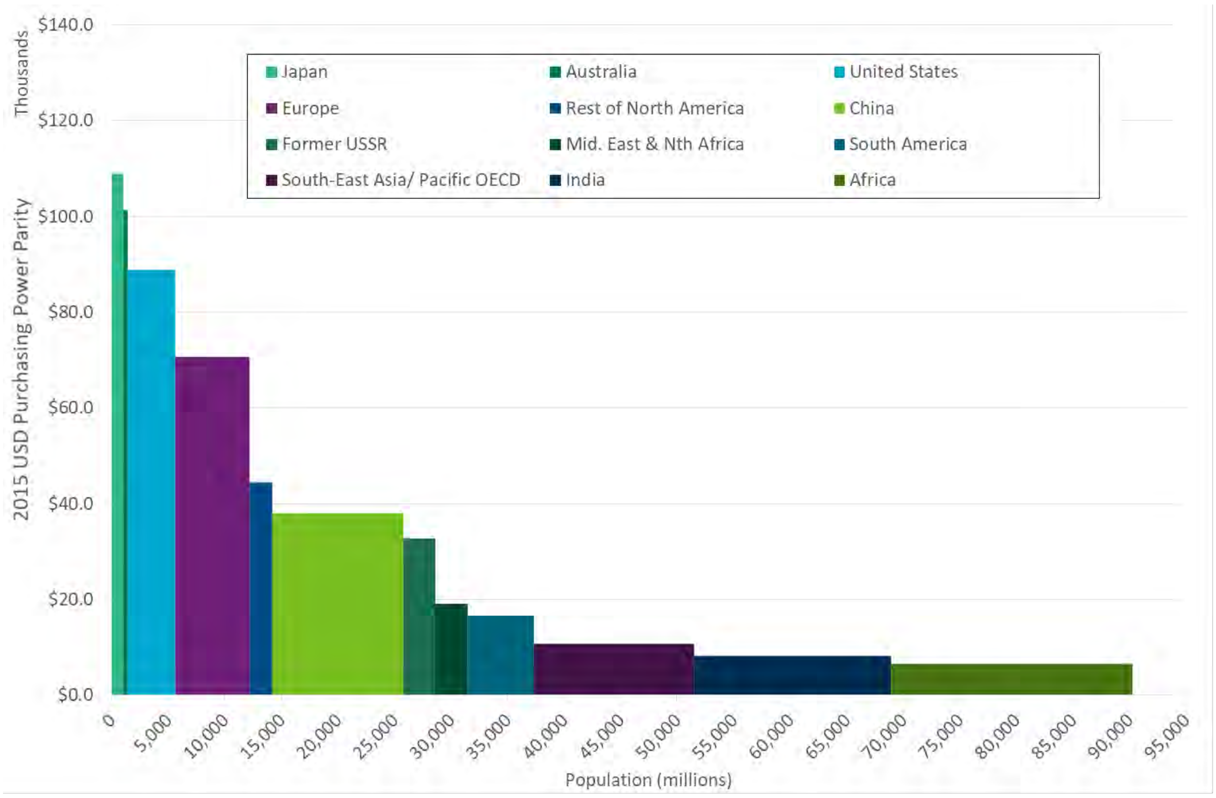

Figure 3.12 Gross Domestic Product per capita (in 2015 purchasing power parity equivalent) and population by region and scenario - 2060 *Nation First*

Source: Centre d'Etudes Prospectives et d'Informations, Fouré et al (2012, 2013) and CSIRO modelling

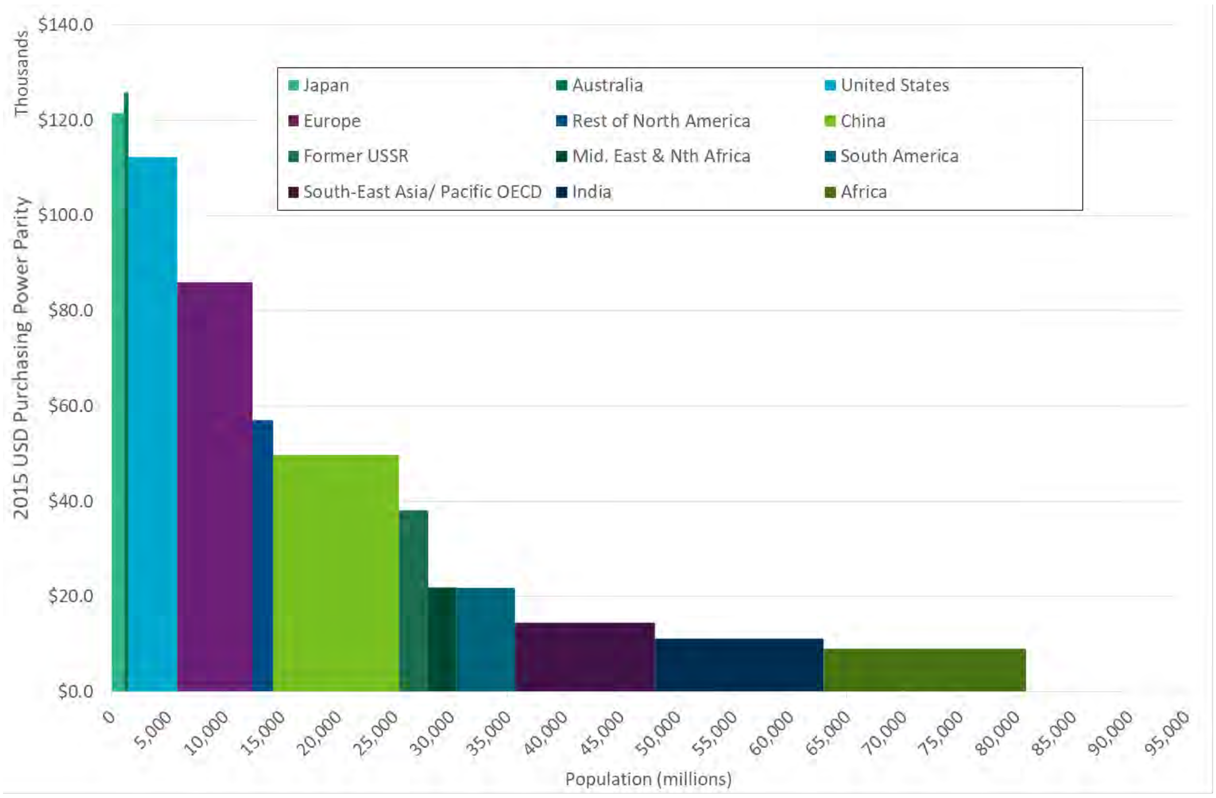

Figure 3.13 Gross Domestic Product per capita (in 2015purchasing power parity equivalent) and population by region and scenario - 2060 *Working Together*

Source: Centre d'Etudes Prospectives et d'Informations, Fouré et al (2012, 2013) and CSIRO modelling

Table 3.6 Population and Economic Growth Rate projections

	POPULATION		GDP (REAL)		PPP PER CAPITA	
	Nation First	*Working Together*	*Nation First*	*Working Together*	*Nation First*	*Working Together*
Africa	1.6%	1.2%	4.8%	5.1%	3.3%	4.0%
Middle East & Africa	1.2%	0.9%	3.4%	3.4%	1.4%	1.7%
China	-0.4%	-0.5%	4.6%	4.8%	5.0%	5.6%
India	0.8%	0.4%	4.6%	5.0%	4.0%	4.7%
South-East Asia	0.7%	0.4%	3.3%	3.6%	2.6%	3.2%
Japan	-0.5%	-0.3%	1.4%	1.9%	2.0%	2.3%
North America	0.6%	0.6%	2.0%	2.5%	1.4%	1.9%
Western Europe	0.3%	0.3%	2.0%	2.5%	1.6%	2.1%
Australia	1.2%	1.2%	3.3%	3.6%	1.8%	2.3%
Pacific OECD	-0.2%	0.0%	2.9%	3.4%	3.1%	3.5%
Latin America	0.5%	0.2%	2.9%	3.3%	2.2%	2.8%
Former Soviet Union	-0.1%	-0.2%	3.7%	3.8%	4.0%	4.3%
Eastern Europe	-0.3%	-0.3%	2.9%	3.4%	3.3%	3.8%
Global	0.6%	0.4%	2.8%	3.2%	2.1%	2.8%

Source: Centre d'Etudes Prospectives et d'Informations, Fouré et al (2012, 2013) and CSIRO modelling

3.5.2 Energy, Emissions and Climate

This section provides global contextual results for energy demand and supply, and the consequential emissions and prospective consequences for global climate change. For more details of the latter, see Chapter 13.

3.5.2.1 Global Energy demand

We consider here how the GDP and energy demand projections from GTAP-ANO compare to global energy scenarios developed by Shell (2018) and the International Energy Agency (IEA 2017a,b). The available scenarios from the International Energy Agency have projections finishing at 2040, and include 'Current Policies' and 'New Policies', the latter closer than the former to a 'Four degrees track' approach to emissions. The IEA scenarios also include a 'Sustainable Development' scenario, which aspires to global temperature increases of below 2 degrees and so is more ambitious than the 'two degrees track' associated with *Working Together*. A relevant comparison Shell scenario is "Sky", a strong decarbonisation scenario.

Since we assume that demand for energy is driven by economic growth, Figure 3.14 compares GDP across geographic groupings. GTAP-ANO, Shell and IEA all show GDP growth declining slightly over time, with Shell and IEA growth projections slightly higher in the nearer term (2016-2025) and slightly lower in the longer term. By region, the higher growth rates in the near term in the comparison sources relative to ANO 2019 modelling is almost entirely within the Asia Pacific.

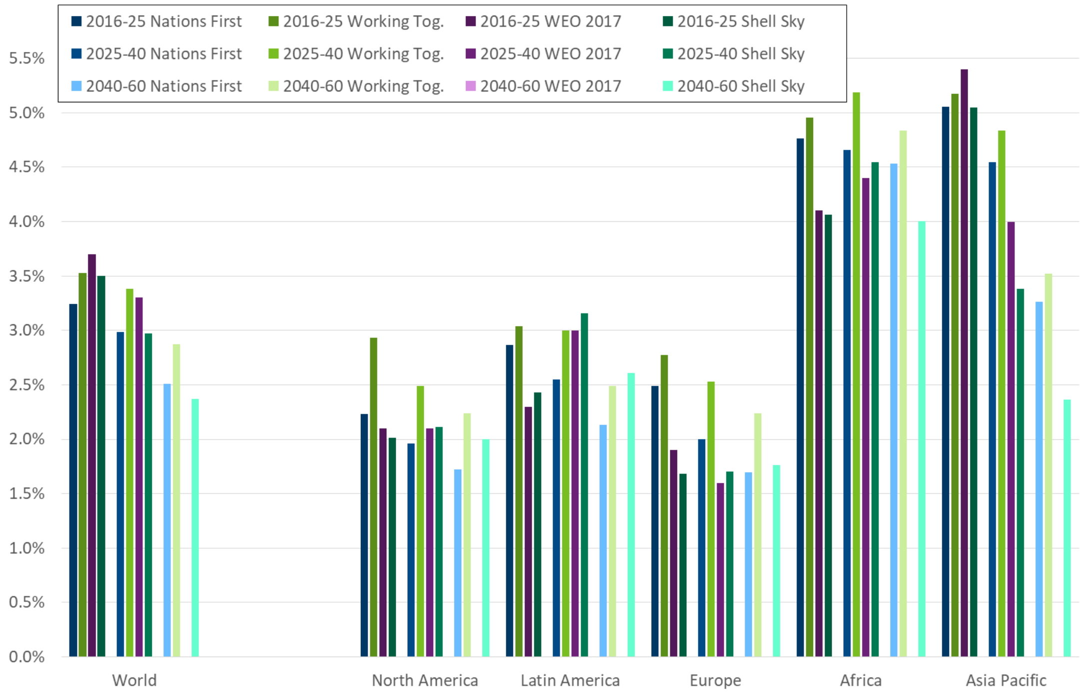

Figure 3.14 Global Domestic Product Growth rates Scenario comparisons

Source: Shell, International Energy Agency and CSIRO modelling

Primary energy demand projections in the near term by Shell and IEA are slightly higher than the ANO 2019 results (Figure 3.16), consistent with higher GDP growth. At 2040 the projections for total primary energy demand from GTAP-ANO *Nation First* are lower than IEA projections under their Current Policies and New Policies Scenarios. The GTAP-ANO *Working Together* primary energy demand projections are lower than *Nation First*, despite the higher GDP, but are still higher than both the IEA “Sustainable Development” and Shell “Sky” scenarios. Projections in 2060 for both ANO 2019 global scenarios remain higher than for Shell “Sky”.

In 2025 the proportional mix of primary energy sources (coal, oil, gas) is fairly similar across the three sources. By 2040, the higher primary energy demand in “Current Policies” and “New Policies” relative to *Nation First* and in *Nation First* relative to *Working Together* is reflected in a an increased proportion of coal. Similarly, the lower primary energy demand in “Sustainable Development” and “Sky” relative to *Working Together* is reflected in a lower proportional share of coal. By 2060 however, the ANO global scenarios relative to Shell “Sky” show a lower proportional reliance on coal and a much greater role for gas.

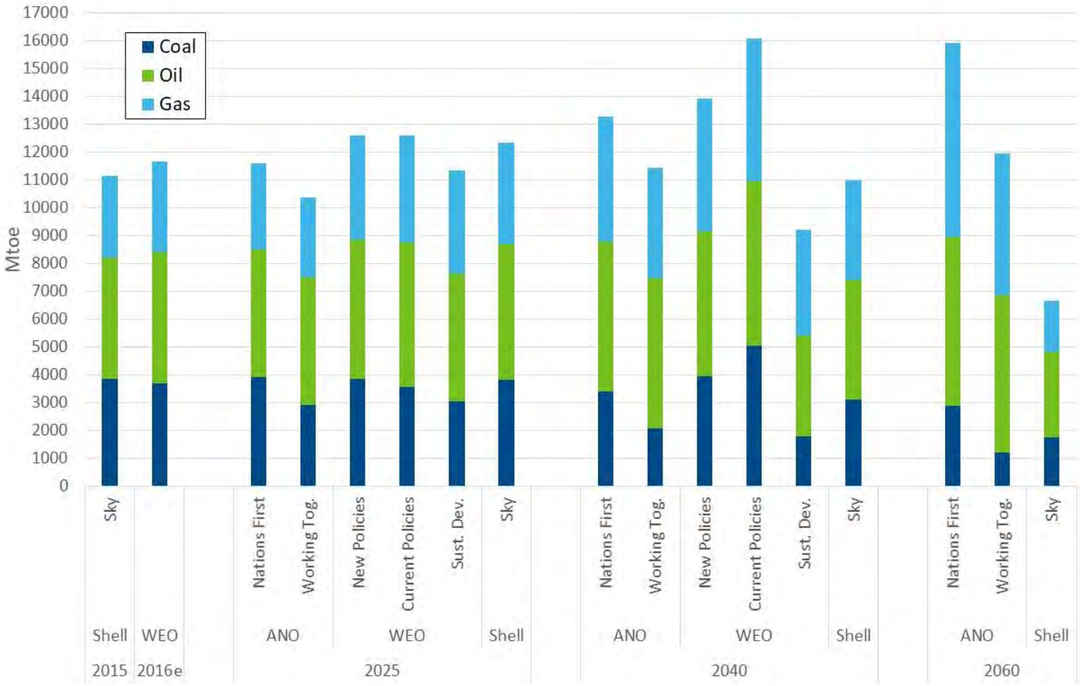

Figure 3.15 Primary Energy Demand Comparisons: Stacked

Source: Shell, International Energy Agency and CSIRO modelling

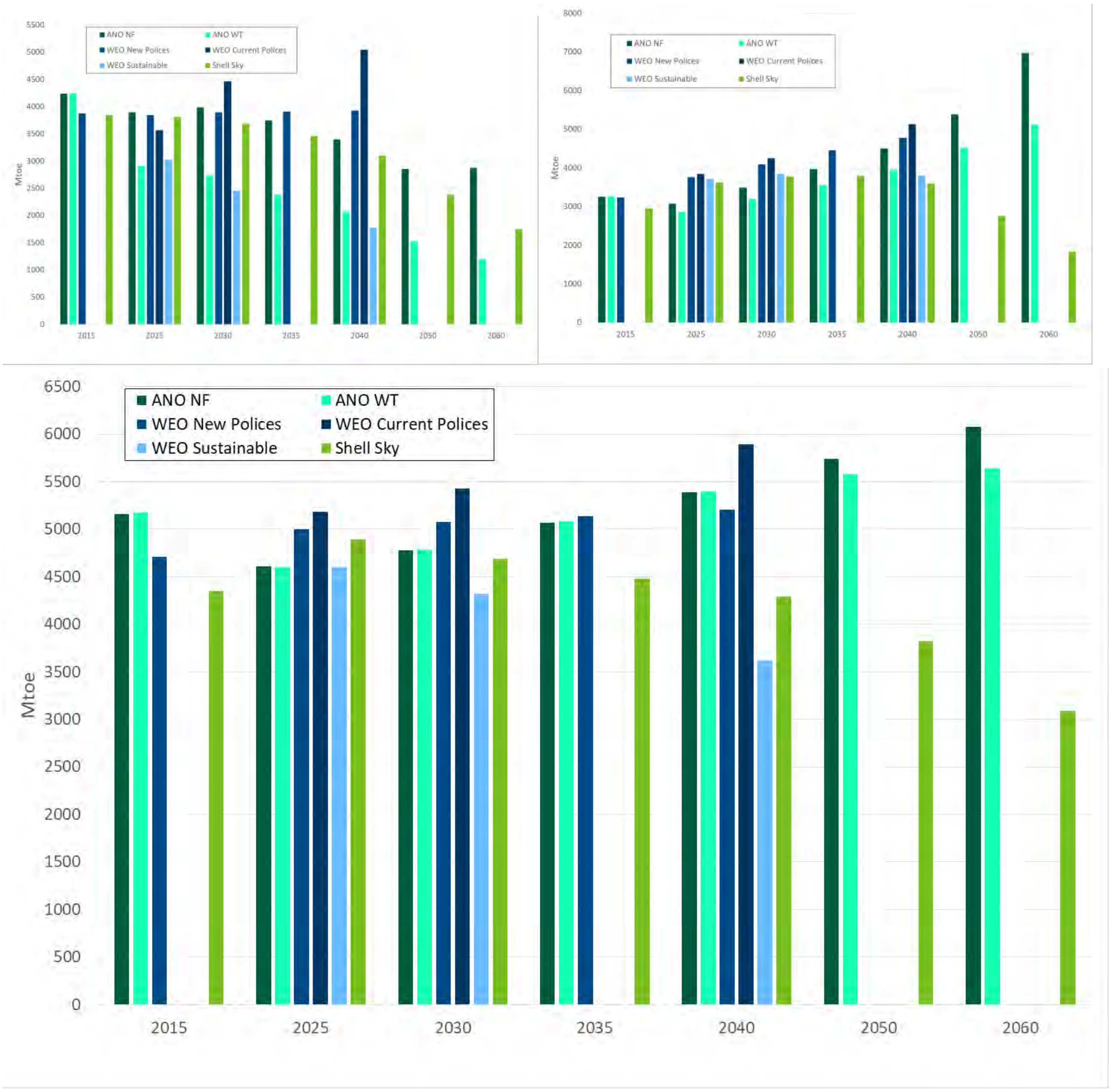

Figure 3.16 Primary Energy Demand Comparisons: Top left – Coal, Top right – Gas, Bottom - Oil.

Source: Shell, International Energy Agency and CSIRO modelling

In absolute terms, coal demand projections for *Nation First* match reasonably well to “Current Policies” and “New Policies”, with *Working Together* matching reasonably well to “Sustainable Development”, but “Sky” projections for Coal are somewhat higher. Oil demand projections in ANO 2019 are between “Current Policies” and “New Policies”, which show slightly increasing demand, and between “Sustainable Development” and “Sky” which show decreasing demand. The same trends apply with gas. The ANO 2019 projections show oil demand increasing moderately, and gas demand increasing even more, whereas “Sky” shows a reasonably rapid decrease in the later years.

There is, however, a significant difference in projections of electricity consumption in the ANO 2019 scenarios compared to both comparison sources. For global electricity projections we are able to include an additional two comparison scenarios from Energy Technology Perspectives, namely a "Reference Technology" scenario (RTS) and a "Two Degrees Scenario". Both *Nation First* and *Working Together* show significant growth in electricity consumption, more than any of the comparison scenarios; while the Shell "Sky" scenario shows greater growth than the IEA scenarios (Figure 3.17). The ANO 2019 projections for global electricity demand are half as much again as "Sky" and close to twice that of both the Energy Technology Perspectives scenarios.

The GTAP-ANO is a general equilibrium model, whereas the World Energy Model used by the IEA is a partial equilibrium model of the energy sector, so that GTAP-ANO represents not only price motivated fuel switching from higher to lower emissions sources in the face of an emissions price, it also permits price motivated extension of demand. Also, the World Energy Model includes sectorally detailed technological options for energy efficiency improvements that are not included in GTAP-ANO, except through a marginal abatement cost curve (see Chapter 10) that is not sectorally specific and reasonably conservative. The high projected demand for electricity in the ANO 2019 scenarios makes it quite challenging to achieve low emissions, particularly in the *Working Together* global scenario. This reflects a broader economic analysis of potential change, including a price motivated increase in electricity demand. It also reflects more conservative assumptions on the potential for improvements in technical energy efficiency, as we were unable to obtain reliable data that respected the economic sectoral and regional disaggregations applied in our models.

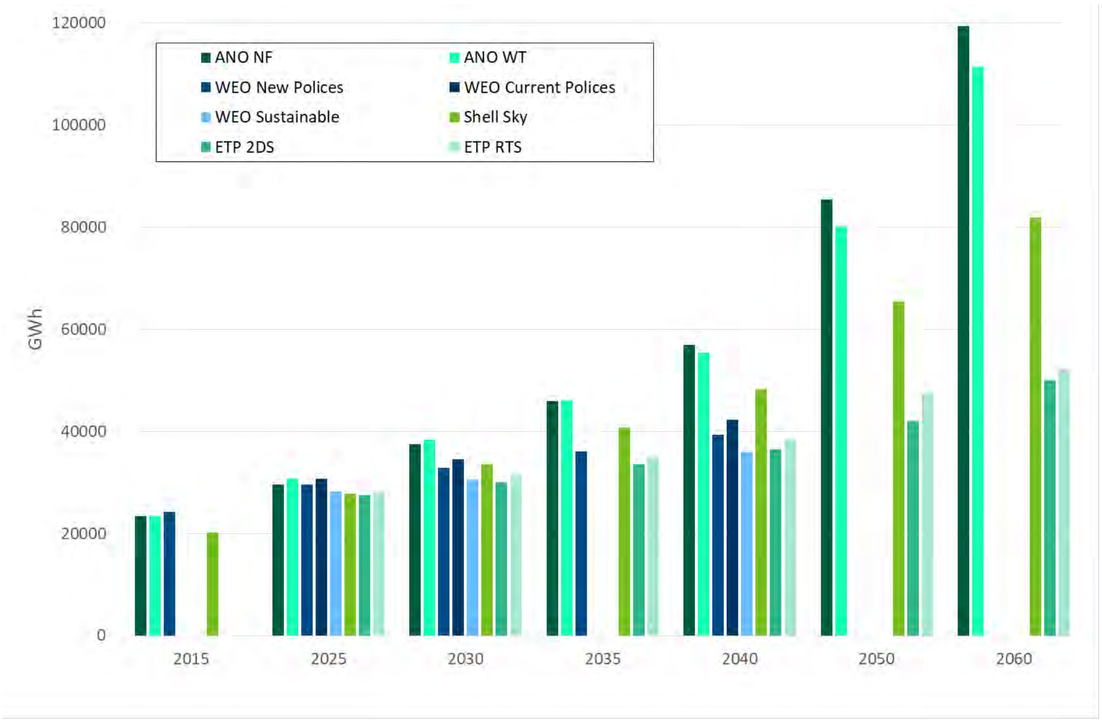

Figure 3.17 Electricity demand

Source: Shell, International Energy Agency and CSIRO modelling

3.5.2.2 Endogenously calculated primary energy prices

Endogenous price trajectories for primary energy commodities (not including an emissions price) appear in Figure 3.18. It can be seen that there is little difference between the two global scenarios and little difference from the baseline calibration case. Endogenous gas prices are a little lower than the baseline, with oil prices marginally lower and coal prices marginally higher;, and these effects are slightly more pronounced in the *Working Together* case. It is to be expected that demand for emissions-generating fuel is lower as an emissions price is introduced, contracting demand and reducing prices, even though economic growth in the *Working Together* scenario is greater than for *Nation First* (see below). An increase in price for higher emissions coal is counter-intuitive.

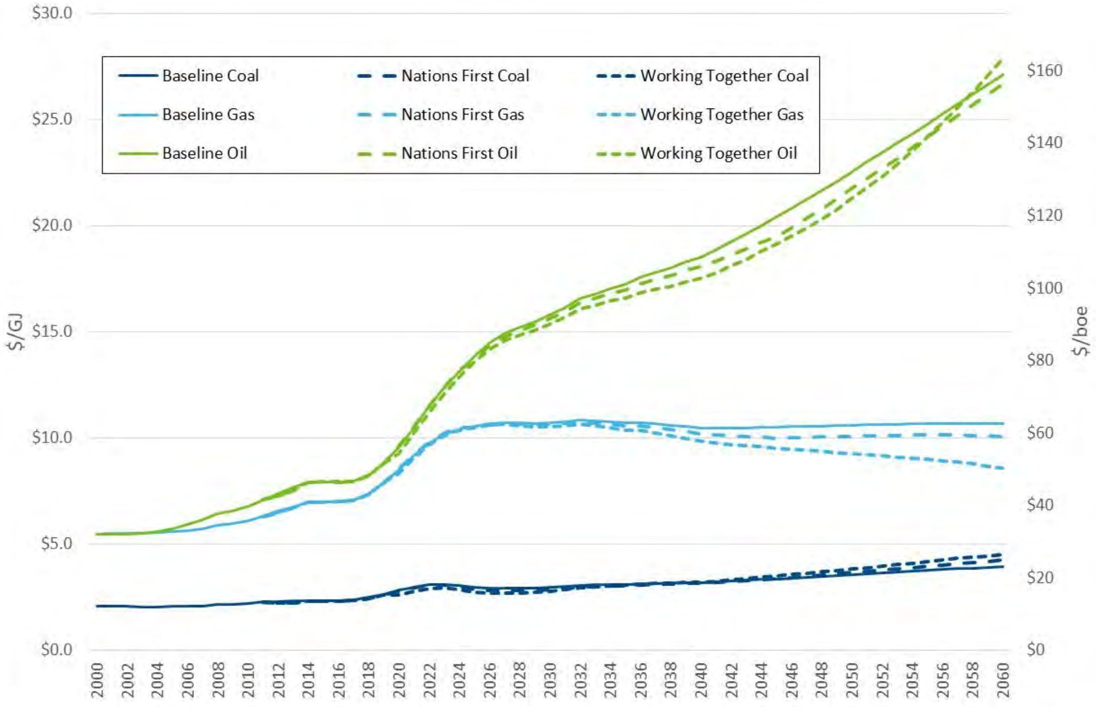

Figure 3.18 Endogenous fossil fuel price trajectories

Source: Energy Information Administration, International Energy Agency and CSIRO modelling

3.5.2.3 Global electricity supply

Under the carbon emissions prices described in Section 3.3.3, and the resulting in the electricity demand projections as described in Section 3.5.2.1, the projected global energy supply mix appears in Figure 3.19 and Figure 3.20. Electrical generation from coal and gas grows in the *Nation First* scenario, but in the *Working Together* scenario, the higher emissions prices drives down the supply of electricity from coal, with carbon capture and storage being installed in the later years, while carbon capture and storage allows the demand for gas generation to grow strongly. The supply of electricity from renewables is slightly higher in the *Working Together* scenario, and there is slightly more biomass. For more detailed discussion see Chapter 11. It will be seen in following sections that emissions from the electricity generation sector increase under the *Nation First* scenario, but decline in *Working Together*.

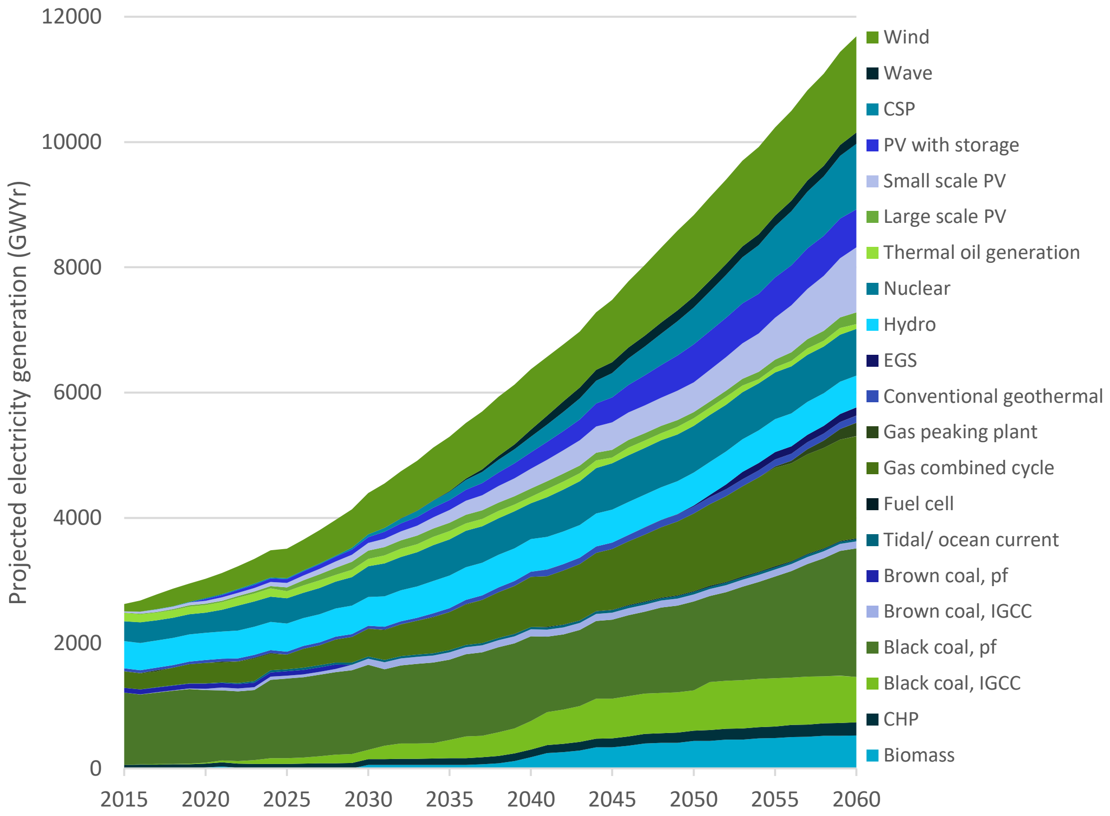

Figure 3.19 Projected global electricity generation under *Nation First* scenario

Source: CSIRO modelling

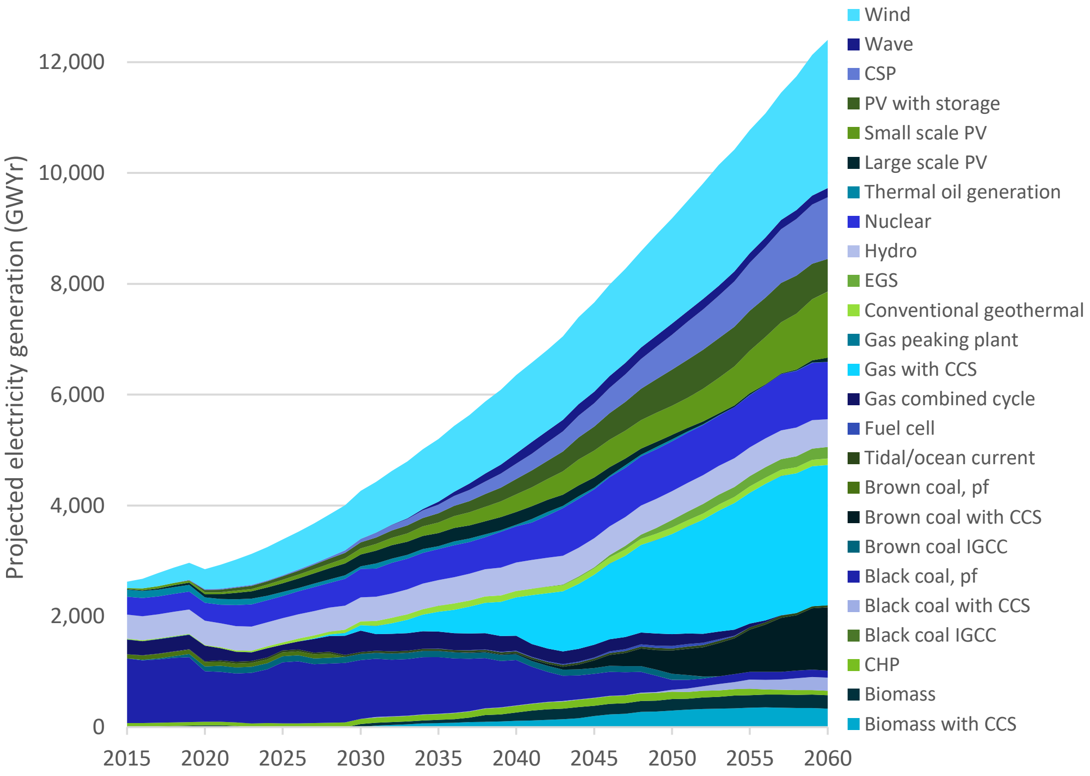

Figure 3.20 Projected global electricity generation under *Working Together* scenario

Source: CSIRO modelling

Figure 3.21 shows how the costs of various alternative electricity generation technologies evolve under the two global scenarios. The major difference is that the costs of carbon capture and storage technologies are expected to decline much faster in the *Working Together* scenario as greater deployments lead to cost reductions due to technological learning (Hayward and Graham 2013). This starts to take place in the early 2020s. The difference between the two scenarios is much less marked for renewable technologies such as wind and photovoltaics, and batteries. Since these renewables are projected to be cost competitive in either scenario, their global deployment in our modelling is limited primarily by the availability of resources. Similarly, our models show that the global demand for batteries will be influenced most significantly by deployment in electric vehicles and to support variable renewables, both markets that we expect to grow even under conditions of relatively modest global action on climate change, due to projected ongoing cost reductions (see Chapter 11).

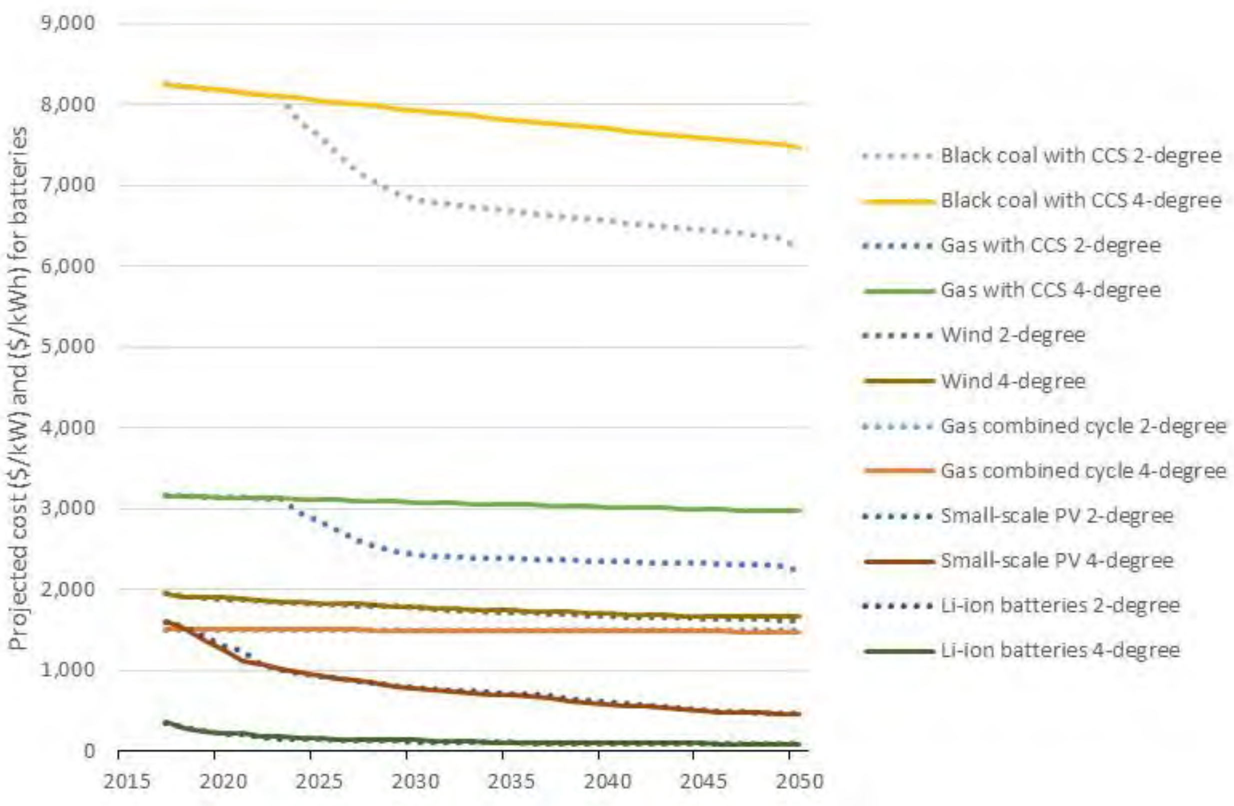

Figure 3.21 Projected technology cost projections under the *Working Together* and *Nation First* scenarios

Source: CSIRO modelling

3.5.2.4 Global transport sector results

The mix of fuel supply in the transport sector is shown in Figure 3.22. The total demand for fuels in 2060 is higher in *Working Together*, due to the higher GDP, but the fuel mix is very similar. Fossil fuel use quantities are similar in both global scenarios but declines significantly from 2030 to 2060 as it is replaced by electricity.

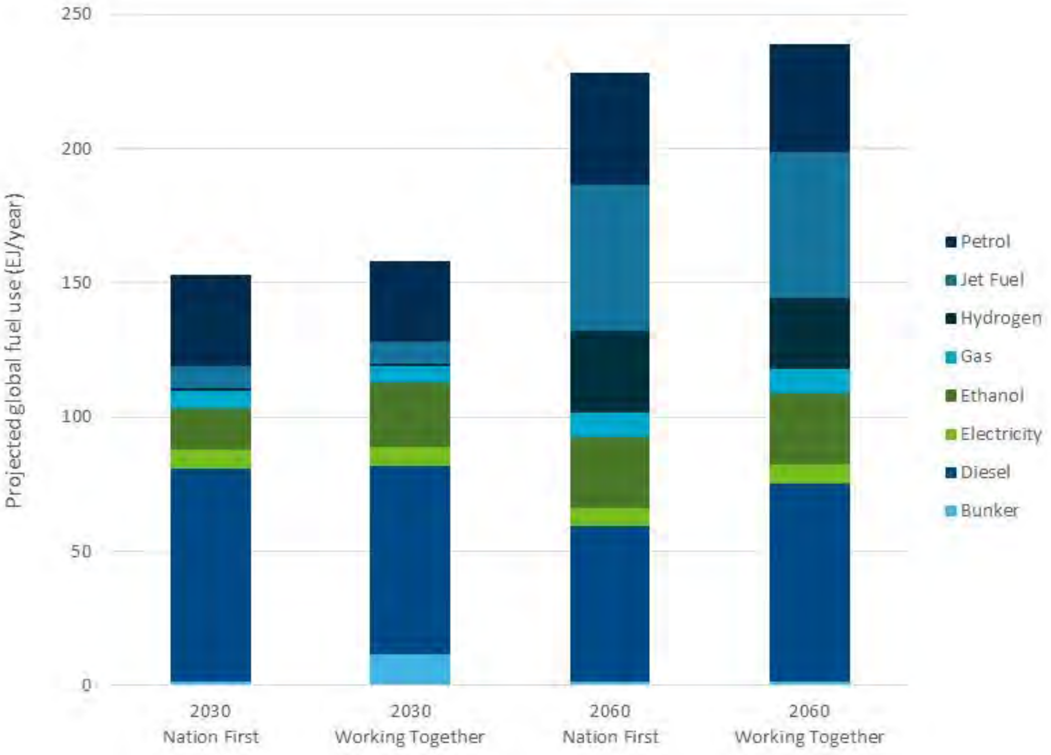

Figure 3.22 Projected global fuel use in the years 2030 and 2060 for the *Working Together* and *Nation First* scenario

Source: CSIRO modelling

3.5.3 Greenhouse gas emissions and climate response

With the emissions pricing settings as described in Section 3.3.3, Figure 3.23 illustrates the projections for global emissions aggregated across four major categories of greenhouse gases (CO_2, CH_4, N_2O and fluorinated gases), from each of the global models, the GLOBIOM emulator for land-use including agriculture, GALLME for the electricity sector, GALLMT for transport and GTAP-ANO for the remaining economic sectors.

The GNOME.3 projections are shown (the blue line) compared to emissions from two particular comparison scenarios extracted from the SSP database (Riahi et al. 2017) that are consistent with Representative Concentration Pathways 6.0 (the intended benchmark for the ‘four degrees track’) and 2.6 (the intended benchmark for the ‘two degrees track’). It can be seen that the projections for the ANO 2019 scenarios (which only extend to 2060) do not achieve the emissions abatement required to match the benchmark RCP trajectories.

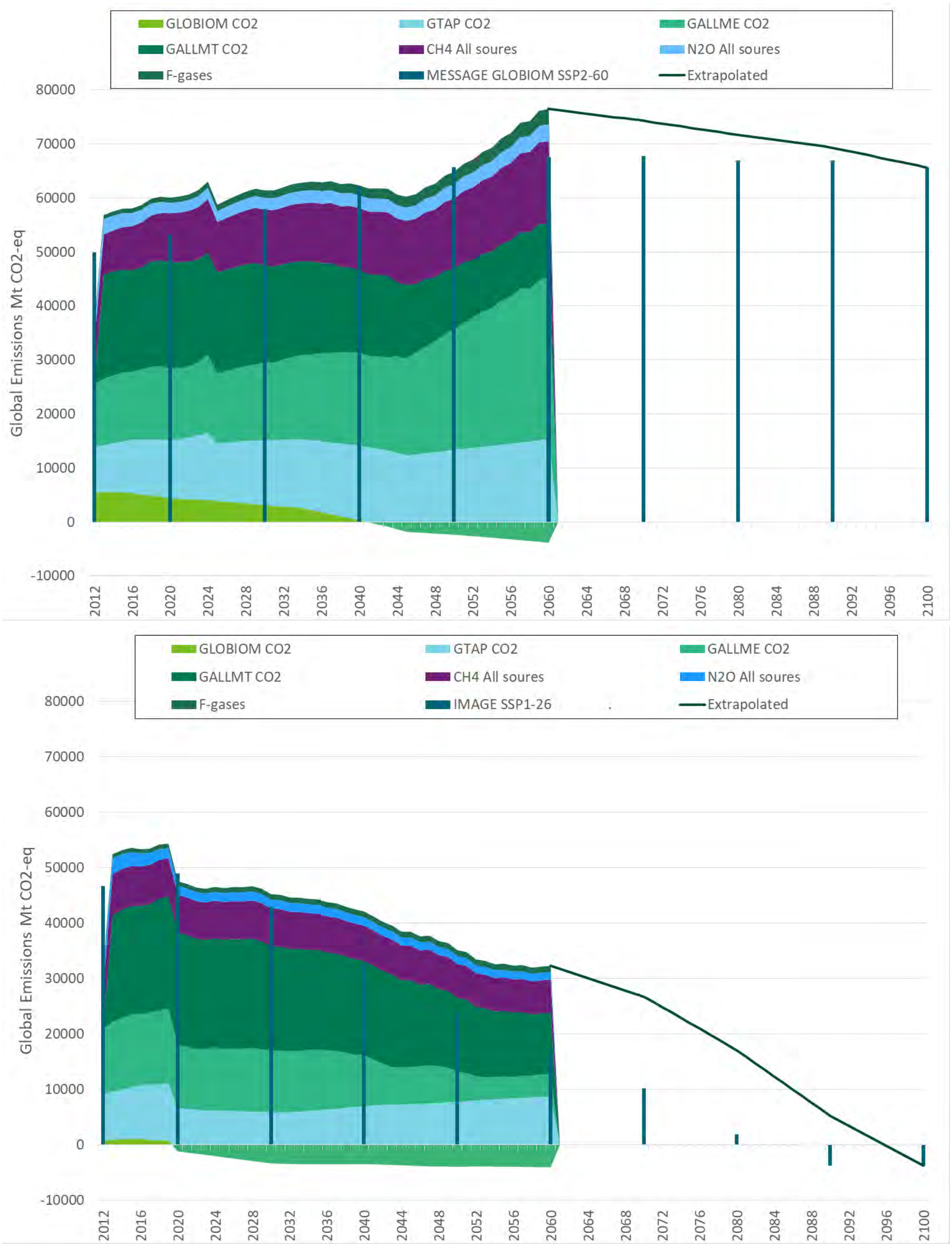

Figure 3.23 Greenhouse emissions projections: ANO 2019 models and decadal SSP Database comparisons [Top *Nation First* global scenario, Bottom *Working Together* global scenario

Source: International Institute of Applied Systems Analysis and CSIRO modelling

For the purposes of completing the climate impacts modelling using MAGICC we have extrapolated the GNOME.3 suite emissions projections at 2060 by converging towards the target scenario emissions to 2100. This is shown in the charts as the brown line. For more details see Chapter 13.

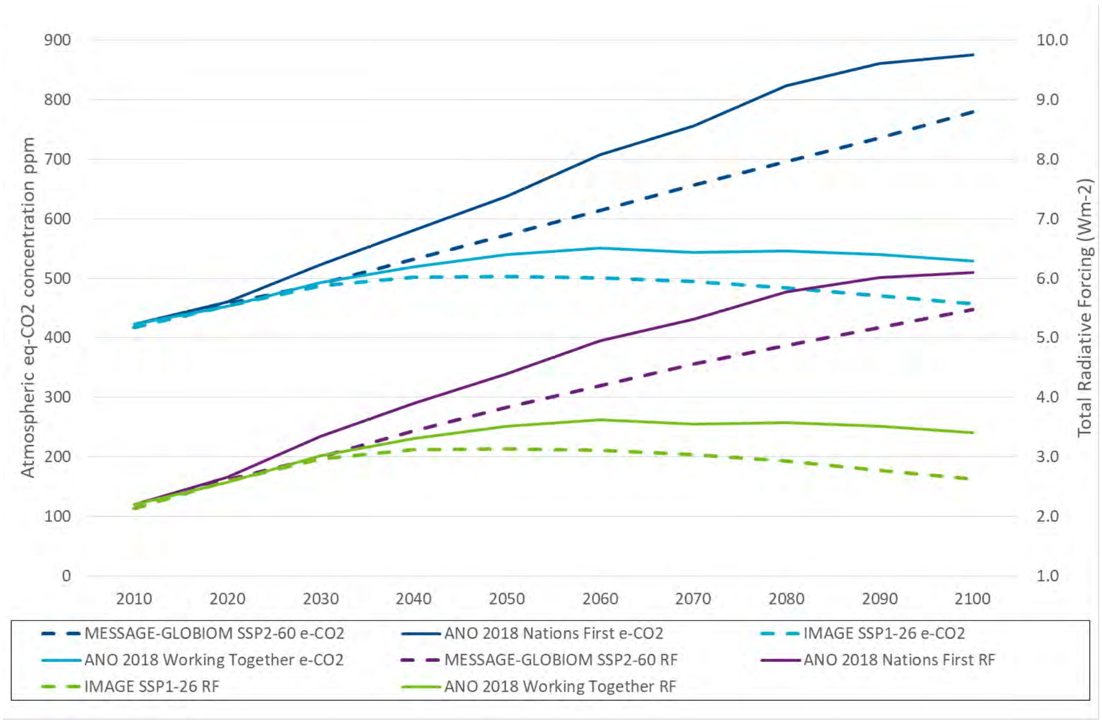

Figure 3.24 Atmospheric concentration greenhouse emissions eq-CO₂ (left axis) and radiative forcing (right axis)

Source: International Institute of Applied Systems Analysis and CSIRO modelling

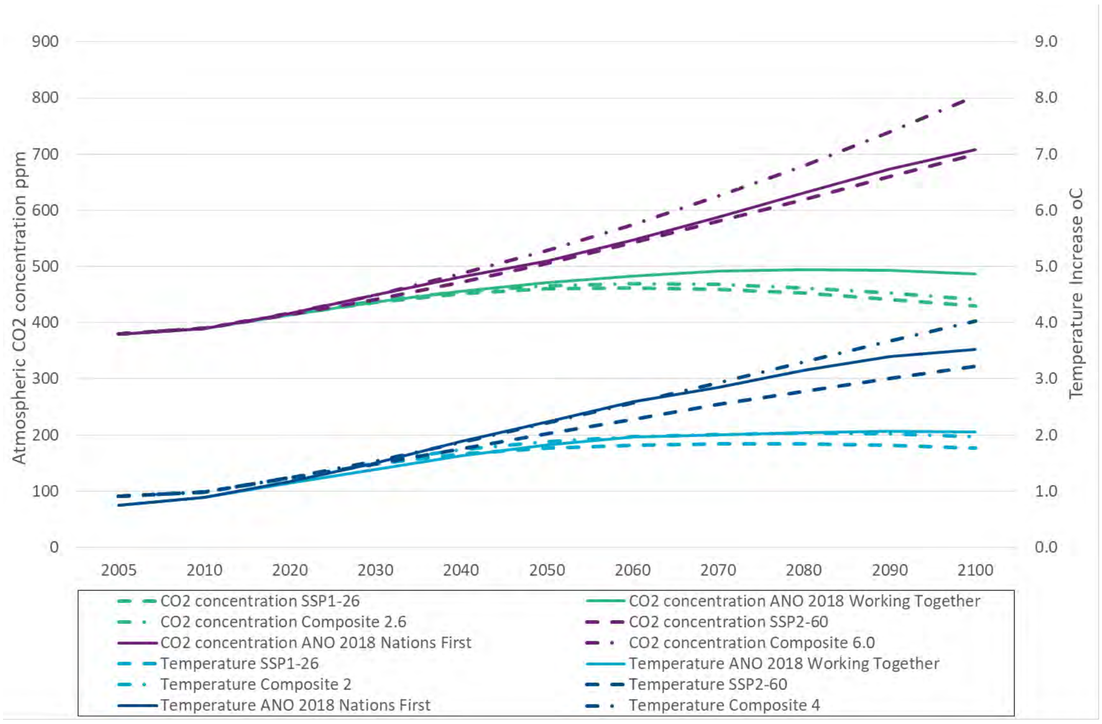

Figure 3.25 Atmospheric concentration CO₂ only (left axis) and temperature rise (right axis)

Source: International Institute of Applied Systems Analyis and CSIRO modelling

The corresponding climate responses modelled by MAGICC are shown in Figure 3.24 and Figure 3.25, which provide comparisons against two specific scenarios from the SSP database. Also shown are comparisons from two sets of data, each comprising an average of four scenarios from the SSP database that have a projected expected average temperature increase at 2100 of close to four degrees and two degrees relative to pre-industrial times. Given that the annual emissions trajectory projections are higher than the selected individual benchmarks, the corresponding atmospheric concentrations of CO_2 are higher, the anthropogenic radiative forcing (and hence atmospheric concentrations of all greenhouse gases expressed in eq-CO_2) is higher, and the projected temperature increase is higher.

3.5.4 Materials Demand

Demand for non-energy materials as projected by GTAP-ANO increases strongly in absolute terms in both global scenarios. Demand for each of non-metal minerals, iron and steel, and non-ferrous metals increases faster than GDP, so that demand intensity relative to GDP also increases. This is significantly different from projections in ANO 2015, as there has been no particular assumptions about a push towards dematerialisation, which was of particular interest in the earlier study. These results for the *Working Together* scenario are also not consistent with the qualitative description of the ‘Peak Early’ intended setting in the Materials Demand global issue.

See Figure 3.26 (non-metals), Figure 3.27 (iron and steel), and Figure 3.28 (other metals) for indicative demand indices scaled to 100 in 2015, showing the relative contribution to global demand by region. The charts show demand both unscaled, and intensity relative to global GDP. These results were calculated from the growth rates for the GTAP-ANO demand quantity by region. The regional proportion of global demand in the base year was inferred from base data from the GTAP 9 database corresponding to the value of economic activity, consisting of the sum of domestic consumption by firms, government and households (at market prices) plus imports (at world prices).

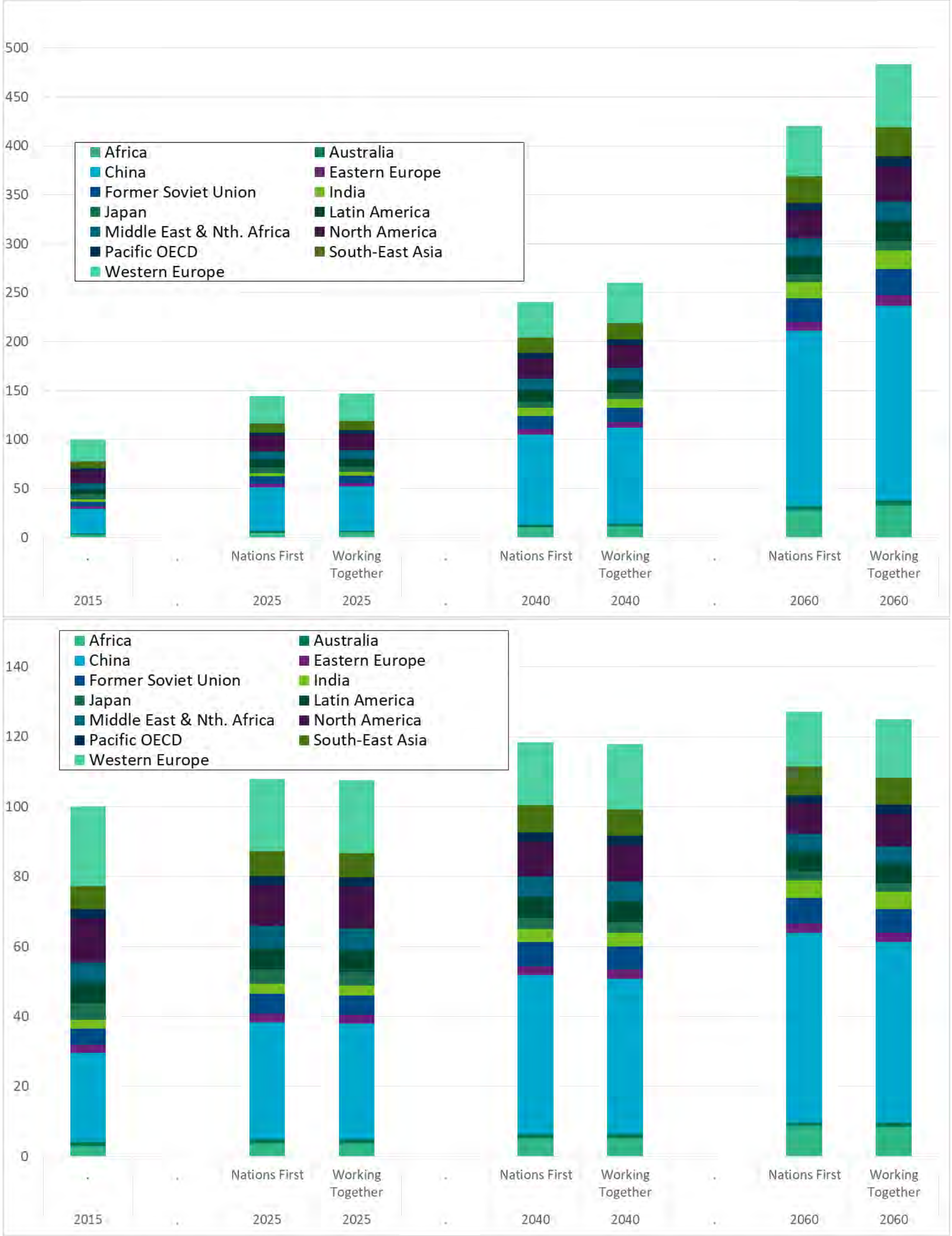

Figure 3.26 Non-metal minerals: Demand and Global GDP intensity, index 2015=100

Source: Fouré et al (2012, 2013), Aguiar, Narayanan and McDougall (2016) and CSIRO modelling

The carbon emissions price in the *Working Together* scenario is enough to slightly reduce the materials intensity relative to *Nation First*, however the difference in GDP is such that the *Nation First* materials demand indices are higher in absolute terms. Demand for materials in each category increases by factors ranging from 4x to 6x current global demand, with materials intensity increasing in the range 20-40%, and demand for metals increasing slightly faster than demand for non-metals.

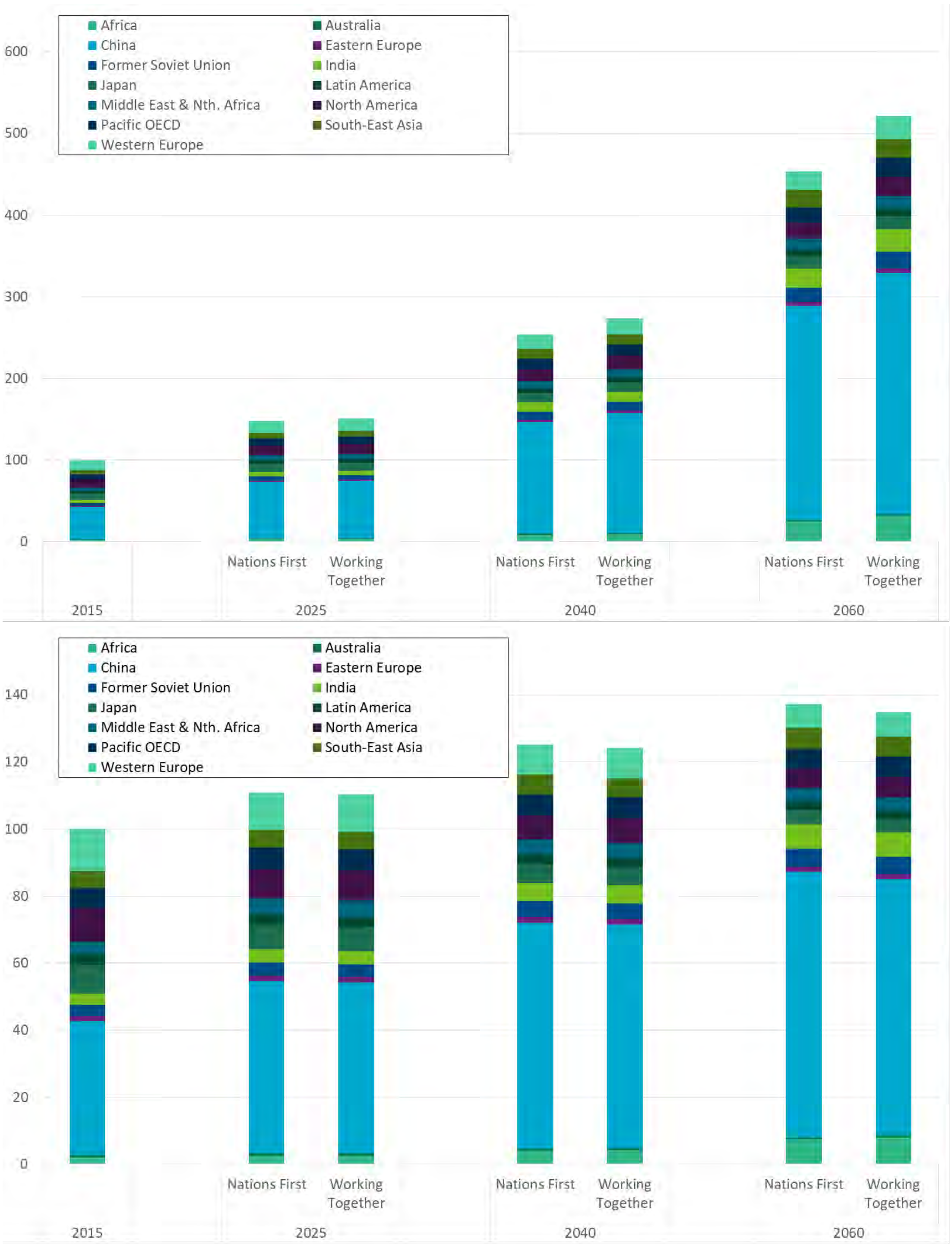

Figure 3.27 Iron and Steel: Demand (top) and Global GDP intensity (bottom), index 2015=100

Source: Fouré et al (2012, 2013), Aguiar, Narayanan and McDougall (2016) and CSIRO modelling

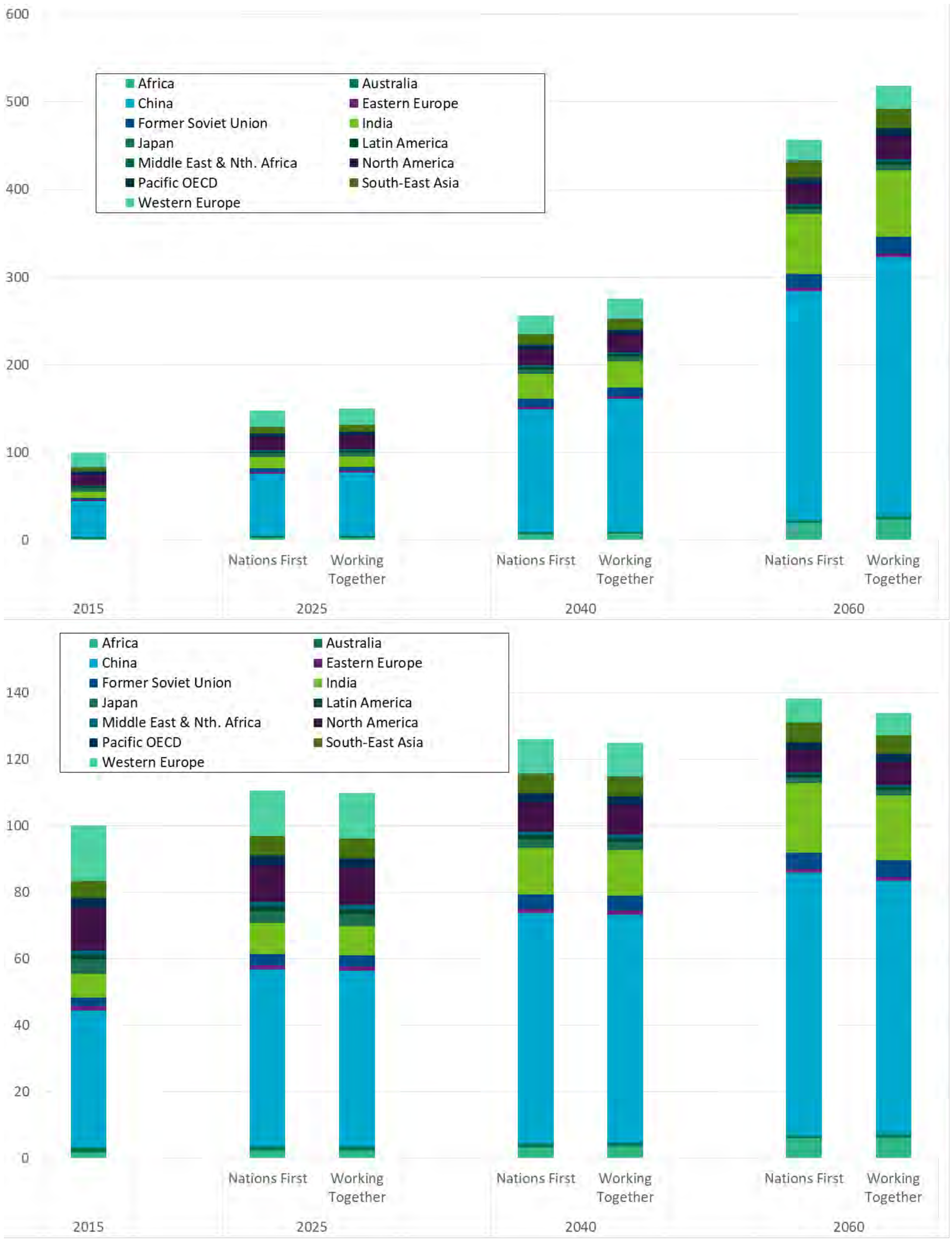

Figure 3.28 Non-ferrous metals: Demand and Global GDP intensity, index 2015=100

Source: Fouré et al (2012, 2013), Aguiar, Narayanan and McDougall (2016) and CSIRO modelling

China is responsible for approximately a quarter of global demand for non-metals and some 40% of metals in 2015, increasing to almost half of global demand for non-metals and more than half for metals by 2060. Even though the material intensity of China increases only slightly for non-metals and decreases slightly for metals to 2060, its projected average GDP growth rates of 4.6% and 4.8% pa result in a market increase in global share of materials.

Table 3.7 shows materials intensity by region. Metals demand intensity decreases in relatively higher income regions such as Western Europe, North America, Japan, Latin America, Australia, Pacific OECD but increases strongly in lower income regions such as Africa, the Former Soviet Union, and India (non-ferrous metals). Metals intensity has a similar pattern, except for Western Europe, which sees a slight increase. Metals intensity increases strongly in Africa, the Former Soviet Union and Eastern Europe. The global growth in materials intensity is explained by a small number of regions with high materials intensity and currently modest relative contribution to global GDP experiencing a significant GDP growth (Table 3.8), notably China for all three categories of materials. India contributes somewhat to the global growth in demand for metals other than iron and steel, and Western Europe continues to make a reasonable contribution to the demand for non-metals 2060, even as its intensity declines, and North America declines in significance as a contributor to global materials demand.

Table 3.7 Materials demand intensity index in 2060 relative to 2015

	NON-METAL MINERALS		IRON AND STEEL		NON-FERROUS METALS	
	NATION FIRST	***WORKING TOGETHER***	***NATION FIRST***	***WORKING TOGETHER***	***NATION FIRST***	***WORKING TOGETHER***
Africa	136.4	138.9	171.0	186.4	164.8	176.2
Australia	76.6	83.5	57.2	67.2	37.3	47.3
China	106.8	107.8	99.8	102.6	97.2	99.7
Eastern Europe	115.6	113.6	100.9	94.4	87.4	80.0
Former Soviet Union	120.6	125.7	120.1	129.9	140.0	161.2
India	102.0	100.5	106.4	104.7	141.1	131.9
Japan	95.4	90.5	93.1	82.3	71.9	62.6
Latin America	97.9	96.8	85.3	82.4	76.9	72.6
Middle East & Nth. Africa	81.5	88.5	88.3	100.0	42.3	49.8
North America	98.2	98.0	86.7	84.4	76.0	72.0
Pacific OECD	97.8	96.7	97.2	95.5	81.8	79.1
South-East Asia	107.9	103.1	113.9	106.4	101.1	94.1
Western Europe	102.0	103.1	82.5	80.0	63.2	57.8
Global	127.1	124.9	137.2	134.7	138.2	133.9

Source: Fouré et al (2012, 2013), Aguiar, Narayanan and McDougall (2016) and CSIRO modelling

Table 3.8 Regional contribution to global materials demand in 2060

	% OF GLOBAL GDP			NON-METAL MINERALS			IRON AND STEEL			NON-FERROUS METALS		
	2015	**2060** ***NATION FIRST***	**2060** ***WORKING TOGETHER***	**2015**	**2060** ***NATION FIRST***	**2060** ***WORKING TOGETHER***	**2015**	**2060** ***NATION FIRST***	**2060** ***WORKING TOGETHER***	**2015**	**2060** ***NATION FIRST***	**2060** ***WORKING TOGETHER***
Africa	3.1%	6.7%	6.5%	2.9%	6.7%	6.7%	2.0%	5.5%	5.9%	1.7%	4.3%	4.6%
Australia	1.8%	2.2%	2.2%	1.2%	0.9%	1.0%	0.8%	0.4%	0.5%	1.7%	0.6%	0.7%
China	10.9%	21.7%	20.3%	25.6%	42.7%	41.2%	39.9%	57.7%	56.8%	41.0%	57.3%	56.9%
Eastern Europe	1.6%	1.6%	1.7%	2.3%	2.0%	2.1%	1.5%	1.1%	1.1%	1.4%	0.9%	0.9%
Former Soviet Union	3.9%	5.2%	4.6%	4.7%	5.8%	5.5%	3.4%	3.9%	3.9%	2.6%	3.5%	3.7%
India	2.5%	5.3%	5.3%	2.3%	3.9%	4.0%	3.2%	5.3%	5.3%	7.0%	15.1%	14.6%
Japan	8.1%	4.4%	4.6%	4.8%	1.9%	2.0%	8.6%	3.1%	3.0%	4.3%	1.2%	1.1%
Latin America	7.2%	6.9%	6.8%	6.0%	4.5%	4.4%	3.2%	1.9%	1.8%	1.5%	0.8%	0.8%
Middle East & Nth. Africa	4.0%	4.6%	3.9%	5.5%	4.1%	3.9%	3.9%	2.9%	2.9%	1.2%	0.4%	0.4%
North America	24.9%	17.1%	18.6%	12.8%	6.8%	7.5%	9.8%	4.3%	4.6%	12.9%	4.9%	5.2%
Pacific OECD	1.9%	1.9%	2.0%	2.6%	1.9%	2.1%	6.2%	4.3%	4.6%	2.8%	1.6%	1.8%
South-East Asia	5.1%	5.7%	5.6%	6.7%	6.5%	6.2%	4.9%	4.6%	4.3%	5.3%	4.4%	4.1%
Western Europe	25.0%	16.8%	17.9%	22.6%	12.2%	13.4%	12.6%	5.1%	5.4%	16.5%	5.1%	5.1%

Source: Fouré et al (2012, 2013), Aguiar, Narayanan and McDougall (2016) and CSIRO modelling

3.5.5 Australian export markets

Figure 3.29 Australian agricultural export price indices

Source: International Institute of Applied System Analysis and CSIRO modelling

The global modelling suite in ANO 2019 provides global context settings for the national modelling. In addition to global primary fossil energy prices (Section 3.5.2.2) and the costs of energy generation technologies (Section 3.5.2.3), the other key global scenario settings that significantly influence the national outlook are those for international trade. These include export prices in agricultural markets which appear in Figure 3.29. The price index for agricultural commodities, that have a significant contribution to (non-CO_2) greenhouse emissions, is higher in the *Working Together* global scenario, whose emissions price trajectory is much higher than in *Nation First*. As livestock has a greater emissions intensity than crops (CH_4), the impact of the global carbon price on livestock is correspondingly greater.

International trade prices with the carbon price included are higher in the Working Together scenario than in Nation First However, the effective price received by a domestic producer will be a lower price that excludes the carbon price component. For a domestic producer, the net effect is an additional cost except where their production processes are less emissions intensive than the global average that sets the international benchmark prices. In ANO 2019, this relationship is modelled by using the international prices that include the carbon price from the global analysis to apply to the national economic modelling, but also applying the same emissions price to domestic production as is applied in the global model suite.

3.6 Global context summary

From a set of three qualitative global scenarios, two were selected for more detailed quantitative modelling, with different assumptions of global population growth and economic productivity, using widely accepted models and datasets. A *Nation First* scenario is based on higher population growth and lower productivity growth than a *Working Together* scenario. The higher economic growth in *Working Together* is assumed to be supported by the same optimistic setting on international political cooperation that is able to achieve strong international action on climate change mitigation, represented as a price on emissions that is eventually applied globally, to both CO_2 and non-CO_2 greenhouse gases. The emissions price trajectories are based on published estimates associated with temperature increases of four and two degrees by 2100 relative to the pre-industrial era, of which Representative Concentration Pathways 6.0 and 2.6 are identified benchmarks.

The combination of economic productivity and carbon prices result in emissions trajectories that, although exceeding comparison benchmarks published elsewhere, are similar enough to give confidence that the global climate results can provide plausible settings for national modelling. The economic model does not explicitly represent the direct impacts of climate change on the global economy; or the costs and benefits of adaptation, it only takes into account the assumed GDP impacts of the emissions price. Other relevant assumptions include carbon price motivated energy efficiency, technical possibilities for fuel substitution, and cost motivated emissions abatement.

Although primary fuel use projections are within the range of comparable scenarios published elsewhere, the ANO 2019 projections of electricity demand growth are significantly higher than others. This reflects less optimistic assumptions about the potential for technical energy efficiency improvements and the scope for lower energy intensity per unit GDP than the comparison studies, as we were unable to obtain reliable data suitable for our models. This significant growth in electricity demand is particularly influential in contributing to the challenge of reducing projected emissions to meet the global targets corresponding to the ‘two degrees track’ in *Working Together* and the ‘four degrees track’ in *Nation First*.

Similarly, without specific assumptions in the global economic modelling to represent improvements in materials intensity or a shift of global consumer preferences towards services and away from materially intensive goods, ANO 2019 projections of demand for material resources is strong growth in both scenarios, with stronger growth in materials demand in the higher global GDP scenario, *Working Together* (with slightly lower materials intensity per unit GDP.) The global markets for materials in the *Working Together* scenario is much stronger than the ‘Peaks Early’ setting consistent with the qualitative scenario description.

The consequence for the national modelling is that the international markets for Australian resources is stronger in the *Working Together* global scenario (which is used to frame the *Green and Gold* and ‘Stronger Regions’ national scenarios, see Table 3.3) and is more weighted towards activity in the resources economic sectors than originally envisaged. This effect adds to the increase in international trade that is expected to result from the modelled decline in barriers to international trade.

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4 Productivity and services

Author: Andrew Rendall

4.1 Introduction

The Productivity and Services[1] parametrisation and calibration of the national model (VURM) focuses on three areas of research: (i) gross domestic product (GDP)[2] growth rates, (ii) total factor productivity (TFP) (see Section 4.4), and (iii) unemployment rate changes. These research areas were naturally defined during the initial research around the broad objectives and map directly to three parametrisation areas that form a model simulation process that conforms to the values, expectations and vision of the Australian National Outlook (ANO) participant group. More specifically, the narratives around the core scenarios are a significant driver of the parametrisation strategy employed. The specific assumptions that support the quantitative economic modelling of the scenarios are detailed in the following sections.

This chapter focuses on the Productivity and Services parametrisation of the three core scenarios: *Slow Decline*, *Thriving Australia*, and *Green and Gold*. Both the *Slow Decline* and *Thriving Australia* scenarios are coupled with the *Nation First* global context. The *Green and Gold* scenario uses the *Working Together* global context.

Note that while the Australian National Outlook 2019 report discusses results under two scenarios: *Slow Decline* and *Outlook Vision*, this report goes into further detail by reporting results for the *Outlook Vision* under two different global contexts: *Thriving Australia* under a fractious global context and *Green and Gold* under a more harmonious global context. It should be noted that both scenarios fall under the *Outlook Vision*. Chapter 2 of this report describes these scenarios in further detail.

4.2 Parametrisation summary

From a modelling perspective, there are two primary parametrisation dimensions: (i) GDP targeting and (ii) TFP-to-capital ratios (TFP/K). The unemployment rate is a third area of parametrisation that is selectively used to explore specific scenario sensitivities. However, it should be noted that, even when specifically identifying the three parametrisation areas, no scenario is parametrised using all three parametrisation dimensions simultaneously. Instead, the parametrisation of the scenarios is done via an iterative process, building up from the basic scenarios to the more complex future visions.

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[1] Productivity and Services is one of three domains in the Australian National Outlook. This domain roughly corresponds to topics in economics and macroeconomics.

[2] The OECD defines GDP as (i) 'an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production (plus any taxes, and minus any subsidies, on products not included in the value of their outputs)', (ii) 'The sum of the final uses of goods and services (all uses except intermediate consumption) measured in purchasers' prices, less the value of imports of goods and services', or (iii) 'the sum of primary incomes distributed by resident producer units'.

Leaving the specific details concerning each individual parametrisation area to their respective sections in this chapter, the general parametrisation process for the core scenarios is as follows.

1. A generalised version of VURM (base model), calibrated to the Australian economy using historical data and without any additional input or shocks, is simulated for the period 2016 to 2060. This initial run produces an annual time series of sector-specific TFP and capital stock estimates, from which annual TFP/K ratios are calculated for each sector.
2. There are two broad sector categories relevant to the Productivity and Services parametrisation of VURM: instrument and non-instrument.[3], [4], [5] The TFP/K ratios of sectors categorised as 'non-instrument' are pinned down for the entire modelling period using the relevant sector-specific values calculated in Step 1. In contrast, the TFP/K ratios of 'instrument' sectors are initially set to the sector-specific values in Step 1, but are then allowed to deviate to target an exogenously specified GDP level. Hence, the sector categorisation terminology becomes clear: GDP is targeted using TFP/K ratios of instrument sectors.
3. Using steps 1 and 2, the *Slow Decline* and *Thriving Australia* scenarios are simulated, albeit with different GDP target levels. Note that both these scenarios are simulated under a *Nation First* global context.[6]
4. Using the set of annual sector-specific TFP/K ratios from the *Slow Decline* and *Thriving Australia* scenarios simulated in Step 3 allows the simulation of both these scenarios in a *Working Together* global context by pinning down the TFP/K ratios from the relevant scenario and updating the global context assumptions. For example, the *Green and Gold* scenario is simulated using the annual sector-specific TFP/K ratios calculated from the *Thriving Australia* simulation. Thus, sector TFP/K instruments, and GDP targeting by extension, are only relevant to the *Slow Decline* and *Thriving Australia* scenarios.
5. For one sensitivity scenario simulation, *Jobless Growth*, the unemployment rate is exogenously defined. The *Jobless Growth* sensitivity scenario takes the *Thriving Australia* simulation and replaces the endogenously calculated unemployment rate with an exogenously defined unemployment rate that is based on research concerning one future labour market vision focusing on automation and artificial intelligence.

Table 4.1 summarises these steps by intersecting the core scenarios[7] and parametrisation areas. The *Jobless Growth* sensitivity scenario is included as an additional point of reference. The

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[3] The 'instrument' sectors are labelled 'latent potentials' in the ANO 2019 report (CSIRO and NAB, 2019), while 'non-instrument' sectors are 'frontier' sectors.

[4] The source of this nomenclature is the econometric definition of an instrumental variable (IV), which is covered in most advanced-level econometric textbooks. For example, see Greene (2008) for in-depth coverage of this topic.

[5] The vocabulary used within this chapter reflects the same terminology used throughout the ANO, rather than the well-defined definitions found in the economics literature. For example, the macroeconomics literature usually defines the 'instrument' sectors as 'parametrised' sectors.

[6] The *Nation First* global context is considered similar to a business-as-usual assumption, which allows the sector-specific TFP/K values to form within a modelling environment that allowed for natural comparisons during the parametrisation process. The *Working Togethe*r global context includes a substantial emissions pricing function that makes such comparisons difficult.

[7] *Jobless Growth* is not considered a core scenario, but is included for informational purposes in many figures and tables throughout this technical report. Please note that ideas within the *Jobless Growth* scenario narrative, as defined by the ANO participant group, required what might be considered the most highly parametrised model run from a macroeconomic perspective and represents an extreme when compared to all other scenarios and sensitivities presented/run.

relatively 'light touch' parametrisation process is evident, which is only possible by relying on the strengths of the general equilibrium modelling.

Table 4.1 Summary of the parametrisation of the core scenarios and sensitivities

PARAMETRISATION AREA	*SLOW DECLINE*	*THRIVING AUSTRALIA*	*GREEN AND GOLD*	*JOBLESS GROWTH*
GDP targeting	Yes	Yes	No	No
Source of initial sector TFP/K values	Base model	Base model	*Thriving Australia*	*Thriving Australia*
'Instrument' sector TFP/K values	Floating	Floating	Fixed	Fixed
Exogenous unemployment rate	No	No	No	Yes

Source: ANO 2019 modelling parametrisation process

4.3 Gross domestic product

While the parametrisation of the various core scenarios revolves around sector-specific TFP growth rates, GDP and the resulting GDP growth rates[8] are the main macroeconomic constraint imposed within the parametrisation strategy. Thus, it is worthwhile to begin the Productivity and Services technical parametrisation discussion from this macroeconomic perspective. While GDP targeting is a somewhat controversial method of parametrising economic models because one of the main results is exogenously specified, there are four compelling reasons GDP targeting is used.

1. **naturally constraining endogenous TFP**. In-depth research presented in Section 4.3.3 strongly identifies TFP as the primary driver of future GDP growth. However, comprehensive sector-specific TFP forecasts are difficult to produce, particularly from micro-founded data. The alternative strategy employed here is endogenising the sector-specific TFP estimates within the modelling framework with macroeconomic (e.g. GDP) constraints.
2. **aligned with scenario narratives**. The macroeconomic picture can be broadly aligned with the scenario narratives. In this case, the exogenous GDP trends embed interesting time-specific trends, such as the technology adoption catch-up period in the *Thriving Australi*a scenario. Thus, exogenously defining the GDP growth path is both convenient and robust, assuming the GDP targets are appropriately underpinned by both the scenario narrative and the empirical evidence.
3. **adding foresight behaviour**. GDP targeting can provide some foresight behaviour in an otherwise myopic modelling framework[9] in that a smooth transition to an expected shock can be forced. More specifically, third-party analyses suggest the decline of some sectors in the future (e.g. coal industry forecasts (see Chapter 6)). By exogenously specifying the GDP trend, the national economy can be subject to 'expected' sector-specific shocks and induced to maintain a GDP level through rebalancing across sectors and technology adoption

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[8] 'GDP targeting' and 'GDP growth rate targeting' will be used synonymously throughout, although the specific exogenous parameters are GDP targets. Hoverer, this is, by definition, also exogenously defining the GDP growth rate path.

[9] VURM is an input-output based computable general equilibrium model where equilibrium is calculated with limited foresight within a mathematically well-behaved, single period (year) optimisation problem. Inter-temporal optimisation in this framework takes the form of linking the year-specific, local optimisation problems with logical inter-temporal variables, such as the stock of sector-specific capital.

resulting in TFP growth. This behaviour is consistent with an expected change and is consistent with the narratives surrounding the core scenarios.

4. **aligned with model output characteristics**. Exogenously specifying GDP levels does not artificially smooth the GDP or GDP growth trends. That is, the common types of models used smooth out calculated GDP trends absent underlying input shocks. Thus, the GDP targets are neutral with respect to the variance of results. In contrast, observed historical GDP growth is generally quite noisy. However, the scenarios modelled here are most concerned with long-term GDP growth trends.

Table 4.2 Annualised growth rates of core scenarios

ANNUALISED GROWTH RATE	HISTORIC (1984–2017)	*SLOW DECLINE*	*THRIVING AUSTRALIA*	*GREEN AND GOLD*
GDP (%)	3.28%	2.09%	2.81%	2.75%
GDP per capita (%)	1.83%	0.88%	1.59%	1.53%

For the *Slow Decline* and *Thriving Australia* scenarios, the annualised GDP growth rate over the modelled period is, by definition, equal to the targeted annualised GDP growth rate.
Source: ANO 2019 modelling; OECD GDP data, retrieved from FRED, Federal Reserve Bank of St. Louis (n.d.)

Table 4.2 shows that the core future scenarios target lower GDP growth rates compared to Australia's historic GDP performance since 1984.[10] These lower GDP growth targets were a conscious choice based on a substantial review of related literature, combined with a formalised parametrisation process, focusing on:

- Australia's historic GDP growth performance since 1984
- cross-country historic drivers of GDP growth
- an assessment of future Australian drivers of growth across inputs, such as capital, labour, and technology.

These topics are explored in the following sections. The motivating logic is that, while Australia's economic performance since 1984 has been quite strong, the recent global slowdown in productivity growth across inputs that underpinned historic GDP growth has spurred significant debate about the future of growth.[11] This debate revolves around the likelihood of continued technological innovation at the level and pace necessary to generate GDP growth consistent with historical trends. However, on all sides of the debate, it is assumed that the future drivers of any GDP growth must come from the technological innovation that is synonymous with TFP, which is further discussed in Section 4.4.

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[10] Small deviations between the targeted and outputted GDP levels are introduced when parametrising (e.g. rounding) and computing the VURM model. With respect to computing the VURM model, the GDP output will match the target with some allowable error to ensure a balance between results and computational time.

[11] OECD (2015) summarises the debate, where pessimists (e.g. Gordon) see diminishing marginal returns to innovation and optimists (e.g. Brynjolfsson) see a lagged adoption of new technological innovation primarily contributing to the observed productivity decline.

4.3.1 Historic GDP

Australia's quarterly GDP growth since 1984[12] has been particularly robust, exhibiting only one technical recession[13] in 1991 (see Figure 4.1). This economic performance is somewhat lower when accounting for population growth (see Figure 4.2). When assessing the bounds of future GDP growth, many researchers rely on historic performance as a starting point of comparison (e.g. see Table A.1 in Guillemette and Turner (2018)). While this is a useful starting point, it should be noted that Australia's GDP growth since 1984 includes the effects of one-off economic reforms (OECD, 2017), relatively high commodity prices (OECD, 2017) and a period of generally strong TFP growth (OECD, 2015)[14].

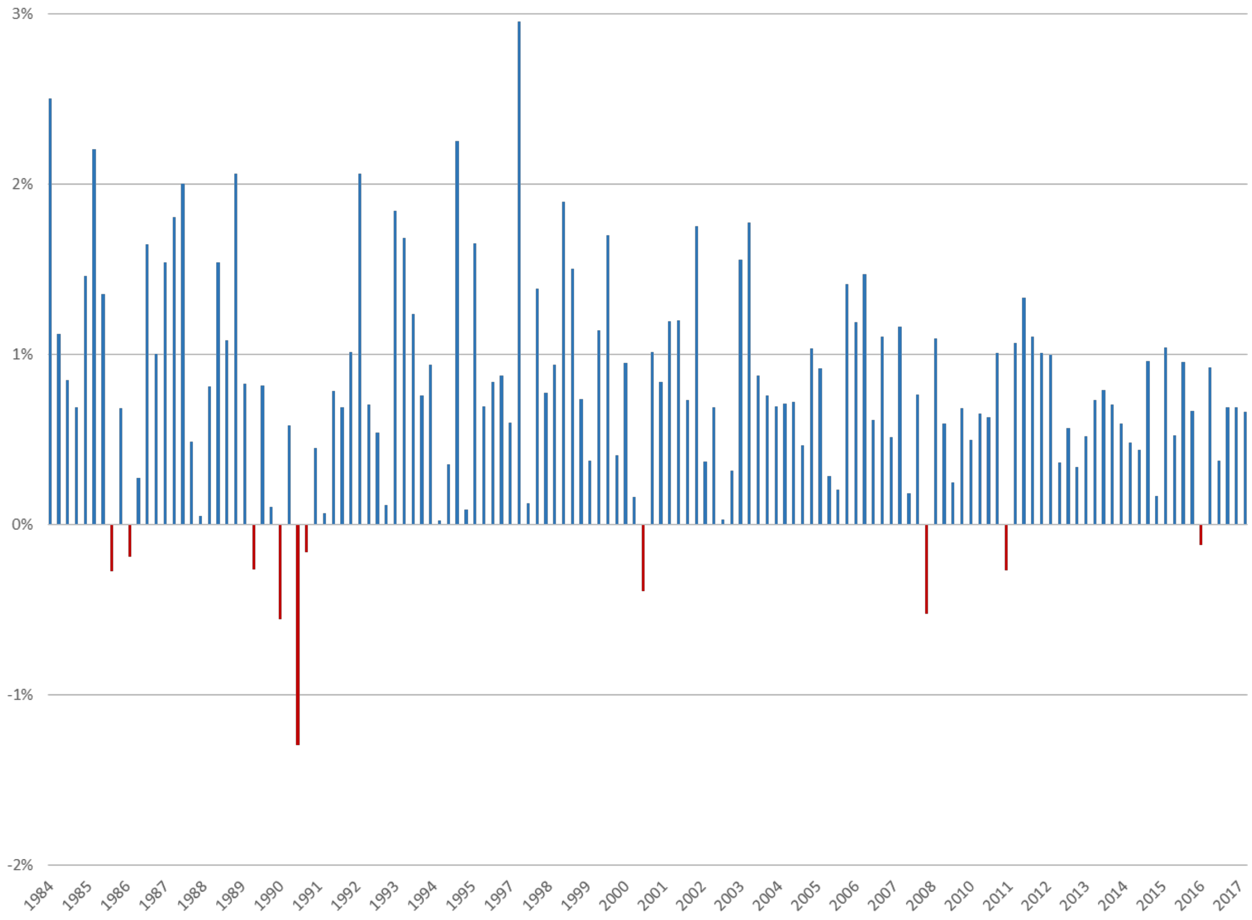

Figure 4.1 Australia's real quarterly GDP growth rate (1984–2017)

Seasonally adjusted real quarterly GDP growth rate
Source: ANO 2019 computation using OECD GDP data, retrieved from FRED, Federal Reserve Bank of St. Louis (n.d.)

The historical bounds of average annual GDP growth can be seen in Table 4.2, with 3.28% being the starting point of research for the *Thriving Australia* GDP targets. However, the future GDP growth rates must be consistent with a micro-founded narrative, without resorting to heroic sector-specific shocks. That is, forecasting specific drivers of GDP growth equivalent in magnitude to those Australia experienced over the last three decades is a difficult exercise. Instead, an

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[12] As Australia floated the Australian dollar exchange rate in December 1983, the relevant historic comparison period is 1984 to 2017.

[13] A technical recession is defined as two consecutive quarters of GDP contraction.

[14] Approximately 28% of GDP growth from 1990 to 2000 was driven by multi-factor productivity (OECD, 2015).

iterative process was used to ensure reasonable levels of GDP and TFP growth. More specifically, the initial GDP targets were determined by the historical trends detailed previously, with the resulting sector-specific TFP growth rates assessed to ensure they fell into sensible ranges based on additional research (described below). In this sense, both GDP and TFP growth rates are constraints in the parametrisation: (i) GDP as a hard modelling constraint that limits TFP/K growth, and subsequently TFP growth; and (ii) TFP as an output informing changes to the GDP targets. This iterative process, combined with the additional research described below, yields an annualised GDP growth rate of 2.81% under the *Thriving Australia* scenario, which is marginally lower than historic trends. The *Slow Decline* scenario sees average GDP growth drop to 2.09% over the 2016 to 2060 period.

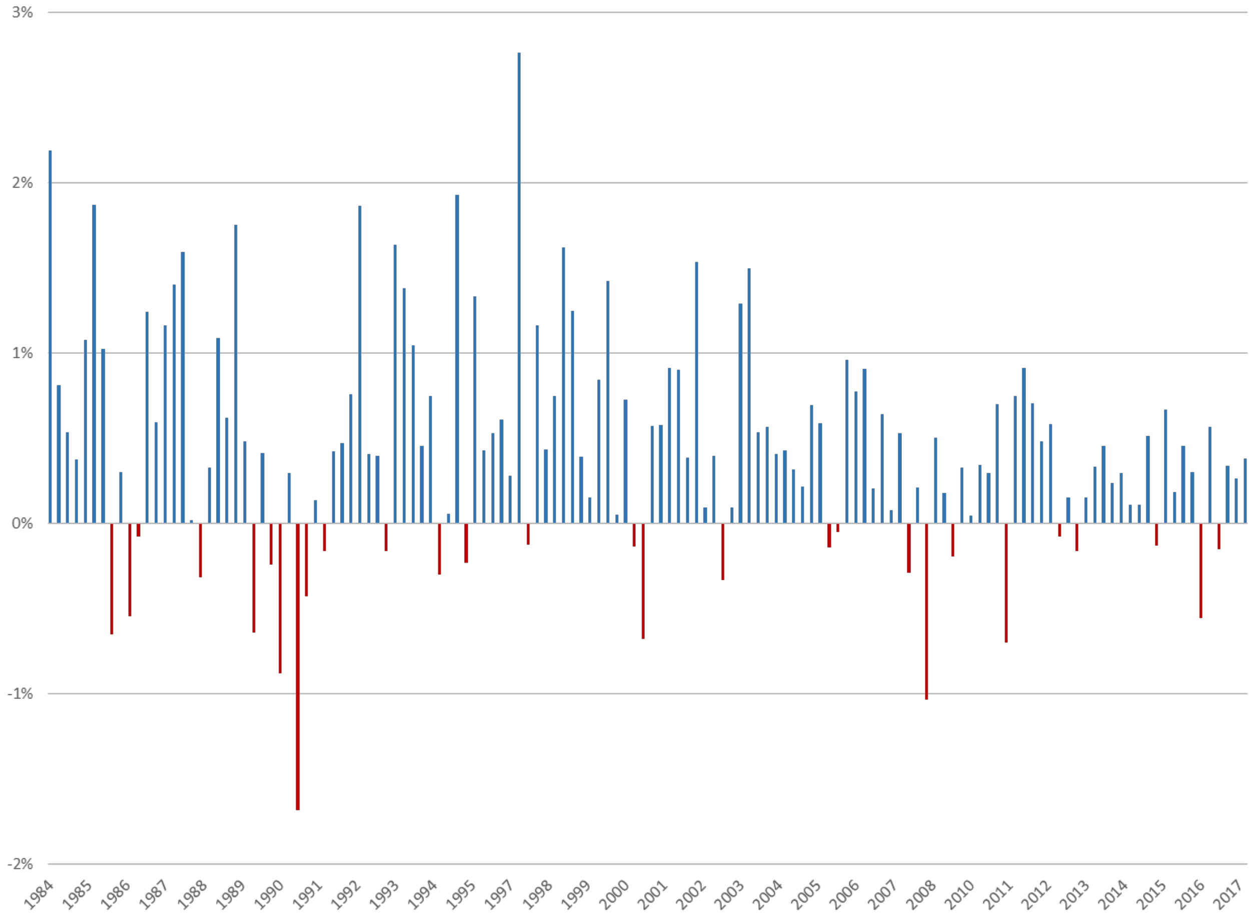

Figure 4.2 Australia's real quarterly per capita GDP growth rate (1984–2017)

Seasonally adjusted real quarterly per capita GDP growth rate
Source: ANO 2019 computation using OECD GDP data, retrieved from FRED, Federal Reserve Bank of St. Louis (n.d.), and population data from the Australia Bureau of Statistics (ABS)

4.3.2 Historic drivers of Australia's GDP growth

The second research area informing the GDP targets concerns Australia's GDP level and growth rate evolution with respect to other countries, particularly for developed countries with similar legal, political and economic structures. Figure 4.3 provides a summary of the relevant points:

- Australia tracks consistently within its developed country peer group, which is particularly relevant in that GDP growth rates have been declining across the developed world (Minifie et al., 2017a).

- While Australia avoided significant GDP shocks associated with the global financial crisis of 2006 to 2008, it has not been immune to the broader declining GDP growth rate trend.

Australia's GDP growth has increasingly relied on capital accumulation since 1990 which has been notably driven by the capital intensive mining sector (OECD, 2015). Thus, there is a largely consistent view that GDP growth rates will continue to decline in the absence of significant productivity gains (OECD, 2015).

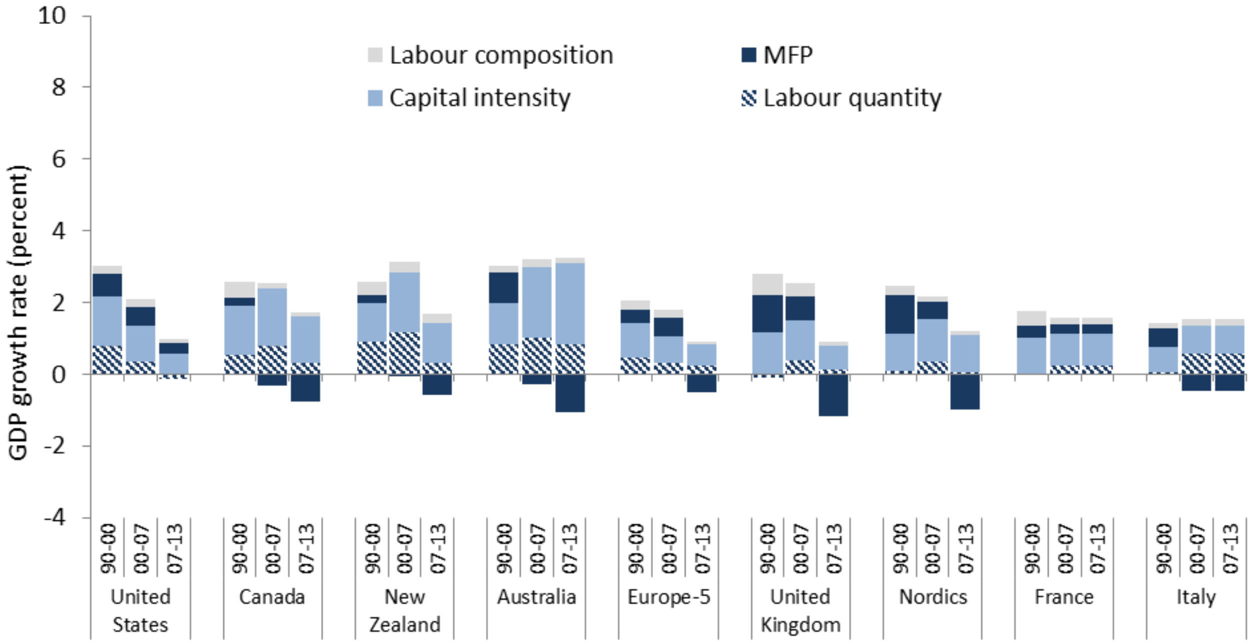

Figure 4.3 Drivers of GDP growth (1990–2013)

GDP growth rate is the annualised GDP growth rate over the relevant period.
MFP = multifactor productivity
Source: OECD (2015)

This global context provides an additional set of facts supporting a reduced GDP growth rate target compared to historical trends. Moreover, these facts point to an increasingly difficult growth environment where easy gains have been logically taken earlier compared to the difficult gains associated with costly innovation at the frontier.

The historical record concerning GDP growth convergence is another area of considerable research that is relevant to the ANO 2019 parametrisation process. In theory, GDP growth across countries should converge, assuming low barriers to technological, capital and labour mobility – if productivity across all inputs converges, then growth should also converge. However, even within the developed world, productivity convergence has not materialised. Thus, care is taken here to avoid simplistic comparisons between countries. For example, there are cross-country frictions to technology adoption that convey deep differences: some countries are more open to technology adoption with respect to legal, economic and cultural dimensions. Thus, country-specific historic GDP trends may also reflect lagged technology adoption (e.g. TFP) that may generate future, above-trend growth. For the *Thriving Australia* scenarios, this idea of lagged technology adoption supports future Australian sector-specific growth (see Section 4.4.2). Furthermore, technology (i.e. TFP) convergence may never eventuate due to various country-specific constraints. For example, Australia’s geographic size and population distribution create physical hurdles to TFP convergence that are unlikely to be overcome (Productivity Commission, 2017).

4.3.3 The future of Australia’s GDP growth

While maintaining the same level of GDP growth experienced since the mid-1980s might seem like a logical assumption, the proceeding sections point to several input trends and obstacles that potentially lower future GDP growth expectations. This GDP forecasting approach is very different to only relying on averaged historical GDP levels. These more nuanced factors were considered in unison when informing the future GDP growth trends. This point is clearly shown in Figure 4.4, with GDP per capita growth declining over time and future estimates continuing the trend based on input contributions. This trend is primarily driven by decreasing TFP growth, without a corresponding increase in the contribution from other factors. In fact, the growth contribution from capital changes is predicted to be negative for both developing (e.g. non-OECD) and developed (e.g. OECD) countries starting around 2030. Theoretically, the parametrisation process could focus on input contributions to GDP growth based on the research presented thus far. However, there is considerable heterogeneity across sectors in terms of GDP drivers, which is not captured in Figure 4.4. For example, Australia’s industries of comparative advantage have very different historical and likely future productivity trends compared with other sectors, with mining and agriculture being the two most obvious examples. This leads the parametrisation process in another direction by looking at sector-specific attributes that will ultimately strengthen the modelling results and their surrounding narratives.

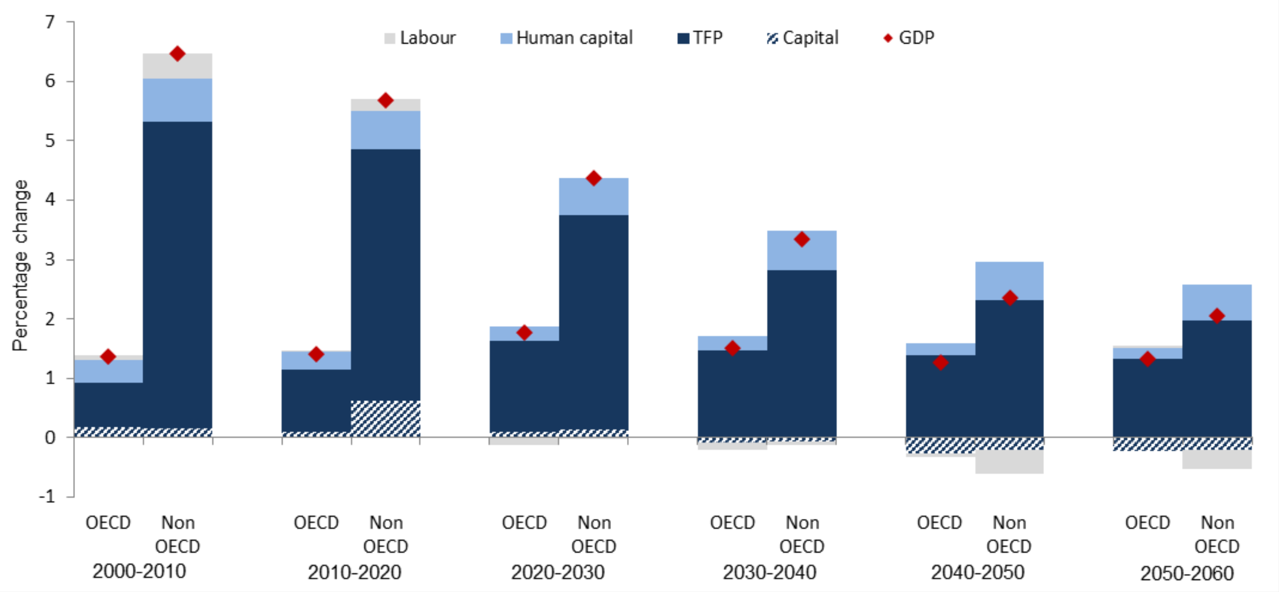

Figure 4.4 OECD estimates for the contribution to GDP per capita growth by decade (2000–2060)

TFP = total factor productivity
Source: OECD (2015)

4.3.4 Scenario GDP growth rate comparison

While the average annualised GDP growth rates were generated through an iterative process where GDP is effectively an indirect constraint on TFP growth, the trends over the modelled period have not been addressed. The most simplistic method would be a constant GDP growth rate for all years. However, such an approach would look unrealistic when considering the many drivers of growth previously discussed. Instead, a more nuanced GDP growth path is chosen for the two scenarios that employ GDP targeting. Thus, it should not be surprising that there are broad GDP trend similarities across the modelled core scenarios and sensitivities.

Both the *Slow Decline* and *Thriving Australia* scenarios exhibit declining GDP growth rates until the mid-2020s. This initial decline follows the broad historical trend[15] in GDP growth (see Figure 4.5). From this point, the *Slow Decline* and more positive scenarios diverge. The *Slow Decline* scenario continues to track downward toward a stable GDP growth level of approximately 1.90% per annum, in contrast to *Thriving Australia* which displays a form of economic catch-up before reaching a steady-state of around 3%. Although GDP levels are exogenously calculated in *Green and Gold*, the scenario mirrors the catch-up seen in *Thriving Australia* before facing emissions pricing headwinds that decrease GDP growth. The assumptions that support these GDP growth time trends are carefully detailed in Section 4.4.

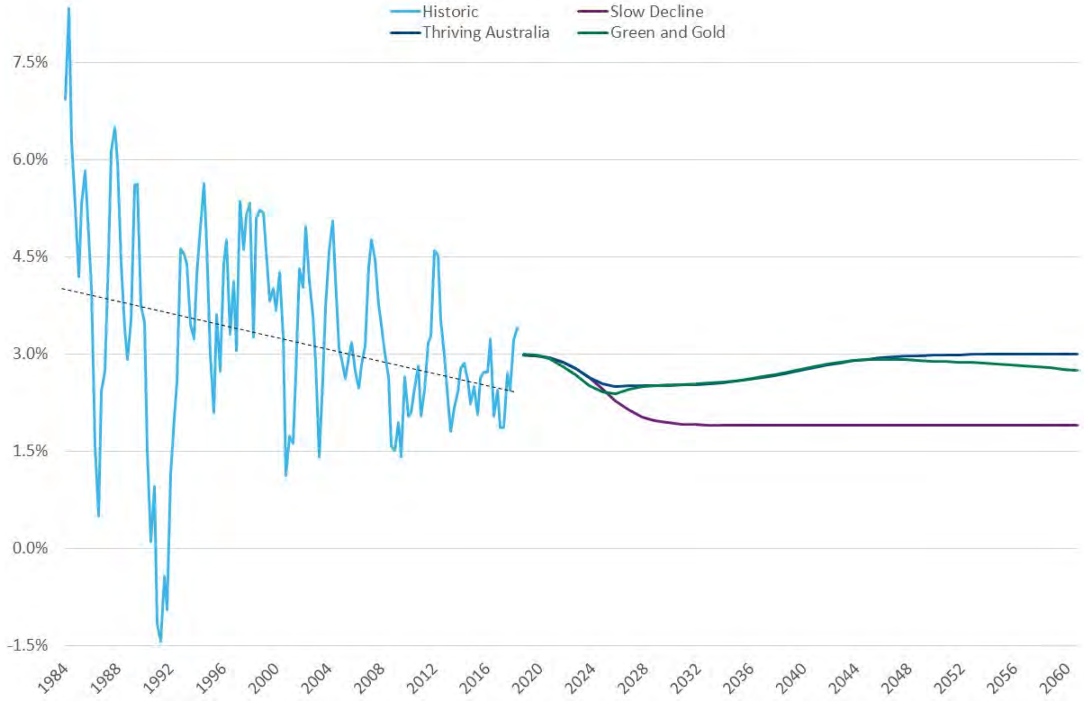

Figure 4.5 Comparison of Australia's historic and scenario GDP growth rates

Seasonally adjusted real annual per capita GDP growth rate by quarter (historic); and real annual per capita GDP growth rate (future scenarios). Source: ANO 2019 computation, retrieved from FRED, Federal Reserve Bank of St. Louis (historic) (Federal Reserve Bank of St. Louis (n.d.)); and ANO 2019 modelling (future scenarios)

The GDP per capita growth rate trends mostly follow GDP, albeit at a lower absolute level that accounts for continued population growth. For comparison, OECD (Guillemette and Turner, 2018) model-based research, using historical levels and trends, paints a different picture. More specifically, their modelling approach does not consider Australia-specific information concerning

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[15] Comparing the historical GDP growth trends, which are calculated from annual changes in GDP at a quarterly observation level, with the scenario GDP growth trends reveals a sharp distinction between the noisy historical data and the scenario results. The VURM model used here is set up to run at an annual time step, but using a quarterly observation level is unlikely to create more realistic GDP growth variance. This is because VURM is a specific type of computational general equilibrium model (input-output) that will generate smooth intertemporal trends unless specifically shocked.

sector-specific TFP. This means that the OECD GDP per capita growth estimates are more aggressive than what is assumed in the ANO 2019 modelling parametrisation, leading to higher modelled GDP growth rates. The OECD suggests a GDP per capita growth rate of 1.4% for 2018 to 2030 and 2.0% for 2030 to 2060. The equivalent per capita GDP growth rates for each period for *Thriving Australia*[16] are 1.15% and 1.77%, respectively, highlighting the relatively conservative ANO 2019 modelling parametrisation approach.

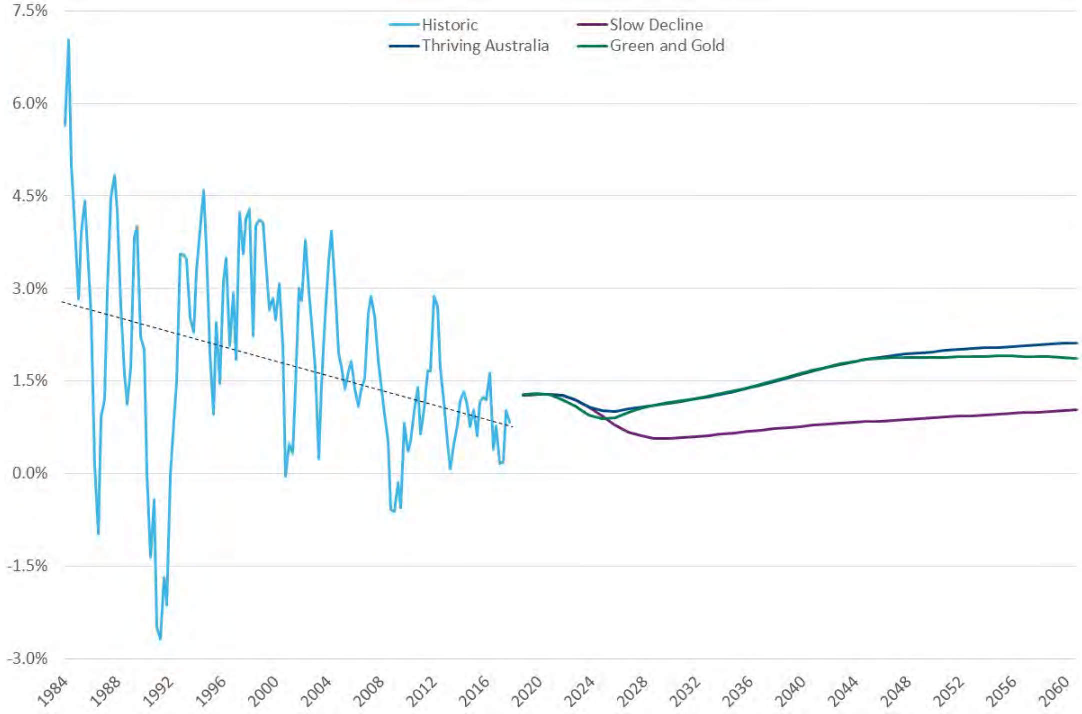

Figure 4.6 Comparison of Australia's historic and scenario GDP per capita growth rates

Seasonally adjusted real annual per capita GDP growth rate by quarter (historic); and real annual per capita GDP growth rate (future scenarios). Source: ANO 2019 computation, retrieved from FRED, Federal Reserve Bank of St. Louis (historic) (Federal Reserve Bank of St. Louis (n.d.)); population data from the Australia Bureau of Statistics (ABS) (historic) (ABS, 2018b); and ANO 2019 modelling (future scenarios)

4.4 Total factor productivity

TFP is generally defined as technological progress (see Productivity Commission (2017) for more detailed definitions)[17] but is usually captured as the additional productivity generated beyond the additive expectations of input (e.g. labour and capital) changes. As discussed in Section 4.3.3, there is considerable debate about the trajectory of future economic growth, but a general consensus that any growth will be underpinned by TFP. Thus, TFP, also known as the Solow Residual,[18] is the fundamental driver of GDP growth within the modelled scenarios.[19]

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[16] The modelling approach in Guillemette and Turner (2018) does not account for climate change, which might explain part of the difference. Thus, the nearest equivalent scenario for comparison purposes is Thriving Australia, even if it includes emissions pricing.

[17] The Australian Productivity Commission focuses on multifactor productivity (MFP), which is conceptually similar to TFP. The Commission see MFP as 'an indicator of technological change' and TFP as 'the measure that comes closest to the underlying concept of technological progress' (see Productivity Commission, 2017).

[18] Robert Solow first proposed the ideas and calculation methodology for what is now referred to as 'total factor productivity'.

[19] The effect of the TFP growth differences between the *Slow Decline* and *Green and Gold* scenarios is decomposed into constituent drivers within the ANO 2019 report (CSIRO and NAB, 2019) (e.g. investment, human capital and technology adoption) to assist in bridging modelling results with the scenario narrative(s). This is done by running separate scenario simulations. For investment, a *Green and Gold* simulation was run using *Slow*

The parametrisation process employed here allows TFP to be endogenously calculated within the modelling framework and is a two-pronged approach. First, a key input of TFP, the sector-specific relationship between TFP and capital, is initially set though a novel iterative process that exploits the existing VURM modelling capabilities. The functional form of this relationship is the ratio of TFP to capital (TFP/K ratio). Second, economic sectors are divided into 'instrument' and 'non-instrument' sectors, where TFP/K ratios for the 'instrument' sectors vary from the initial value to target the exogenously supplied GDP values. This methodology has several key advantages.

1. **endogenously calculated TFP.** Endogenously calculating sector-specific TFP, and by definition sector-specific TFP growth, side-steps the inherently complex micro-founded approach of directly forecasting TFP for each sector. This means that the general equilibrium features of the model, particularly around the allocation of investment based on the returns to capital, can be exploited with respect to TFP. Additionally, given the scenario narratives, this ensures that TFP is not statically pinned down and falsely driving the results.[20]
2. **physical and knowledge-based capital contributions to TFP.** TFP is generally associated with physical capital, although research points to significant knowledge-based drivers as well. The parametrisation process employed here embeds both physical (K) and knowledge-based capital (KBC)[21] contributions to TFP, although both contributions are assumed to be a function of the physical capital stock. This means that the model outputs can be interpreted easily within the scenario narratives around drivers of change that include investment in physical and knowledge-based capital.
3. **a balanced approach to TFP growth across the economy.** Sector-specific technology adoption in Australia varies considerably. As such, some TFP and broader productivity performance of sectors are relatively high when compared across countries, while others lag such as Australia's mining sector, which is broadly considered to operate at the frontier of technological adoption. Thus, two sector groups are defined within the parametrisation process, separated by their capacity to produce additional TFP.

Table 4.3 summarises the TFP growth rates for the core scenarios, as well as the historical values since 1995. While the GDP growth rates of the core scenarios are lower than the historical reference period (1984 to 2017), the TFP growth rates are higher than the historical reference period (1995 to 2017). Superficially, this might be seen as a more aggressive output. However, in the context of the future drivers of GDP growth (see Section 4.3.3), it is assumed that TFP must now underpin the bulk of GDP growth. Thus, three research areas support the TFP parametrisation process and the subsequent TFP growth outputs:

- Australia's historic TFP growth

Decline sector-specific investment trends. For human capital effects, a *Green and Gold* simulation was run using an exogenously supplied unemployment rate consistent with a well-research proposed technology-labour divergence (see Section 3.5). The net effect, subtracting the investment and human capital contributions, is attributed to technological adoption.

[20] The model production of industry *i* is determined through the interaction of demand and supply. Supply of industry *i* reflects, in part, the unit cost of production. The unit cost of production reflects, in part, TFP. In a normal simulation, TFP is an exogenous variable – set to values proscribed by the user, and production is endogenous. However, by changing the closure of the model exogenous production can be made and free up TFP. Thus, in the context of the model, TFP for industry *i* will be endogenously determined to achieve the exogenously determined change in production for industry *i*.

[21] Knowledge-based capital (KBC) can include research and development (R&D), firm specific skills, organisational know-how, databases, design and various forms of intellectual property (OECD, 2015).

- the broad relationship between TFP and capital
- identifying the specific sectors that can exhibit higher TFP growth.

These three research areas are discussed in the following sections with the dual aim of supporting the parametrisation process and providing a deeper analysis around TFP. Moreover, the parametrisation and assumptions associated with the modelling of TFP are built upon the scenario narratives. More specifically, the overall productivity picture is formed around empirical analysis (presented in the following sections) that is mapped to scenario narratives that are then parametrised and modelled. The resulting outputs are then subject to additional *ex post* review at the sector level within an iterative modelling process.

Table 4.3 Total factor productivity (TFP) growth rates of core scenarios

ANNUALISED GROWTH RATE	HISTORIC (1995–2017)	*SLOW DECLINE*	*THRIVING AUSTRALIA*	*GREEN AND GOLD*
TFP (%)	0.58%	0.72%	1.32%	1.33%
TFP range (%)	[–1.30%, 3.01%]	[0.43%, 1.08%]	[0.75%, 1.88%]	[0.67%, 1.95%]

The ABS KLEMS TFP estimates more closely align with the TFP values computed within VURM, as both series account for inputs beyond capital and labour (e.g. energy).
Source: ANO 2019 modelling; Australian Bureau of Statistics (ABS), KLEMS estimates (ABS, 2018a)

4.4.1 Historic TFP growth and policy recommendations

To the extent that historic TFP growth informs the future values calculated within the modelling, this connection is based on (i) the trajectory of global technological innovation and adoption, combined with (ii) a cross-country assessment of Australia's historic productivity performance. A growing body of research directly points to slowing global productivity growth, particularly around TFP (OECD, 2015). Within that global TFP growth trend, Australia has tended toward the lower-middle of the OECD, with a recent dip toward the bottom (see Figure 4.7).[22, 23] These productivity trends and their underlying drivers have been researched by a number of well-regarded global institutions, such as the OECD, IMF and World Bank. The Australian Productivity Commission, McKinsey Australia, the Grattan Institute and the OECD, among others, have tackled the broad topic of productivity at a national level. Thus, synthesising the existing research to identify the primary underlying productivity relationships was necessary in order to produce likely scenario-specific productivity trends. This process is highly relevant to the accuracy of this modelling effort. In this sense, because the modelled TFP output is endogenously calculated within a highly granular general equilibrium model, all dimensions leading toward the final TFP growth rate must be consistent with a logical interpretation of the empirical evidence and the scenario narratives simultaneously.

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[22] Austraia's productivity performance has been similar to other developed countries since the 1950s (Minifie et al., 2017a).

[23] This interpretation was quantitatively supported by the Productivity Commission's 2014 *Productivity Update* (see Productivity Commission, 2014).

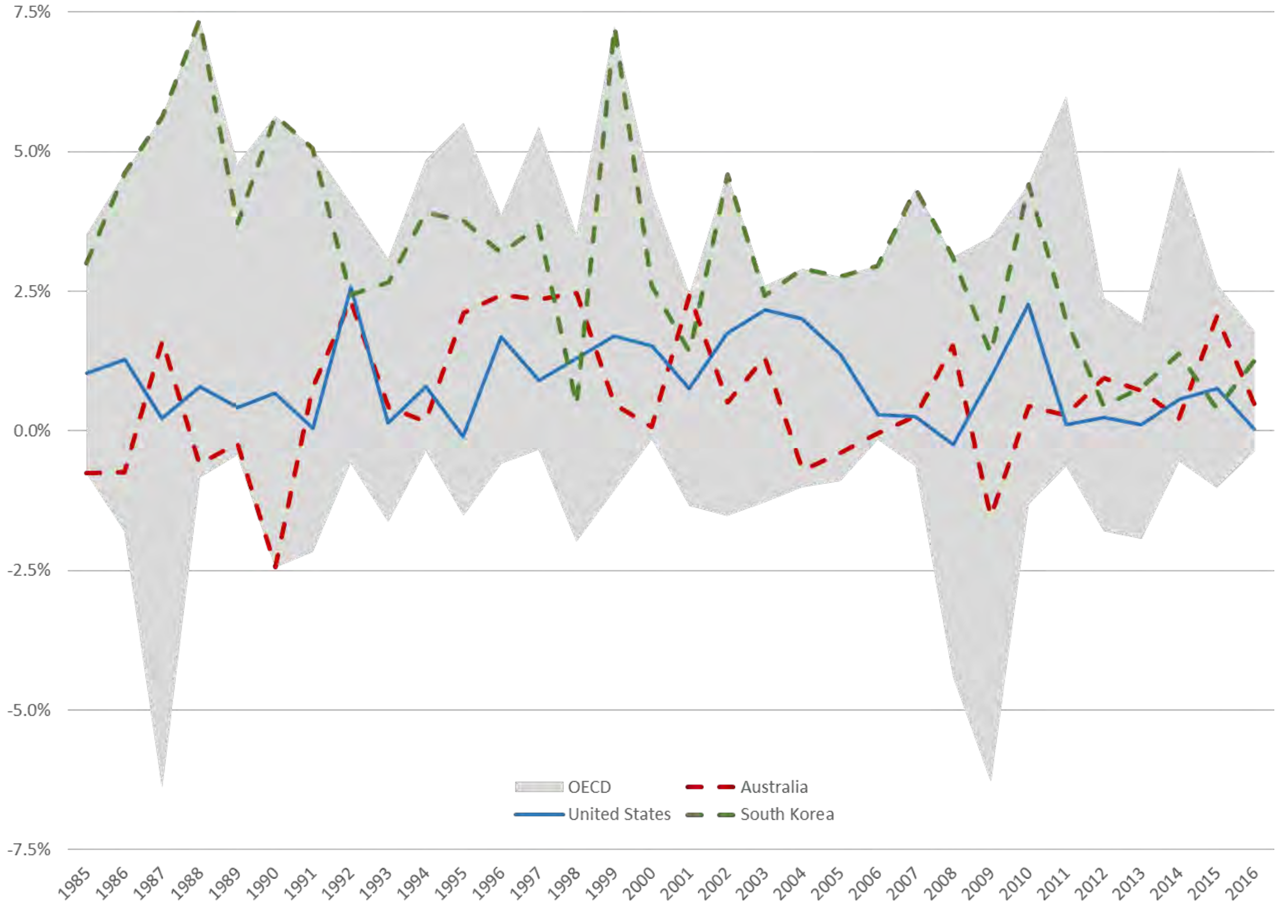

Figure 4.7 Comparison of OECD multifactor productivity (MFP)

MFP is a relative of TFP, where MFP only includes capital and labour in computing the residual productivity.
Source: OECD productivity statistics (database) (OECD.stat, 2018)

The OCED (OECD 2015; Adalet McGowan and Andrews, 2015), IMF (Adler et al., 2017; Dabla-Norris, 2015) and World Bank (Cirera and Maloney, 2017)[24] have produced a series of insightful productivity-related research in the last few years. These publications address global TFP trends and the associated drivers, which, when taken together, indicate strong consensus among these global institutions. The main points of agreement are: (i) productivity is an important determinant of economic growth, (ii) there is a growing gap between the firms at the productivity frontier and others, (iii) global TFP trends have been driven by the return on investments in physical and knowledge-based-capital, and (iv) recent TFP growth has been impacted by both decreasing marginal returns to innovation and lower investment levels.

For addressing productivity issues, these three global institutions highlight several common themes. Where they focus on mildly different productivity improving prescriptions, it is a function of specialised research and domain coverage within each institution. The OECD sees productivity growth reinvigorated by: improvements in the funding and organisation of basic research; rising international connectedness, both with respect to global value chains (GVCs) and research and development (R&D); product, labour and capital markets that foster the efficient allocation of

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[24] Although the referenced World Bank research focuses on developing countries, the global trends and policy recommendations are still relevant to the CSIRO modelling assumptions.

resources; increased market competition; and regulation that reduces barriers to reallocation.[25] The IMF advocates short- and long-term remedies. For short-term remedies, they believe increased investment and strengthened balance sheets, more efficient infrastructure spending and reducing policy uncertainty will provide some productivity improvements. In the long term, the IMF provides advice that aligns with the OECD: incentives to improve innovation and technological progress; human capital improvements; labour market policies to improve allocation (e.g. mitigating the effects of an aging workforce); changes to migration policy; and greater internationalisation in terms of trade, production (e.g. GVCs) and the movement of resources, including knowledge. The World Bank points to the importance of complementarities,[26] supporting the idea that declining productivity growth is due to a lack of complementing physical-, human-, and institutional-capital factors. These complementarities are supported by many of the policy recommendations described by the OECD and IMF, such as market competition and capital market efficiency. The World Bank concludes that policy must go beyond addressing individual factors and consider the space of interaction between technology/innovation and complementing inputs and institutions. Linking technological change with complementary inputs is an area of considerable academic research that is explored in Section 4.4.2.

The OECD (2017) economic survey of Australia provides a similar set of productivity enhancing policy recommendations as those proposed for the global economy (see Section 4.4.1.). The report introduces Australia-specific points around the analysis of domestic monetary policy, fiscal policy settings, and drivers of economic and social instability, such as decreasing human capital levels. The OECD’s overarching narrative is that Australia should rebalance its economy to support future growth. As sectoral rebalancing is a prominent feature of the ANO 2019 model parametrisation (for example, see Section 4.4.2, where domestic sectors are classified based on potential future growth), the OECD’s overarching narrative is consistent with the ANO 2019 modelling framework.

Australia’s Productivity Commission has produced an annual ‘productivity update’ since 2013. Each annual report discusses recent national productivity trends and presents findings on a specific productivity topic. The Productivity Commission (2013) points to slowing domestic multifactor productivity (MFP) growth since 2004, driven by both temporary and structural factors. For example, high capital expenditures within the mining sector exacerbated the usual capital intensive mismatched input and output growth of industries. Over time, this misalignment will be resolved as output rises. In contrast, structural changes in the mining sector decrease long-term productivity and are mostly related to the complexity of new mining deposits, combined with lower ore grades. The main message from the 2014 update (Productivity Commission, 2014) was that Australia’s MFP growth performance was significantly worse than other developed countries. The 2015 update (Productivity Commission, 2015) discussed the importance of capital deepening, particularly in public infrastructure. The 2016 edition (Productivity Commission, 2016) pointed to substantial MFP growth in the mining sector. The Productivity Commission’s 2017 update (Productivity Commission, 2017) provided additional detail around Australia’s productivity trends, highlighting the relative importance of mining and the inherent economic vulnerability. This

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[25] The OECD (2015) suggests a number of specific policies to improve productivity that can be broadly classified (see Section 3.4.1).

[26] The concept of technology complementary factor endowments is detailed by Acemolglu and Zilibotti (2001) and further analysed in Gancia and Zilibotti (2009).

update also discussed drivers of Australia's productivity slowdown, including technology diffusion between frontier and non-frontier firms, management practices and the macroeconomic policy environment hindering investment.[27]

The Grattan Institute's recent research (Minfie et al., 2017a) concerning Australia's historic and potential future productivity helps put the ANO 2019 modelling assumptions into perspective. In this research, Minifie et al. rightly point to the effect of capital investment on productivity, both in terms of physical and knowledge-based capital. They present evidence that investment across the developed world collapsed in the late-2000s and never fully recovered, which in turn partly explains decreasing productivity over the same period. Australia follows these same broad investment and productivity trends, albeit with a much smaller decrease in investment in the late 2000s. Additionally, the authors decompose the decrease in non-mining investment from the 1990s to 2016, showing that around one-third was driven by low-growth factors. Several strategies are then assessed with respect to their likely (potential) impact on Australian investment, including corporate taxes and their associated foreign-direct investment (FDI) effects, macroeconomic and monetary policy levers, public investment and growth-promoting reforms. It is within the growth-promoting reforms that is the focus of the ANO 2019 modelling and parametrisation assumptions,[28] with additional emphasis on sector-specific opportunities discussed in Section 4.4.3.

Similar to focus of the ANO 2019 model parametrisation process on identifying sectors of future productivity growth, McKinsey Australia asked, 'where [will] the next wave of growth come from?' (Lydon et al., 2014). Their answer can be summarised as increasing productivity through improved competitiveness throughout the economy. More specifically, their research identifies five sector groups of interest:

- advantaged performers (mining, agriculture, education, and tourism)
- latent potentials (food manufacturing, pockets of advanced manufacturing and selected niches in global supply chains)
- transitionals (most of manufacturing)
- enabling industries (finance, utilities, construction, professional services, logistics, real estate services); and
- the domestic core (communications, retail and wholesale trade, domestic services and public administration).

McKinsey Australia sees the 'advantaged performers' and 'latent potentials' as Australia's comparative advantaged sectors. In comparison, 'transitionals' display weaker endowments, while 'enabling industries' and 'the domestic core' are insulated sectors with limited exposure to international competitive pressures. It is assumed that Australia can most efficiently support future growth by focusing on sectors where Australia has a comparative advantage. CSIRO research supporting the parametrisation process takes a similar high-level approach in classifying sectors by productivity potential, but with a different set of assumptions around productivity. Even

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[27] The report lists a number of additional productivity drivers, with an emphasis on cross-country research.

[28] Two specific growth-promoting reforms described by Minifie et al. (2017a) directly map to the ANO 2019 modelling parametrisation: increasing competition intensity and improving the efficiency of the urban landscape. An additional growth-promoting reform on streamlining regulation is implicitly assumed.

with this different approach, the McKinsey Australia and CSIRO sector classifications share several characteristics. However, differences surface due to CSIRO's assumption that investment incentives (e.g. rate of return) are driven by performance potential, which is a function of the distance to the frontier of sector investment.

4.4.2 The relationship between TFP and capital

Numerous studies highlight the important relationship between productivity and capital. The parametrisation and modelling undertaken for ANO 2019 focuses on capital deepening – the per capita capital stock increases usually thought of as technology adoption – that ultimately drive TFP growth through more efficient coupling of physical capital, knowledge-based capital and human capital (for example, see OECD (2015), Adler et al. (2017), Cirera and Maloney (2017) and Minifie et al. (2017a)). These themes are deeply embedded within the modelling framework through sector-specific assumptions around productivity and capital.

Australia is broadly comparable, along physical and human capital dimensions, with developed countries considered at the productivity and technological frontier, such as the United States (see Dabla-Norris et al. (2015) and Adler et al. (2017)). For example, mean wealth (Credit Suisse Research Institute, 2017), mean income (OECD.stat, 2018) [29] and the proportion of college educated (OECD.stat, 2018)[30] are superficially similar in the United States and Australia. Thus, it is proposed that differences in TFP and technology diffusion are likely determined by deeper factor differences (Keller, 2004).[31]

One of the main reasons for pursuing capital deepening as a primary TFP driver within the ANO 2019 modelling framework relates to the idea of input technology complementarities across factor endowments. While this idea was originally motivated by observed TFP differences across developing and developed countries (Acemoglu and Zilibotti, 2001) and supported by evidence of heterogeneous technology diffusion and returns, the ANO 2019 modelling parametrisation employs this concept at a sector level. That is, it is proposed that TFP differences observed between developed countries can be potentially be explained by differences in their sector-specific factor endowments, assuming there is convergence across a broad set of relevant macroeconomic dimensions (e.g. infrastructure, human capital, institutional capital).

Keeping in mind that the aim of most economic modelling is simplifying complex relationships (Varian, 1997). The ANO 2019 model parametrisation concentrates on technology adoption driving TFP growth through semi-endogenised,[32] over-time, sector-specific TFP/K. This is a simplified representation of the effects of technology adoption with three non-trivial benefits (i) technology adoption can be broadly defined across physical and knowledge-based capital dimensions; (ii) the parametrisation process endogenously produces sector TFP, which side-steps the crude approach of directly parametrising TFP growth; and (iii) TFP/K can be parametrised at a sector or sub-sector

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[29] The mean 2017 wage in the United States and Australia were USD$60,558 and USD$61,620, respectively, at 2017 exchange rates.

[30] The proportion of individuals, aged 25 to 64, who have completed a bachelor's degree (equivalent) or higher in the United States and Australia is 35.5% and 33.8%, respectively.

[31] For example, distributional and purchasing power parity (PPP) differences might be important.

[32] Semi-endogenised in the sense that values are not explicitly supplied to VURM by the user, rather taken from previous model runs and change based on GDP targets.

level to ensure simultaneous alignment with empirical evidence and scenario narratives. This third benefit points to the next step in setting up the theoretical parametrisation framework: identifying the sectoral distribution of technology adoption.

To assign domestic sectors to either high- or low-growth potential categories, cross-sector capital-labour (K/L) ratios were computed for selected OECD countries, which acts as a proxy for relative factor endowments. The resulting comparison is shown in Figure 4.8, sorted by ascending capital-labour ratio for the Australian sectors. The figure highlights well-established facts concerning capital-intensive domestic sectors (right side), such as mining and utilities. However, due to heterogeneity across countries, a well-defined sector inclusion rule is necessary. That is, the comparison with OECD countries for some sectors might be driven by country-sector outliers that do not reflect Australia-specific characteristics.

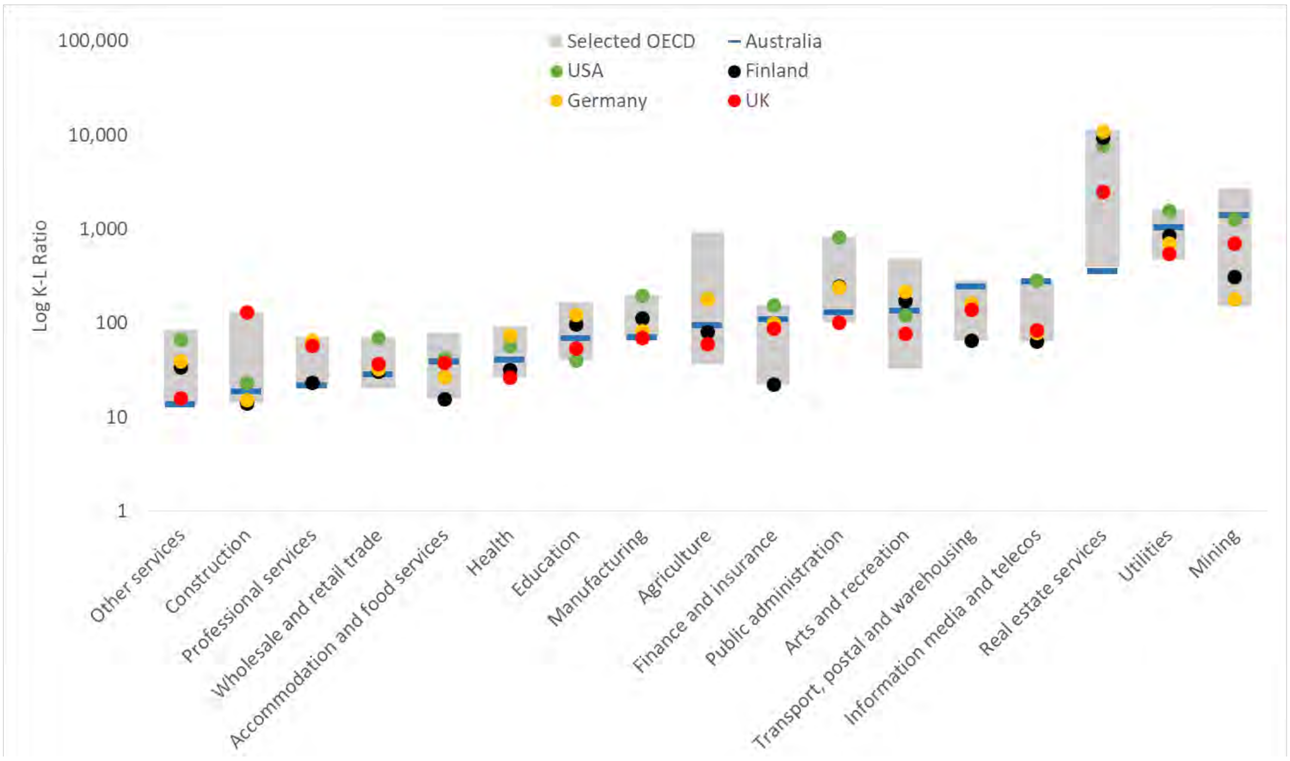

Figure 4.8 Comparison of selected OECD capital-labour ratios (2015)

Sector capital stock is measured in 2010 PPP AUD, where PPP exchange rates are used, and labour is measured in hours worked within each sector. Sectors are sorted by ascending Australian capital-labour ratios.
Source: CSIRO (internal CSIRO computations), World KLEMS (n.d.), EU KLEMS (2017), ABS (2018a) and OECD (exchange rates) (OECD, n.d.)

Domestic sectors fall into two groups within the ANO 2019 modelling: ‘instrument’ and ‘non-instrument’ sectors. TFP/K ratios of ‘instrument’ sectors vary to target the exogenous GDP targets, meaning that productivity growth will tend toward the ‘instrument’ sectors. To identify domestic sectors with capacity for substantial above-trend growth (e.g. ‘instrument’ sectors), the sector-specific ratio of Australia-to-United States K/L ratios were calculated. As the United States is a good proxy for the frontier of productive and allocative efficiency (Dabla-Norris et al., 2015) Australian sectors with at least 70% of the equivalent K/L ratio for the United States are considered near the frontier and unlikely to exhibit significant gains from capital deepening. However, there are some sector exceptions in both directions.

Construction, accommodation and food services, and education are domestic sectors with K/L ratios exceeding 70% of the equivalent US levels, but are defined as ‘instrument’ sectors for other reasons. Globally, the construction sector has averaged about 1% productivity growth over the past 20 years, whereas the world economy has averaged 2.8% over the same period – that is, construction is a global underachiever when it comes to productivity (Barbosa et al., 2017). Thus, including construction as an ‘instrument’ sector is underpinned by assumptions about the sector’s global productivity growth frontier, where consolidation and integration yield productivity gains. The inclusion of both the education and accommodation and food services sectors is driven by the scenario definitions (see Chapter 2) and aligning the sectors’ productivity growth with broader scenario narratives around tourism and human capital.[33] Their inclusion is further supported by research done by McKinsey Australia that highlights education and tourism as part of Australia’s exports and competitiveness core (Lydon et al., 2014).

Conversely, the utilities sector is not defined as an ‘instrument’ sector, even with a capital-labour ratio slightly below 70% of the US level. This sector comprises electricity generation and transmission, natural gas transmission and water services. Of these sectors, the electricity generation and transmission sub-sectors will likely see the most substantial change, although the net effect on TFP is unclear. As the electricity generation sector shifts from conventional forms of generation (e.g. baseload coal) to renewables, non-trivial capital investments will be required that will be associated with productivity changes.[34] To the extent there is TFP growth on the electricity generation side, it would potentially offset losses from the electricity transmission side, where increased investment is necessary to build more robust and flexible transmission grids. Australia’s geographic size is an additional headwind to future electricity transmission TFP growth. While off-grid generation will alleviate some of the demand, both for on-grid generation and transmission network investments, the absolute size of this shift is not certain. Finally, the idea that capital deepening can drive productivity growth in the utilities sector cannot be logically supported (Productivity Commission, 2013).[35]

Even with the 17 broad domestic sectors classified within the ‘instrument/non-instrument’ modelling structure, it should be emphasised that the model output with respect to sector-specific productivity and economic growth is not yet determined. The only assumptions made, thus far, concern which sectors will be allowed to vary their TFP/K ratios to target the exogenous GDP targets. As summarised in Section 4.2, this is one step in a linear parametrisation process that ultimately generates results for the core scenarios.

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[33] The accommodation and food services sector is a proxy for ‘tourism’, which is defined as an area of growth in the scenario definitions. The scenario definitions around human capital described in Section 3.5.1 are aligned with the education sector as an ‘instrument’ sector.

[34] The net effect of different capital expenditure profiles, lower utilisation per unit of capital, near-zero fuel costs and varying capital depreciation rates by type cannot be usefully decomposed to predict TFP levels to 2060.

[35] Any changes in electricity generation will be reflected in capital stock changes.

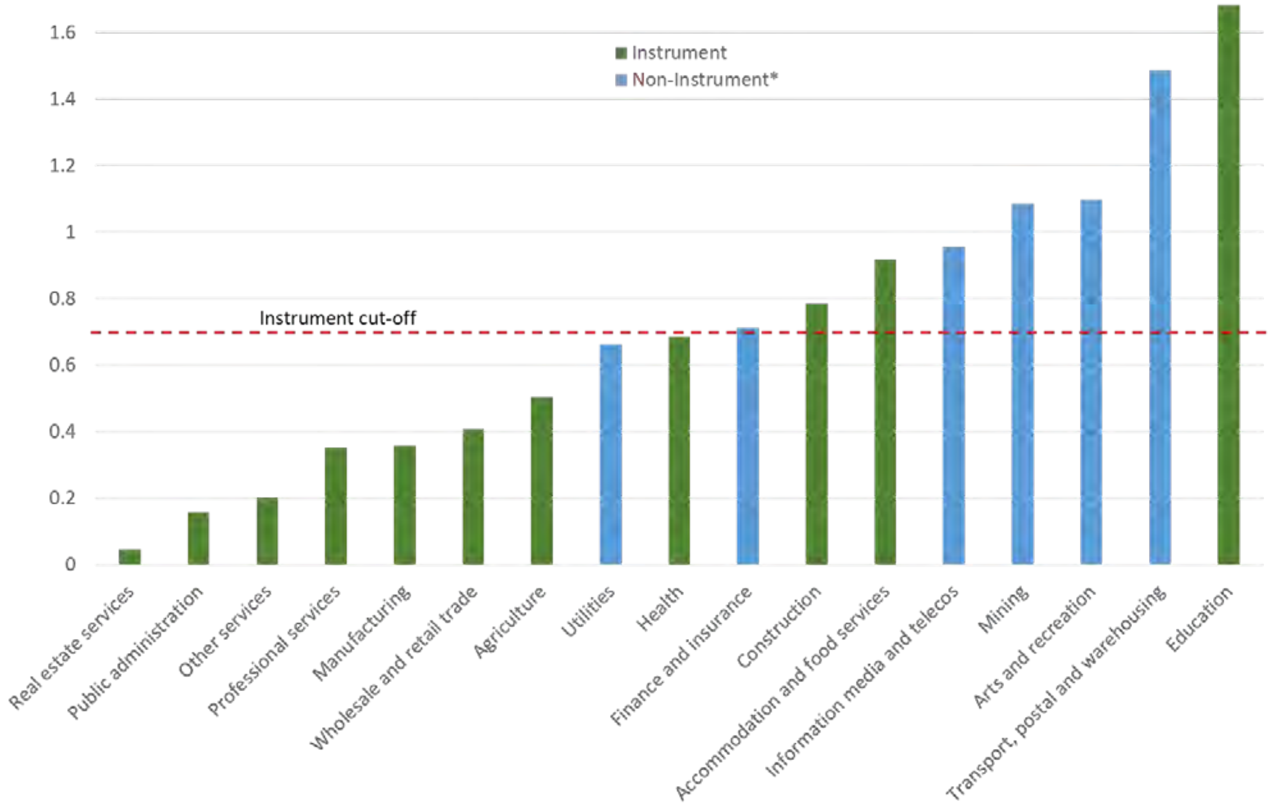

Figure 4.9 Ratio of Australia-to-United States capital-labour ratios (2015)

Sector capital stock is measured in 2010 PPP AUD, where PPP exchange rates are used, and labour is measured in hours worked within each sector. Sectors are sorted by ascending Australia-to-United States capital-labour ratios.
*See definitions in Section 4.2.
Source: CSIRO (internal CSIRO computations), World KLEMS (n.d.), EU KLEMS (2017), ABS (2018a) and OECD (exchange rates) (OECD, n.d.)

4.4.3 Balancing growth across the economy

The allocation of sectors across ‘instrument’ and ‘non-instrument’ groups allows a nuanced approach to the indirect productivity parametrisation. The results presented in Table 4.4 depict an empirically based, balanced growth projection that takes advantage of the general equilibrium modelling in VURM. Despite the pre-classification of sectors, which affects the sector TFP/K levels, several other factors additionally contribute to the economic performance of each sector. This can be seen through variable sector growth within and between groups. For example, under *Green and Gold* the education sector’s GDP share declines from 4.6% to 4.0% from 2016 to 2060, even if the sector’s TFP/K ratios increased over time. However, the ‘non-instrument’ mining sector increases its share of GDP over the same period, growing from 6.8% to 8.5%. Such outcomes reflect the modelling complexities across multiple layers of input at the global, national, sector, and scenario narrative levels.

Table 4.4 Sector TFP growth rate summary statistics of core scenarios

SECTOR	INSTRUMENT	HISTORICAL (1996–2017)			*SLOW DECLINE*			*THRIVING AUSTRALIA*			*GREEN AND GOLD*			GDP SHARES	
		AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX	2016	2060
Accommodation and food services	Y	0.4%	–1.6%	2.4%	0.7%	0.1%	1.2%	1.5%	0.5%	2.3%	1.4%	0.5%	2.0%	2.5%	2.8%
Agriculture	Y	1.2%	–7.8%	9.7%	-0.7%	–1.2%	–0.1%	0.0%	–0.9%	0.4%	0.6%	–0.9%	3.3%	2.1%	4.4%
Business services	Y	–0.1%	–2.0%	2.6%	0.7%	0.4%	1.2%	1.4%	0.5%	2.0%	1.4%	0.5%	2.0%	13%	12%
Construction	Y	0.3%	–4.1%	3.4%	0.8%	0.2%	1.2%	1.5%	0.7%	2.1%	1.5%	0.4%	2.0%	7.1%	5.8%
Education	Y				0.7%	0.4%	1.2%	1.4%	0.4%	1.9%	1.3%	0.4%	1.9%	4.6%	4.0%
Finance and insurance		1.0%	–1.8%	3.0%	0.9%	0.5%	1.4%	1.3%	0.9%	1.8%	1.3%	0.8%	1.7%	9.8%	8.9%
Health	Y				0.7%	0.4%	1.2%	1.4%	0.4%	2.1%	1.4%	0.4%	1.9%	4.0%	3.7%
Information, media and telecos		0.4%	–3.6%	4.0%	0.9%	0.6%	1.1%	1.3%	0.9%	1.7%	1.3%	0.8%	1.6%	3.1%	2.5%
Manufacturing	Y	0.1%	–1.3%	1.1%	0.7%	0.1%	1.2%	1.5%	0.6%	2.1%	1.4%	0.4%	2.0%	8.2%	7.9%
Mining		–1.0%	–5.5%	3.8%	0.9%	0.8%	1.1%	1.4%	0.9%	2.0%	1.4%	0.8%	2.2%	6.8%	8.5%
Other services	Y*	0.0%	–3.3%	3.1%	0.7%	0.3%	1.2%	1.5%	0.6%	2.2%	1.5%	0.6%	2.1%	6.7%	7.3%
Private dwellings and transport					0.6%	0.4%	0.8%	1.1%	0.7%	1.6%	1.1%	0.7%	1.4%	12%	14%
Public admin and safety	Y	0.2%	–5.8%	5.9%	0.7%	0.4%	1.2%	1.4%	0.4%	2.1%	1.4%	0.4%	1.9%	5.5%	5.1%
Retail trade	Y	0.7%	–1.0%	2.1%	0.7%	0.3%	1.2%	1.5%	0.5%	2.1%	1.4%	0.5%	2.0%	3.9%	3.5%
Transport, postal and warehousing		0.3%	–2.5%	2.0%	0.9%	0.6%	1.1%	1.3%	0.8%	1.7%	1.3%	0.7%	2.0%	4.8%	4.8%
Utilities		–0.7%	–3.0%	2.6%	0.8%	0.6%	1.1%	0.9%	0.6%	1.2%	1.2%	0.7%	1.8%	1.9%	1.6%
Wholesale trade	Y	1.2%	–2.0%	3.5%	0.7%	0.3%	1.2%	1.5%	0.6%	2.1%	1.5%	0.6%	2.3%	4.1%	3.8%

*For use as an instrument sector, other services excludes the gambling and culture sub-sectors. The ABS KLEMS TFP estimates more closely align with the TFP values computed within VURM, as both series account for inputs beyond capital and labour (e.g. energy). The ABS did not produce historical TFP growth estimates for all sectors listed above.
Source: ANO 2019 modelling; Australian Bureau of Statistics (ABS), KLEMS estimates (ABS, 2018a)

While the heterogeneity across sector-level results is laudable, there is a clear cross-sector trend toward higher TFP growth in the more positive *Thriving Australia* scenarios that is supported by a mix of quantitative and qualitative research.[36] For the sector-by-sector discussion of TFP (detailed in Section 4.4.4), there are several cross-sector shifts that can be overlaid on the results that are aligned with the scenario narratives. These shifts are generally focused on sectors with lower technology complementary endowments, meaning that they are seen as balancing growth within the domestic economy. Note that most of these shifts are not explicitly parametrised within the ANO 2019 modelling framework, but the parametrisation process considered the qualitative merits of various input shifts in order to bound productivity growth.

The World Bank proposes a three-stage heuristic framework called the ‘capabilities escalator’ to progressively support higher stages of productivity and economic sophistication (Xavier and Maloney, 2017).[37] The ANO 2019 modelling adopts implicit assumptions that broadly map to this framework. Specifically, potential cross-sector drivers of productivity improvements and TFP growth in Australia include (i) targeted investment in technological capital, both physical and knowledge-based; (ii) increased participation and integration within global product and knowledge chains (e.g. internationalisation); (iii) increased competition intensity; (iv) more efficient use of the urban landscape, both across land use and infrastructure; (v) better human capital allocation; and (vi) improvements in management and collaboration practices. These six cross-sector drivers are described in additional detail below.

Technology investment

This chapter covers technological adoption in substantial detail (see Section 4.4). However, investment is a separately and endogenously calculated metric within VURM. Instead of directly parametrising investment, the ANO 2019 model parametrisation indirectly addresses investment changes through the incentives to invest. The rate of return is directly influenced by the endogenously calculated TFP growth, which is, in turn, driven by the sector TFP/K ratios. Thus, technology investment can be explored in some very relevant detail within the scenario results. For example, the decomposition of investment effects on GDP growth (see the Australian National Outlook 2019 report (CSIRO and NAB, 2019)) highlights the importance of economy-wide growth in technology investment.

Many definitions of technology investment focus on information and communications technology (ICT). Substantial growth in ICT in the 1990s and early 2000s, particularly in the United States, revolved around capital deepening (Dabla-Norris et al., 2015). This ICT ‘revolution’ was responsible for considerable TFP growth during this period, although related productivity growth has since slowed (Fernald, 2015). However, Australia’s equivalent ICT adoption period was slightly delayed compared to the United States (OECD, 2015). This is primarily related to frictions in domestic ICT adoption. For example, Australia’s National Broadband Network (NBN) has experienced several costly delays for what might be dated technology (BBC News, 2017).

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[36] Qualitative research includes feedback from the Australian National Outlook participant group experts.

[37] The ‘capabilities escalator’ is composed of three stages of upgrading that (i) primarily supports production and management capabilities, (ii) increases the focus on supporting technological capabilities, and (iii) expands the support to invention and technology-generation capabilities.

Internationalisation

As discussed in Section 4.4.1, the internationalisation of sectors can potentially lower barriers to technology diffusion. The mechanism can take many forms, such as integration within existing trade patterns, parent-subsidiary knowledge-based capital transfers, or the participation in GVCs. The main point around all internationalisation mechanisms is they are typically open to global competitive pressures and usually exhibit relatively high levels of efficiency and productivity.

Competition intensity

Similar to the effect of GVC on opening domestic sectors to international competitive pressures, domestic competition intensity can enable shielded sectors to pursue productivity improving strategies. One of the main discussion points with respect to improving competition intensity revolves around appropriate regulation. Barriers to entry can additionally lead to competition problems, which is exacerbated by Australia's increasing regulatory burden.[38] For example, sector consolidation can improve economic performance through efficiency gains, but increased market concentration might lead to monopolistic market behaviours and/or other abuses. For example, research shows that between 65% and 80% of Australia's wealthiest individuals owe their success to political connections, compared to 1% in the United States.[39] However, while home to some relatively concentrated sectors[40] that have exhibited passive collusion practices (Byrne and de Roos, 2017), Australia is not a global outlier when it comes to large-firm profits, market concentration or market share trends (Minifie et al., 2017b). This does not mean that Australia will not benefit from intensifying competition. Rather, targeted policy measures, such as those addressing overly high barriers to technological diffusion, could be implemented (The Economist, 2018). Substantial detail around improving Australian competition policy across multiple dimensions was presented in the Australian Government's *Competition Policy Review* (Harper et al., 2015).

Urban landscape

The current physical infrastructure in Australia's largest urban areas, and the development plans concerning land use and proposed infrastructure development, can potentially yield broad, cross-sector productivity improvements if appropriate cost-benefit analysis is utilised. This means taking a system integration approach that accounts for both financial and economic (e.g. social welfare) performance. Some of these considerations are explicitly parametrised within the ANO 2019 modelling framework, while others are implicitly overlaid. See the Cities and Infrastructure technical report (Chapter 5) for detail around this topic.

Human capital allocation

The under- and over-skilling of labour, broadly defined as individuals whose skills are not efficiently matched with their current occupation, is a non-trivial source of allocative inefficiency, with a one-time 6% productivity increase associated with moving Australia to the frontier (Adalet

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[38] The OECD has highlighted that Australia's advantage in 'lighter regulation' has eroded (see OECD, 2017).

[39] Bagchi and Svejnar (2015) estimate that approximately 65% of Australian billionaires (1% in the United States) amassed their wealth through political connections, while Frijters and Foster (2015) estimate the value at 80% by repeating the analysis with different definitions of wealth and political connection.

[40] Minifie et al. (2017b) identified banking and finance, supermarkets and fuel retailing as sectors with increased market concentration.

McGowan and Andrews, 2015). Barriers to the efficient allocation of human capital are potentially linked to other areas of cross-sector productivity improvements, such as an urban landscape that expands the labour market search area for all individuals due to higher transportation efficiencies or better management practices that identify and allocate talented individuals based on meritocratic principles. This topic is discussed in Section 4.5.2 at a macroeconomic level that combines human capital formation and technology topics.

Management and collaboration practices

Knowledge-based capital can sometimes be referred to as a generalised term that covers a spectrum of both well-defined topics and fuzzy concepts. Management and collaboration practices are two well-researched topics where specific recommendations can be made that can logically support productivity improvements. A range of productivity impacts related to management and collaboration capital are highlighted by a growing stock of international research (OECD, 2015; Cirera and Maloney, 2017; and Acemoglu et al., 2014) and national research (for example, see Green et al. (2009)), including the assessment and allocation of talent (e.g. human capital allocation), modern human resource practices, organisational restructuring promoting technological change, and alignment of R&D policy with intellectual property incentives.

4.4.4 Scenario TFP growth rate

The TFP growth rate performance of Australia's economy-wide historic (since 1996) and future scenarios (since 2016) can be seen in Figure 4.10. As previously discussed, despite significant noise, Australia's historic TFP growth rate has been declining (see historic linear trend). This contrasts with the TFP growth rates envisioned (i.e. endogenously computed) in the core scenarios. Although this is an expected and desired result based on the multiple lines of research summarised in previous sections, these higher TFP growth rates are a significant reversal of current trends. As the economy-wide TFP growth rates presented in Figure 4.10 cannot capture the nuanced sector heterogeneity, this section provides additional detail at the sector level. To provide additional insight and a basis for the subsequent discussion, provides a similar TFP growth rate representation as seen in Figure 4.10, but for 17 broad sectors covering the entire economy. Each panel presents a single sector, which should be referenced while reading the sector-specific discussion below.[41]

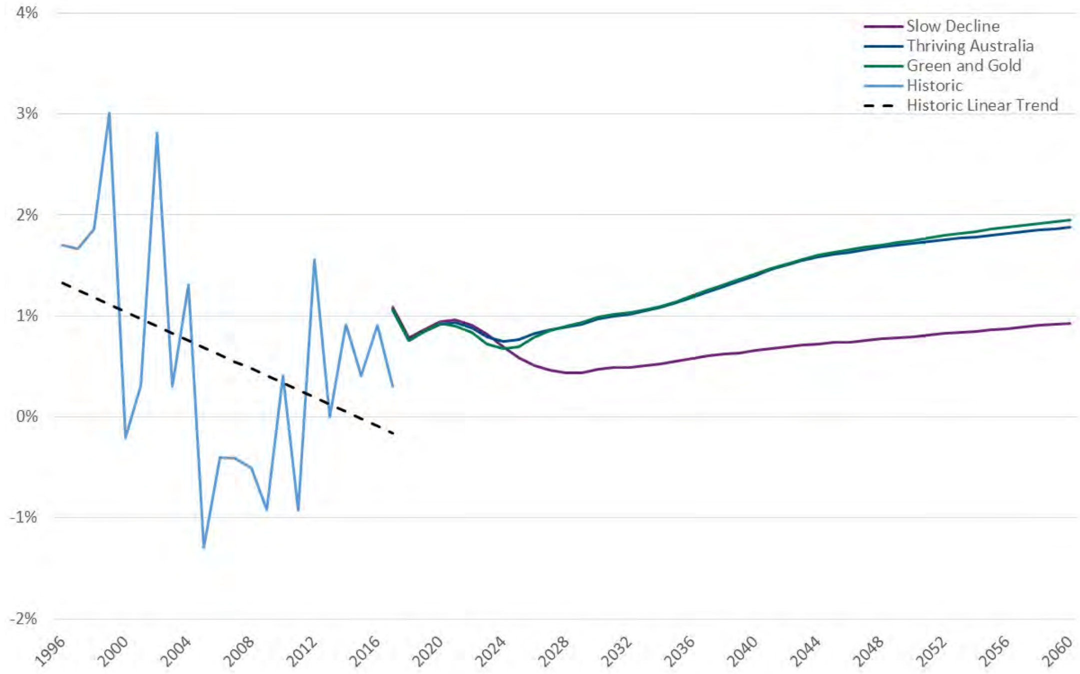

Figure 4.10 Comparison of Australian TFP growth rates for historic and future scenarios

The ABS uses the term 'MFP', although their KLEMS estimates include inputs beyond capital and labour. ABS KLEMS MFP estimates are the most natural comparison to VURM TFP in a modelling sense, which is why historic OECD TFP estimates are not compared. ABS KLEMS estimates are not available for the education and health sectors. Additional (VURM) sector weightings are used for other- and business services to allow comparison with reported ABS KLEMS sectors.
Source: Australian Bureau of Statistics (ABS), KLEMS (historic) (ABS, 2018a); and ANO 2019 modelling (future scenarios).

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[41] Private dwellings and transport is not discussed, as there is no historical data for this sector. Additionally, neither private dwellings nor private transport appears in the Australian National Accounts. These sectors are included in VURM for other purposes.

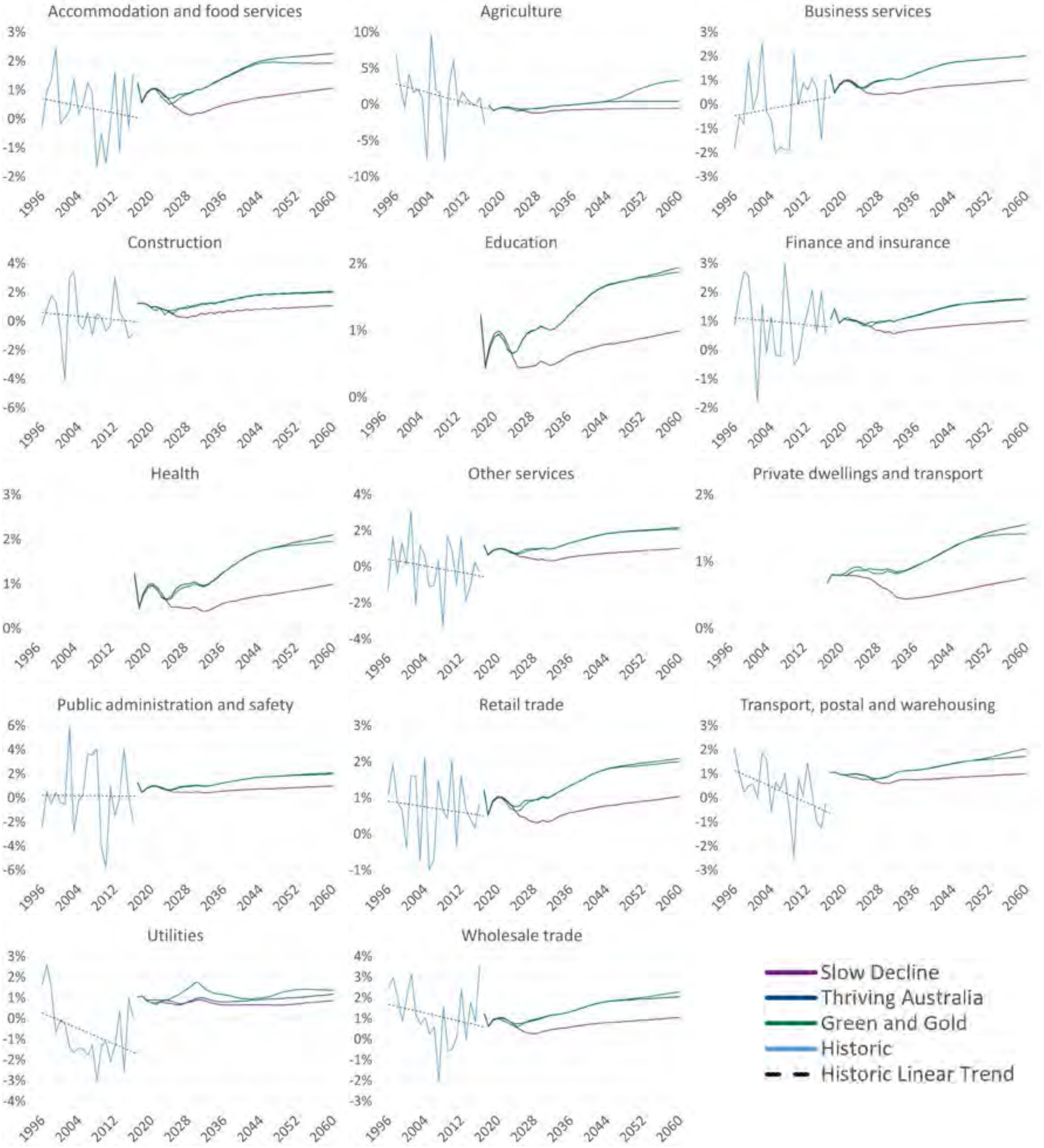

Figure 4.11 Comparison of Australian historic and scenario TFP growth rates by sector

The ABS uses the term ‘MFP’, although their KLEMS estimates include inputs beyond capital and labour. ABS KLEMS MFP estimates are the most natural comparison to VURM TFP in a modelling sense, which is why historic OECD TFP estimates are not compared. ABS KLEMS estimates are not available for the education and health sectors. Additional (VURM) sector weightings are used for other- and business services to allow comparison with reported ABS KLEMS sectors.
Source: Australian Bureau of Statistics (ABS), KLEMS (historic) (ABS, 2018a); and ANO 2019 modelling (future scenarios)

Accommodation and food services

As an ‘instrument’ sector, accommodation and food services has considerable scope for TFP improving capital and KBC investments. However, the incentives for such investments (e.g. rates of return) are somewhat difficult to resolve in this context. Because this sector generally services a domestic market, even with respect to tourism, there are few incentives to increase productivity. In particular, competition within the sector is blunted by the non-substitutability of output. Thus, the primary driver of increased TFP is assumed to revolve around the internationalisation of the sector, where multinational firms lead productivity improving practices that broadly increase competition and raise the sector's investment return expectations.

Agriculture

While technically an 'instrument' sector, due to the high productivity growth potential, the Australian agricultural sector has historically exhibited mixed TFP growth relative to the frontier (Sheng et al., 2015). Thus, the modelling results potentially suggest sector-specific structural issues, as increases in the TFP/K ratio do not generate substantial gains in TFP across the core scenarios. The off-trend TFP growth seen in *Green and Gold* is generated by the carbon/emissions price dependent forestry (carbon sequestration) sector. Therefore, the modelling framework outputs very reasonable agriculture TFP growth trends for all scenarios.

Business services

The modelling framework generates upward trending TFP growth consistent with the historical business services sector TFP growth performance since 1996. This output is consistent with the sector's 'instrument' sector status combined with scope for increased TFP improving investments. Thus, the core scenario TFP growth rates for the business services sector are both reasonable and consistent with the scenario narratives.

Construction

The construction sector is generally considered one of the global laggards with respect to productivity, with TFP levels that have broadly remain unchanged for decades (Barbosa et al., 2017). This reflects the lack of global competition and the non-substitutability of output. Thus, as in all countries, the construction sector represents a unique opportunity for significant productivity gains. This is reflected in its 'instrument' sector status. In this regard, Australia is moving forward in some relevant areas, such as prefabricated building methods and materials. It should be noted that the modelling framework produces a fairly gentle upward sloping TFP growth trend, which is additionally underpinned by substantial energy efficiency increases.

Education

The scenario narratives point to a substantial increase in the productivity of the education sector, driven by a range of TFP improving investments. As an 'instrument' sector that already faces substantial international competition, there is an implicit assumption that the Australian education sector will follow global trends in education TFP. Australia's strength as an education provider, particularly with respect to tertiary education, is taken as strong evidence that Australia will continue to exploit its comparative advantage in the education sector, even with significant global competition.

Finance and insurance

As articulated by the Productivity Commission (Productivity Commission, 2015), Australia's finance and insurance sector has experience significant change over the last decades. This reflects the productivity improving investments across the sector that have moved it toward the global TFP frontier. As such, the finance and insurance sector is classified as a 'non-instrument' sector. However, various factors beyond TFP/K ratio changes enable the sector to maintain (*Slow Decline*) or improve (*Thriving Australia*) its TFP growth performance. These factors include the sector's return on investment and the associated general equilibrium effects.

Health

Comprising health care and social assistance, the Australian health sector exhibits both considerable lag and innovation simultaneously (CSIRO, 2018). While the ABS does not provide historical Australian health sector TFP estimates, research over the last decade shows Australia's health sector TFP performance was consistent with its OECD peer group, which itself exhibited relatively low variance with annual TFP growth tending toward 1% (Petrie et al., 2009). Additionally, Australia's health sector displays a 'late start/fast growth' technology uptake pattern that converges to technology frontier (Productivity Commission, 2005). Going forward, this means that Australia's health sector TFP growth will come from the adoption of innovation at the technological frontier, combined with better data management practices and a broader focus on lifestyle improvements (CSIRO, 2018).

Information, media and telecommunications

The core scenarios envision the domestic information, media and telecommunications sectors to continue producing gradual productivity improvements through 2060. The trend difference between the more positive- and Slow Decline scenarios is not meaningfully driven by sector specific characteristics within the scenario narrative. I.e., the differences are driven by broader changes across the modelled economies, such as global context and energy efficiency. Furthermore, the sector has experienced several one-off events such as consolidation that, in theory, improve productivity (Minifie et al*.,* 2017b).

Manufacturing

The well-established facts around manufacturing in Australia do not superficially point to an impending industry renaissance. The long-term trends show a sector in almost monotonic decline since the mid-1980s, as reflected in sector employment and output trends (Langcake, 2016). The scenario narratives forecast a turning point for the broader sector, one which is empirically supported within the modelling framework. The quantitative conclusions are predicated on a number of changes within the sector including (i) value-add technological adoption that favours small- and medium-sized enterprises (SMEs) that (ii) spurs renewed interest in advanced manufacturing due to increasing rates of return on investment, which are driven by (iii) favourable global and domestic shifts, such as improving energy efficiency coupled with relatively low country-specific energy costs and monotonically increasing emissions pricing (see Chapter 8).

Mining

The broad mining sector grouping includes all extractive industries, including the extraction of commodities such as iron ore, coal, oil and natural gas. Australia's extractive industries sector has been singled out as a global benchmark within the mining sector, with high levels of capital investment around technology and innovation (Dabla-Norris et al., 2015). However, as these high capital costs are usually made in anticipation of greater productive output, there is a lag between the measured input and output of the sector. As such, the mining sector's TFP growth has trending down since 1996, albeit with notable noise around this trend. While mining is not an 'instrument' sector within the modelling, the framework to support higher future TFP growth (e.g. capital investments) enable the sector to maintain its place on the frontier of productive performance. Even with a relatively high emissions price level in *Green and Gold*, the mining sector is able to adjust to the changing global environment based on its fundamental comparative advantages (see Chapter 8).

Other services

Similar to the business services sector, the other services sector experiences a considerable upward trend in TFP growth. However, unlike the business services sector, the other services sector does not have a strong historical TFP growth trend. Instead, TFP growth is assumed to come from the spillover effects from similar and/or interaction sectors, such as the business services and public administration sectors.[42] The other services sector includes gambling and culture sub-sectors that are not included when the sector is employed as an 'instrument' sector.

Public administration and safety

There is an assumed historical productivity relationship between the business services sector and public administration, in that private sector practices influence the public sector in a lagged manner with a reduced productivity impact. This can be seen in the empirical evidence, where historical TFP growth for both the business sector and public administration is near zero.[43] The core scenarios broadly reflect this thematic relationship, with business services and public administration achieving average TFP growth rates of 0.5% and 0.4 %, respectively, in the *Green and Gold* scenario.

Retail trade

See wholesale trade sector discussion below.

Transport, postal and warehousing

See wholesale trade sector discussion below.

Utilities

See Section 4.4.2.

Wholesale trade

The broad chain of transport-warehousing-wholesale-retail trade is envisioned to broadly increase TFP growth in all core scenarios. The narrative that supports this pivot in productivity trajectories is increasing pressure from international competitors entering the domestic marketplace. These international competitors are global leaders in productivity and efficiency along their entire operations chain. For example, Amazon.com has recently entered the Australian domestic market and is expected to expand its operations both vertically and horizontally (The Australian, 2018).

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[42] Spill-over effects can include labour resources moving between sectors and the associated operations knowledge diffusion.

[43] The historical average TFP growth rates for the business services and public administration sectors is -0.1 and 0.2 percent, respectively (see Table 5 for additional detail).

4.5 The unemployment rate

4.5.1 Human capital and technology

Australia's human capital levels have been broadly considered among the highest worldwide (OECD, 2016a). This human capital strength has manifested itself in human capital measures extending into adulthood, such as the strong performance of those aged 16 to 65 years in problem solving in technology-rich environments (OECD, 2016b). However, this high level of achievement is declining.[44] Reflecting research concerning the link between technology and skills, Australia's declining mathematical abilities are of particular relevance to the ANO 2019 model parametrisation and scenario narratives.

Finding qualitative evidence of the math-technology link is straightforward (for example, see The Economist (2014)). However, understanding the empirical literature around the math-technology relationship requires some technical understanding of the assumptions and methods use. At its core, much of the task-based literature concerning occupations, employment and polarisation explicitly links math and technology. This started with the seminal research by Autor et al. (2003) that investigated the skill content of occupations and statistically collapsed the information along two dimensions: (i) routine/non-routine and (ii) manual/cognitive. The main findings of this research are that, 'computerization is associated with reduced labour input of routine manual and routine cognitive tasks and increased labour input of nonroutine [sic] cognitive tasks.' That is, technology most easily replaces routine tasks in the labour market, but is highly complementary to non-routine cognitive tasks. The authors' selection of variables linked to the task interpretation (see Appendix 1 in Autor et al. (2003)) above shows that only one variable is used to proxy non-routine cognitive tasks ('nonroutine analytical tasks'): math. This methodology and the associated assumptions are replicated throughout the literature. For example, in another seminal paper, Autor and Dorn (2013) progressed the literature by defining abstract tasks as a combination between managerial tasks and math (see Section D in Autor and Dorn (2013)). Thus, the connection between math and non-routine cognitive/abstract tasks, which are complementary to technological change, is embedded in the literature.

More direct empirical evidence of the math-technology link can be found in the career and occupation literature. For example, recent work by Deming and Noray (2018) highlights the relationship between STEM jobs and technological change, showing that the, *'earnings premium for STEM majors is highest at labour market entry, and declines by more than 50% in the first decade of working life. This pattern holds for 'applied' STEM majors such as engineering and computer science, but not for 'pure' STEM majors such as biology, chemistry, physics and mathematics.'* The authors argue that, *'new technologies replace the skills and tasks originally learned by older graduates, causing them to experience flatter wage growth and eventually exit the STEM workforce.'* Looking at the relationship between cross-occupation wage differences and skills, Rendall and Rendall (2014) find that a large portion of inequality amongst college graduates can be explained by math-biased technical change (MBTC). MBTC is conceptually similar to skill-biased technical change (SBTC), but instead of assuming that a college degree indicates specific

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[44] For example, (i) the proportion of low performers in science increased by five percent to 18 percent, at the same time as the proportion of high performers declined by three percent to 11 percent; (ii) overall math performance declined significantly between 2003 and 2015, suffering a 30 point decrease; and (iii) overall reading performance declined significantly between 2009 and 2015, with a 12 point fall (Thompson *et al.*, 2015).

technology complementary skills, the authors use the math requirements of college majors and occupations instead.

For the ANO 2019 model parametrisation assumptions, there are three technology-human capital setups employed. The parametrisation does not explicitly link mathematics and technology, but rather speaks to a more broad set of human capital dimensions because (i) the modelling framework does not accommodate specific human capital skill dimensions and (ii) mathematics might only be informative about technology complementary skills, which is just one component of employment. The first setup is the most commonly used within the ANO 2019 modelling framework, and does not require any exogenous parametrisation. The second and third setups, discussed in Section 4.5.2, address questions about the future of work and the impact of technological change on employment. These two setups model a human capital-technology skill gap using the unemployment rate.[45]

1. Aside from the *Jobless Growth* and *Human Capital* sensitivities, all scenarios and sensitivities use a technology-human capital setup that assumes the Australian labour force continues to efficiently couple with technology. This means that exogenous parametrisation around this topic is not necessary.
2. The second setup is specifically designed for the *Jobless Growth* sensitivity scenario. This sensitivity scenario is a worst-case scenario that reflects many of the fears about technological change. As such, the exogenous unemployment rate peaks at 20%, before settling at a relatively high 10% 'new' natural unemployment.
3. The third setup is used to model an expectations-based employment impact from technological change using a more 'conservative' unemployment rate that likely reflects more realistic employment impacts from a technology-induced skills gap. This means that the unemployment rate peaks at 10% (half that of the *Jobless Growth* sensitivity scenario) and settles at a post-peak rate of 7%. This setup is used in the *Human Capital* sensitivity scenario, which provides an estimate for the effect of human capital levels declining relative to the requirements of industry.

4.5.2 The future of work, automation and artificial intelligence

There are a number of concerns with respect to the effect of future technological progress on employment. Due to the unpredictability around the pace and scope of technological progress, combined with the resulting dynamic interactions, the impact of technological progress is difficult to estimate with any certainty. This does not stop researchers from trying to predict the impact of technological progress on employment. CSIRO compiled a comprehensive list of research that estimated employment impacts from technological change. Using various methodologies, from task-based frameworks and historical evidence to more flexibly defined qualitative approaches, a large range of employment impacts have been proposed (CSIRO and NAB, 2019).

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[45] Aside from the decreasing labour market size, one of the biggest impacts is seen in the modelled inequality via the proxy Gini coefficient. See Productivity Commission (2018) for historical inequality trends.

As a first step in finding a common theme within this noisy area of research,[46] the selected[47] third-party estimates were standardised to Australian unemployment rate values assuming they (i) account for the general equilibrium effects,[48] (ii) directly relate to the additional long-term displacement of workers,[49] (iii) estimate impacts in addition to the natural unemployment rate,[50] and (iv) account for all employment effects.[51] These assumptions likely bias the final unemployment rate estimates to the higher side, which aligns with the narrative around the *Jobless Growth* sensitivity scenario.[52] Even with assumptions (i) and (iv), the impact estimates are grouped into 'general equilibrium' and 'non-general equilibrium' bins, where the general equilibrium estimates explicitly consider both the potential positive and negative impacts on employment. The employment rate estimates were then grouped into 5-year periods (2020 to 2035), with the range of employment impacts separately provided for the entire sample and the general equilibrium sub-sample in Figure 4.12. This figure also depicts a weighted average unemployment rate that is a weighted average of the general equilibrium estimates (two-thirds) and all other estimates (one-third). The reason for this weighting is the clear quantitative strength of the general equilibrium research compared to other estimates. This methodology informed the *Jobless Growth* unemployment rate estimate, in that the weighted average unemployment rate estimate settles just above 20%. Thus, the unemployment rate for *Jobless Growth* peaks at 20% (in 2040) by following a smoother unemployment rate trend than the weighted average estimate suggests. After a period of adjustment, the unemployment rate for both scenario sensitivities trends down, reflecting long-term, intergenerational human capital accumulation effects.[53, 54]

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[46] There is considerable statistical noise around the estimated employment impacts, and also media-related noise that incentivise researchers to produce 'shocking' estimates.

[47] Of the original set of forecasts, four estimates were excluded. Two estimates from Frey (MD+DI, 2013) were excluded based on their opaque methodology that generally referred to highly qualitative statements. Two additional UK estimates (Haldane, 2015; Nedelkoska and Quintini, 2018) were excluded because these researchers estimated impacts for both the US and UK using the same methodologies that yield very similar results for both regions. Thus, to avoid double weighting these methodologies, only their US impact estimates are included.

[48] Where available, the referenced research explicitly mention that estimated employment effects are computed in a partial equilibrium setup. It is otherwise fairly clear that research that does not mention the general equilibrium effects do not consider this point.

[49] The long-term displacement of workers is assumed to directly affect the unemployment rate, rather than increase other classifications, such as those claiming long-term disability.

[50] The structural unemployment rate is taken as 5.8% based on the average unemployment rate calculated within the VURM base model.

[51] That is, the estimated impact on employment is a net value, accounting for any potential negative and positive effects.

[52] The *Jobless Growth* sensitivity scenario can be considered the most negative 'worst-case scenario' that can be supported by current research.

[53] See Schwandt and von Wachter (2018) and references therein.

[54] The post-peak natural unemployment rate for both the *Jobless Growth* (10%) and *Human Capital* (7%) sensitivity scenarios is based on the assumption that 30% of the technological change impact is a long-run (persistent) effect, after accounting for the pre-peak natural unemployment rate.

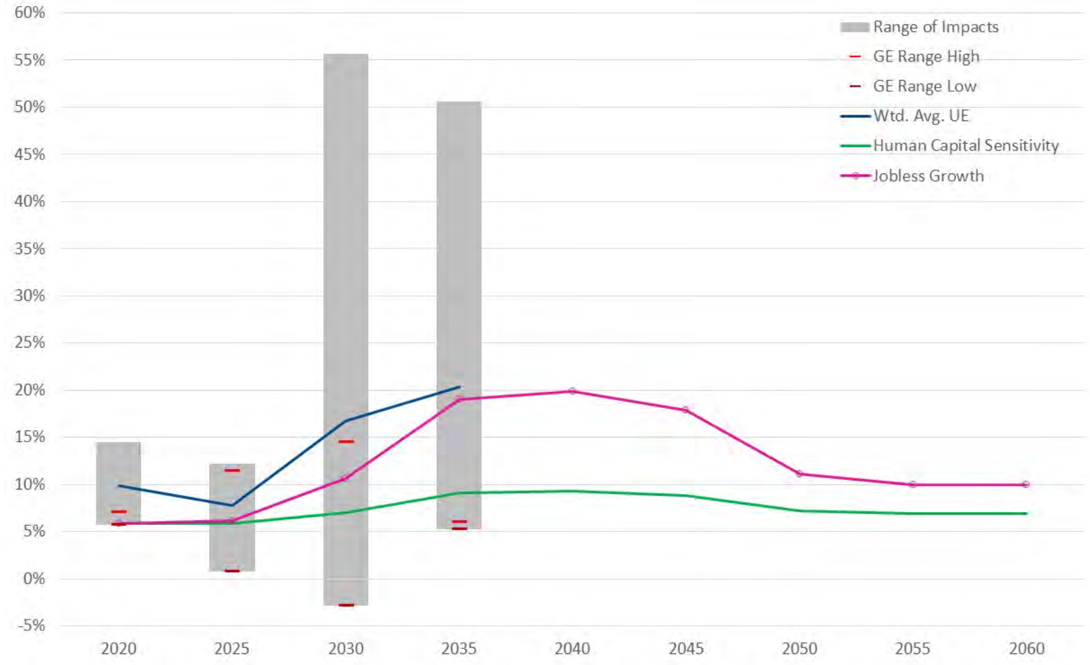

Figure 4.12 Unemployment rates of scenario sensitivities compared with ranges based on third-party estimates for the employment impact from technological change

Each year range covers the 5 years prior, for example, 2020 covers the 2015 to 2020 period. The employment impacts are standardised to Australian unemployment rate estimates (see text).
Source: CSIRO internal computations, Frey and Osborne (2017), Frey (2013), IFR (2013), Metra Martech (2013), AlphaBeta (2015), Haldane (2015), Chui et al. (2015), Forrester (2016), OECD (2016), WEF (2016), Acemoglu and Restrepo (2017), Forrester (2017), Gartner (2017), Lawrence et al. (2017), Manyika et al. (2017), Berriman and Hawksworth (2017), Nedelkoska and Quintini (2018), and Hawksworth and Fertig (2018)

4.6 Scenario parametrisation process summary

To ensure there is transparency around the assumptions and parametrisation of the ANO 2019 modelled scenarios, the parametrisation process for each scenario is described in the following sections with respect to the Productivity and Services domain. No additional information is included in this section, rather each scenario is described along all dimensions of relevance. This may also add clarity to the various interactions that were considered, both as exogenous and endogenous parameters.

4.6.1 Scenario: *Slow Decline*

1. A generalised version of VURM (base model), calibrated to the Australian economy using historical data and without any additional input or shocks, is simulated for the period 2016 to 2060. This initial run produces an annual time series of sector-specific TFP and capital stock estimates, from which annual TFP/K ratios are calculated for each sector.
2. The base model’s sector-specific TFP/K ratios are then used as initial values in the *Slow Decline* scenario, which also includes a range of other parametrisation (see Chapter 2). Unlike the base model, the *Slow Decline* model’s TFP is a direct function of the capital stock. This means that the TFP/K ratios are a simplified representation of the relationship between TFP and capital stock levels in each year and for each sector.

3. A GDP series was calculated from 2016 to 2060 that quantitatively and qualitatively accounted for potential economic growth trends through in-depth research around the broad drivers of growth, such as capital, labour and technology. The GDP series was calculated using an iterative process where the sector-specific TFP output was assessed against both research-based, empirically derived expectations and the scenario narratives defined by the participant group.
4. The 76 VURM sectors are grouped into 17 broad sectors that are then split into two groups. The first group, called 'instrument' sectors, identifies domestic sectors with relatively low technology-complimentary capital endowments as measured by their capital-labour ratios. The second group, called 'non-instrument' sectors, contains sectors that are generally considered at the frontier of potential productivity.
5. The GDP series produced in (3) is targeted by moving the sector TFP/K ratios, which represents TFP growth through the adoption of physical and knowledge-based capital. As the general equilibrium modelling framework still endogenously produces sector-specific TFP, there is a balance to how GDP growth is derived.

4.6.2 Scenario: *Thriving Australia*

The parametrisation process for *Thriving Australia* follows the same process described for the *Slow Decline* scenario, except that the GDP target series differs.

4.6.3 Scenario: *Green and Gold*

Taking the sector-specific TFP/K results of the *Thriving Australia* scenario in a similar way as the base model is used to seed sector TFP/K values in both the *Slow Decline* and *Thriving Australia* scenarios, *Green and Gold* is parametrised with one significant difference: the sector TFP/K values are pinned down at the *Thriving Australia* levels. Thus, *Green and Gold* displays similar broad trends as *Thriving Australia*, but with the additional impacts produced from changing the global context and parametrisation from other domains. Note that GDP levels are now endogenously calculated by VURM, as well as the usual endogenised TFP.

4.6.4 Scenario: *Regional Growth*

Taking the *Green and Gold* parametrisation from above, only one change is necessary to model the *Regional Growth* sensitivity scenario. This change relates to the agglomeration (i.e. population density) and congestion effects on labour productivity.

4.6.5 Scenario: *Jobless Growth*

Taking the *Thriving Australia* parametrisation process from above, three changes are made to create the *Jobless Growth* sensitivity scenario. First, sector TFP/K ratios are pinned down from the *Thriving Australia* scenario in a similar fashion as *Green and Gold*, which represents technology adoption by industry. Based on this first change, the second change is GDP is now endogenously calculated rather than targeted to understand the effects of the third parametrisation change. The second change reflects a skills gap between industry and labour – an exogenous unemployment rate is introduced as a crude representation of a divergence between the skills industry needs and the human capital skills offered by the labour force.

4.6.6 Scenario: Other Sensitivities and Decompositions

There are many additional VURM runs that generate specific output that inform various topics within the ANO. These VURM runs are well-defined deviations from core scenarios, where a single input is varied to capture the *ceteris paribus* effect. Care was taken throughout the various chapters to define the core scenario basis and the varied input to the extent they are not explicitly defined in a separate section in Section 4.6.

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5 Cities and Infrastructure

Author: Tim Baynes

5.1 Introduction

Australia is one of the most urbanised countries on Earth (World Bank 2018) and, at a high level, its cities appear to the rest of the world as great places because they are growing in population and income and are among the most liveable cities in the world[1]. The macro statistics do not, however, show the lived experience of different parts of Australian cities and regions where challenges remain and where there are substantial opportunities to improve.

As Australian cities have expanded through migration, Australians have benefitted from economies of scale and a wider skills base but the economy and spatial structure of the present is much transformed from that of the two previous generations. In the 1970s, Sydney and Melbourne both had around 2.5 million people, largely living in low-density suburbs that were still close to the main central business district (CBD), accessible by private car or via a hub-and-spoke public transport system. Manufacturing and light industry were a significant part of the national economy and located in or near those suburbs, enabling a ’30-minute city’ for workers in a variety of occupations.

Just over 45 years later Australian cities have doubled in population and their urban economies have shed most of the secondary industries in favour of services, but the essential primacy of the CBD and the residential structure of the suburbs remain (Dodson 2012; Coffee et al., 2016). Employment is concentrated in a few locations and the physical scale of the largest cities has outgrown the mass transit designs of the past (Kelly et al., 2012; Daley et al., 2017)[2]. Recent reports have also considered these themes (Deloitte Australia 2015) and assessed the current detailed spatial nature of liveability in Australian cities (Arundel et al., 2017). While their results are nuanced, they generally found that inner suburbs have better access to job-dense areas and amenities and are better serviced by public transport. Some well-observed side-effects of this spatial differentiation are longer average commuting distances for outer suburbs, historically high car dependency, vulnerability to fuel prices and housing financial stress for middle-to-low income groups (Perkins 2003; Dodson and Sipe 2008; Infrastructure Australia 2010; Commonwealth Department of Infrastructure and Regional Development 2015; Kelly and Donegan 2015).

Looking to the next 45 years, Australia’s major cities are not only expected to grow in population, from 14 million at 2016 to total some 27 million by 2060, but growth will also occur at a faster rate than in the preceding decades[3]. There are several potential responses to this population pressure.

In this chapter prior retrospective studies are complemented with a national scenario analysis of possible future states for Australian cities and other urbanised settlements aligned with the core

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[1] The Economist Intelligence Unit (2017)

[2] See also recent reports at Property Council of Australia (n.d.) and The Committee for Sydney (2018).

[3] ABS (2013)

scenarios of the Australian National Outlook (ANO) 2019: *Slow Decline*, *Thriving Australia* and *Stronger Regions*, a variation of *Thriving Australia* with more regional growth. These scenarios extend from a base year of 2016 to an end point at 2060. Although they are bound by the existing state and recent changes to Australian cities and infrastructure, they are not forecasts or predictions. Their purpose is to explore possible, even aspirational, futures as developed through discussion, critique and refinement in a series of workshops with ANO participants.

Note that while the Australian National Outlook 2019 report discusses results under two scenarios: *Slow Decline* and *Outlook Vision*, this report goes into further detail by reporting results for the *Outlook Vision* under two different global contexts: *Thriving Australia* under a fractious global context and *Green and Gold* under a more harmonious global context. It should be noted that both scenarios fall under the *Outlook Vision*. Chapter 2 of this report describes these scenarios in further detail.

The high-level narrative of these scenarios in the Cities and Infrastructure context is as follows:

Slow Decline: The experience of a large number of apartments being built in the last 10 years is assumed to be a transient response prosecuted through the re-zoning of industrial land to residential in the inner and middle suburbs. Once easily available land for re-zoning has been used up, the preferences of incumbent residents and local building regulations maintain the character of individual suburbs, effectively also maintaining density and land use mix. The effect is a modest increase in density but the spread of our cities precludes easy access to public transport at the outer. Population pressure is resolved with more peripheral development of land uses aligned with current characteristics, with consequences for accessibility and socio-economic polarisation.

Thriving Australia: Planners, urban strategists and developers innovate with mixed land use and mixed housing types to accommodate more (and different) people to be close to the activity centres of the city. Creating more dense areas and destinations enables better use of existing infrastructure and mass transit or autonomous transport options. There are still trade-offs: less parkland per capita; re-zoning of residential low-rise to medium or high-rise; and redevelopment of predominantly residential areas to realise the metropolitan strategic infill and density targets. This will challenge legacy preferences of the ideal family home but will likely provide a greater variety of housing close to amenity and jobs. Population pressure is resolved by a marked qualitative change to suburban living whereby traditional housing preferences are exchanged for accessibility and more affordable high-quality areas.

Stronger Regions: The imposition of infill and medium-high density is partially accepted by citizens of major cities but it is not for everyone. Even as major cities grow, over 110,000 people gravitate to satellite cities and regional urban centres each year. At 2060, 16 million Australians will have chosen to live *outside* the major cities, and this underlies the optionality of this scenario. Traditional housing preferences and suburban lifestyles are still available to urbanites in regional satellite cities that are a few hours away from a major city. Major cities get some relief from population pressure while regional cities benefit from agglomeration. This resolves population pressure with different options in different places.

In practice these narratives are translated into assumption bundles regarding future population distribution, land use, density and housing. Three Cities and Infrastructure assumption bundles, ‘low road’, ‘metro style’ and ‘stronger regions population’ settings, are mapped to the overall core scenarios of the project (refer to Table 5.1).

Table 5.1 Mapping of Cities and Infrastructure assumption bundles to Australian National Outlook core scenarios showing how differences in population distribution, density, land use mix and diversity of housing are analytically separated

ANO CORE SCENARIO NAME	LOW ROAD	METRO STYLE	STRONGER REGIONS POPULATION
Slow Decline	Similar regional population distribution, density, land use mix, and diversity of housing to that at 2016		
Thriving Australia	Similar regional population distribution to that at 2016	Higher density in major cities; more mixed land use and more local diversity in housing	
Stronger Regions		Higher density in major cities; more mixed land use and more local diversity in housing	Population distribution has more growth in satellite cities and regional centres

5.2 Scope and scale

ANO 2019 has obtained data and developed models to represent the different scenarios as experienced by Australian urbanised settlements[4] across seven broad topics. The analyses described in the following sections are intended to sufficiently inform the topics, using a small set of versatile indicators rather than modelling each topic exhaustively with variables and calculations that represent every nuance. For example, the demand for dwellings with a direct connection to population is simulated but no attempts are made to derive long-term house prices, optimise floor space allocation or represent the cycles of residential building construction. The high-level topics used to organise this chapter are:

- **population**: including overall trends and demography projections for Australia and distribution in major cities and regional areas
- **housing**: the supply of housing and the mix of dwelling types in different places
- **land use**: including the total urbanised area and the diversity of land uses in sub-urban locations
- **transport**: including the overall road transport task, and possible future split between transport modes
- **infrastructure**: total investment in buildings and engineering construction and also identifying major priority urban and national connectivity projects over the next 50 years.
- **productivity**: benefits for labour relating to agglomeration and indicators of cost from increasing size of settlements
- **liveability**: incidence of financial stress related to housing, incidence of volunteerism, places for aged care, distance to work, proximity to health care, green space per capita and qualitative analysis of access to urban amenities.

It is important to recognise that cities, and human settlements in general, are complex spaces with many components that interact in many ways, including feedbacks (Batty 2008; Baynes 2009). This is not modelled in ANO 2019. Given the national and long-term scope of the project, it was neither feasible nor desirable to create a detailed dynamic urban model of each major city. Instead, a limited set of key indicators for Australian cities in general were analysed, and there is less

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[4] 'Urbanised settlements' is synonymous with the Australian Statistical Geography Standard (ASGS): 'Significant Urban Areas' – see ABS (2017c).

concern about predicting the future as exploring plausible urban futures. For any *specific* city it would be important to model many more variables and their interactions for a more precise quantitative treatment of future scenarios.

The most detailed spatial analysis in this chapter uses the Australian Bureau of Statistics (ABS) 2011 Statistical Area Level 2 (SA2) boundaries[5] as the fundamental geographical unit. This enabled an analysis of intra-urban density and land use diversity, and reporting on inner, middle and outer suburbs, regional cities and rural settlements. Multiple datasets were aligned with this fundamental set of boundaries. Some of these data were not yet available for the base year (2016) at the time of writing but in all cases, the data dated closest to 2016 were used.

It was not feasible to address every component of each theme over 45 years at such a fine spatial resolution. As such, the analysis and reporting is focused on sufficiency and reasonable accuracy rather than completeness and precision. In general, the Cities and Infrastructure workstream analysis operates at two levels:

- At a state or national level aggregate data are used and reported that are consistent with the assumptions, inputs and outputs of the other ANO modelling efforts and are complete in national coverage.
- More detailed spatial or sectoral analysis allows investigation of particular topics that may have national scale but for where a complete national analysis is not intended.

Although discussions relate to all human settlements in Australia, no detailed analysis of rural communities, smaller state capitals (Hobart, Adelaide, Darwin, Canberra) or significant urban areas of population less than 75,000 people[6] has occurred.

The base year for most data is 2016 although historical data back to 1981 is used and scenario analysis extends from 2016 to 2060. Much of the reporting in this chapter focuses on Australia's four largest cities: Sydney, Melbourne, Brisbane and Perth, which are referred to as the 'major cities'. These cities have an outer jurisdictional boundary, and an associated resident population, defined by their respective Greater Capital City Statistical Areas (GCCSA)[7]. Where possible, the following sub-regions or 'zones' were investigated: inner suburbs, middle suburbs, outer suburbs, regional cities and rural settlements (Figure 5.1).

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[5] ABS (2011)

[6] Noting the exception of regional development for some fast-growing locations in Western Australia: Busselton and Bunbury

[7] ABS (2016b)

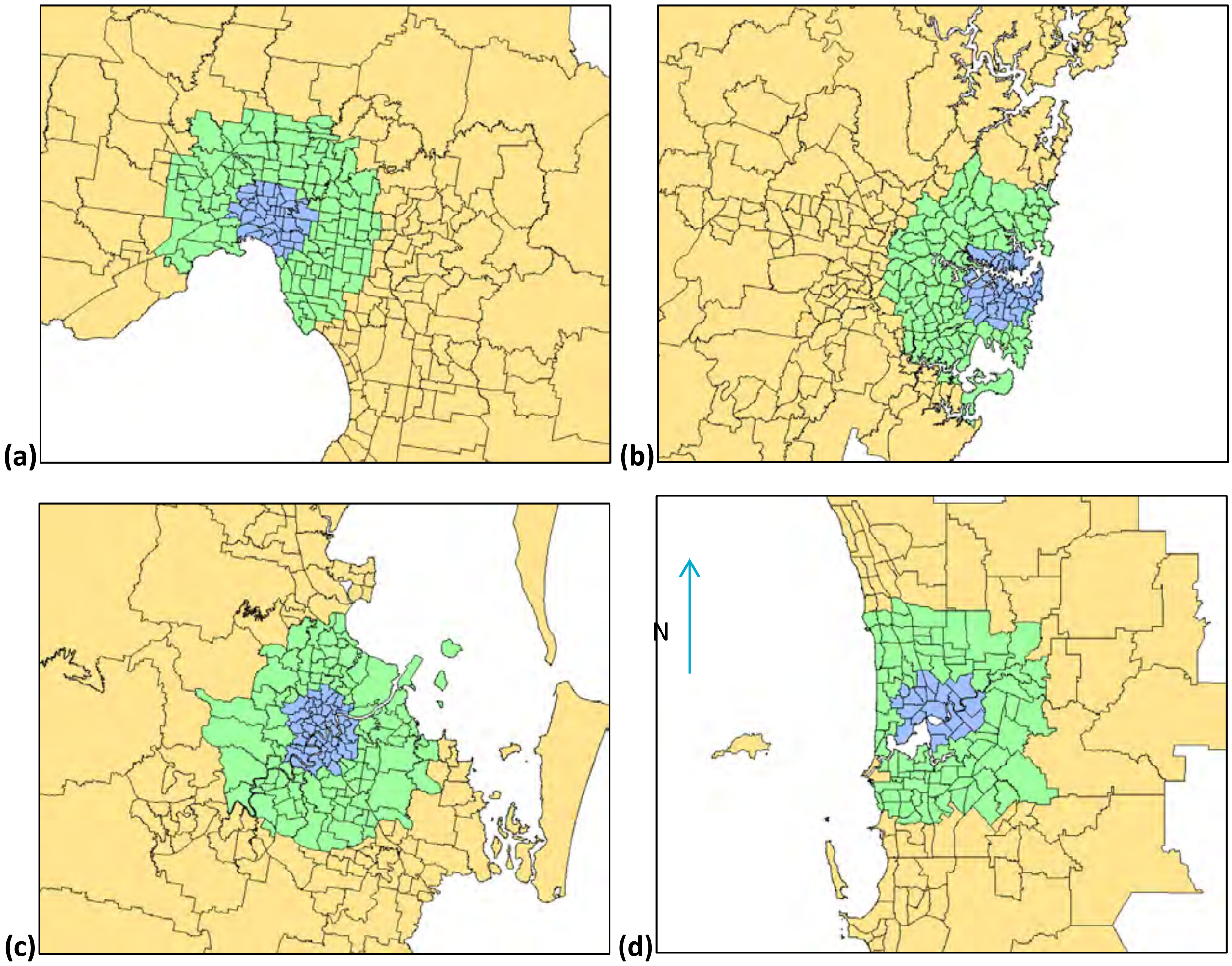

Figure 5.1 Spatial resolution of the analysis for the 'major cities' (a) Melbourne, (b) Sydney, (c) Brisbane and (d) Perth showing boundaries of Statistical Area Level 2 coloured by zones: inner suburbs are blue, middle suburbs are green, and outer suburbs, yellow

The width of each map is 100 km and all areas shown are within the GCCSA boundaries.

Zones within GCCSA are defined by straight-line distance between SA2 centroids and the centroid of the SA2 hosting the general post office within the central business district (CBD)[8] of the respective major city.

- inner suburbs are less than 7 km from the CBD
- middle suburbs are 7 to 20 km from the CBD
- outer suburbs are greater than 20 km from the CBD.

Outside of the GCCSA (rest-of-state areas) the zones are:

- regional cities: Significant Urban Areas (SUA)[9] with population greater than 50,000, which may include SUAs that are 'satellite' cities that are closer to the major cities.
- rural settlements: includes all other areas not defined in the zones above (including remote settlements, farmland, reserves and crown land among other land uses).

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[8] A similar definition was used in Deloitte Australia (2015).

[9] ABS (2016c)

5.3 How data and information are used

The topics mentioned in Section 5.2 are often interrelated in that parameters of the ANO 2019 scenarios (e.g. population distribution) may influence more than one topic (transport *and* productivity), and parameters relating to different topics (e.g. population distribution and land use) may combine to influence a third topic (transport).

To represent the topics within the scenarios quantitatively, key parameters or levers of change that affect outcomes directly, or through intermediate variables, were identified (refer to Figure 5.2). Future population and demography projections, congestion forecasts, fuel prices, and current or historical data on liveability and transport are exogenous inputs from outside the modelling suite. Future income and gross domestic product (GDP) are inputs to the Cities and Infrastructure domain settings from other models or analysis in other workstreams. Within the Cities and Infrastructure workstream, assumptions are made about future land available for new development, change in population density and distribution, housing diversity and land use mix. Through intermediate calculations combining these inputs, key outputs on productivity, transport demand and the level of investment in infrastructure construction and maintenance are estimated. A collation of contemporary socio-economic data about different areas of settlement (referred to as the Spatial Social Database) is paired with the future settings of population distribution to explore the gross numbers of future population living in circumstances of varying social inclusion.

The choice of these parameters and the expectation that they influence urban performance are based on empirical observations and established concepts of new urbanism and transit-orientated design regarding: density, diversity, distance to destinations and urban design (Newman and Kenworthy 1996; Cervero and Kockelman 1997; Lund 2003; Rickwood et al., 2008; Rickwood and Glazebrook 2009; Ewing and Cervero 2010; Filion 2010; Cervero and Guerra 2011; Seto et al., 2014; Coffee et al., 2016). Where there is precedence in the literature for functional relationships between drivers and outcomes, these are used. For example, there is prior peer-reviewed Australian research that finds good regression relationships for transport mode choice based on density, car ownership and distance from the CBD (Rickwood and Glazebrook 2009). Otherwise, relationships are constructed based on regression relations found in existing data for Australia or cities globally.

The influence diagram in Figure 5.2 shows the important parameters where the basic input data and assumptions first appear in the Cities and Infrastructure workstream analysis, and the subsequent flow of information through intermediate variables to outputs of concern to ANO 2019 and its participants. As mentioned previously, the different topics may make use of one or more of any these variables in combination (mapping of topics to the influence diagram is not shown).

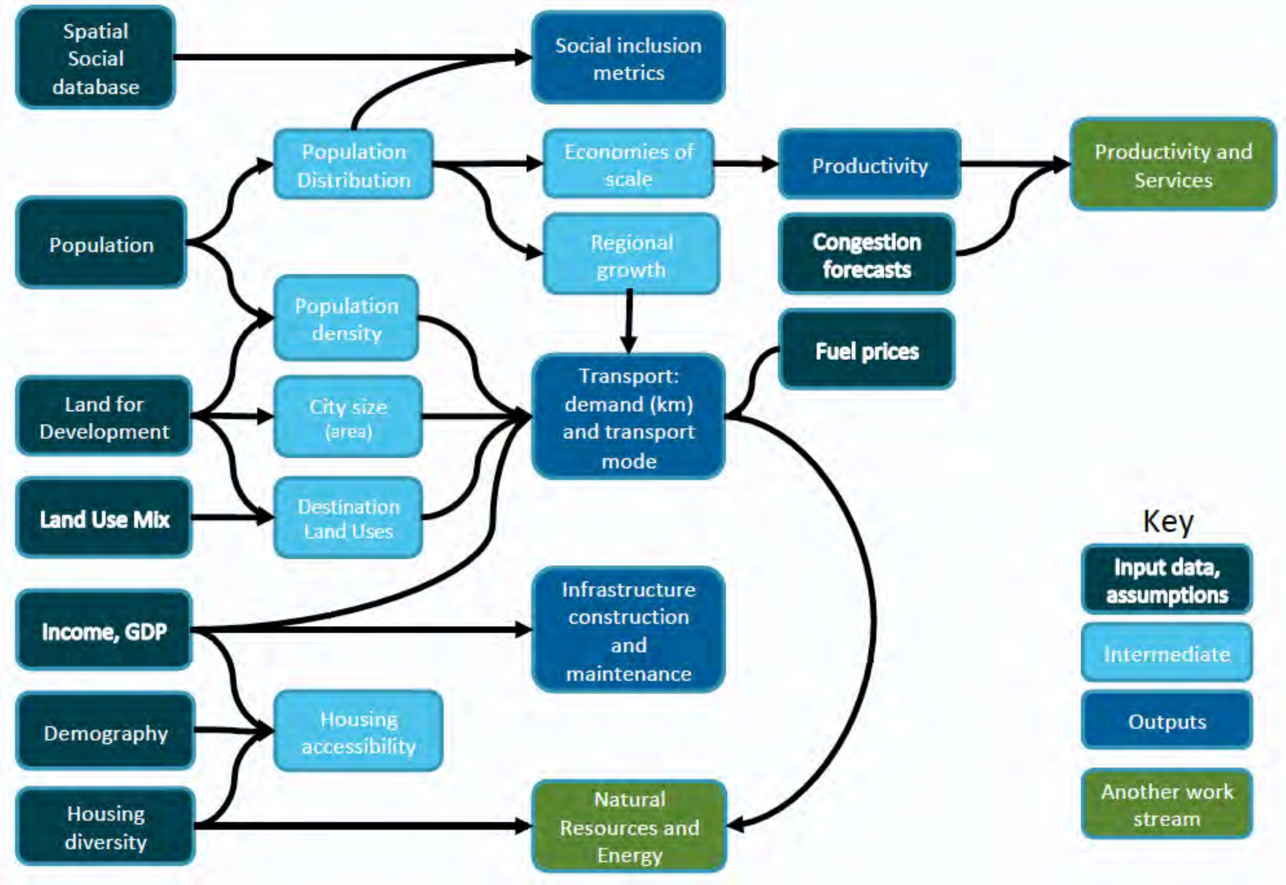

Figure 5.2 High-level representation of the modelling framework showing flows of data and information in the Cities and Infrastructure workstream

Note that Liveability is not a single measure for a metro area and is presented later as more multi-dimensional and spatially defined.

5.4 Population

Population is projected to grow mainly through international arrivals feeding into expanding urban populations. In all the ANO 2019 scenarios, Australia’s total population increases to 41 million at 2060, driven by a net inward migration of 240,000 people per year. The proportion of the population aged 65 and over rises from 15% to 25%. Within these national projections are three differing settings of population distribution:

- **Low road**: metropolitan areas and the rest-of-state regions grow as in ABS population projections (ABS 2013)[10], with particular increases in the urban core and periphery
- **Metro style**: metropolitan areas and the rest-of-state regions grow as in ABS population projections. However, current medium-density areas in major cities gain proportionally more population with less growth on the periphery
- **Stronger regions population**: the ABS projections are modified so that population in regions doubles to 16 million by 2060. Populations in the four major cities increase by 52% (but share of total population falls from 58% to 51%). Within major cities, the same population distribution by zone as in ‘metro style’ applies, although with lesser aggregate population

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[10] See also ABS (2018b).

5.4.1 Population projections

State, national and regional population projections were obtained from the ABS Population Projections Series B, Cat. 3222.0 (ABS 2013). This projection is derived from demographic and migration assumptions situated in the middle of the ABS range of population projections and it accurately anticipated the national population exceeding 25 million in 2018. Based on these projections, population distributions to GCCSA and rest-of-state regions for each state between 2016 and 2060 were used. The components (birth rates, death rates, migration, etc.) were also available at spatial resolution of GCCSAs and rest-of-state regions.

5.4.2 Migration

Flows of international migration were also obtained from ABS Population Projections Series B (ABS 2013) – the essential feature being net annual international migration to Australia of 240,000 people per year across all settings. With the national birth rate set to decrease below the death rate, international migration is essential for population growth.

Recent statistics[11] show strong internal migration flows to Melbourne's west, and regional centres around the Gold Coast, Sunshine Coast and Geelong. There has also been consistent positive net internal migration to the NSW Hunter region, the Barwon region of Victoria and south-western WA. By contrast, Sydney has the largest negative flows of net internal migration followed by Adelaide and Perth.

All settings conserve the ABS's Series B state-level migration projections. Neither 'low road' nor 'metro style' make any specific alteration to the destination of incoming international migrants but the 'stronger regions population' assumes that, over the long term, some internal and international migrants are destined to move to regional cities, supporting their growth within the constraints of the demographic distribution assumptions from the original ABS projections.

In the 'stronger regions population', approximately 5 million citizens who *would* be in major cities under the ABS's projections are distributed to rest-of-state regions around Australia, particularly for 15 significant urban areas. This cumulative figure may be thought of as an additional 110,000 migrants to regional areas per year to 2060. During 2016–17, more than 40,000 people left Sydney for regional NSW and *net* internal migration to regional NSW is approximately 20,000 per year (ABS 2017a). In the 'stronger regions population' setting, Sydney is taken as the model for the behavioural reaction to population pressure and/or densification as major city population approaches or exceeds 5 million.

5.4.3 Demography

International migration generally brings in working-age people and families to mix with the extant age distribution of Australia's population. Internal migration also sees a spatial re-distribution of age representation; for example, there is a persistent trend of 15 to 24 year olds migrating away from regional areas to major cities (McGuirk and Argent 2011). The ABS population projections provide demographic detail at the resolution of GCCSA and rest-of state regions. These data are

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[11] ABS (2017b)

applied across all settings and assume that all age groups participate proportionally in the internal migration required to realise the ‘stronger regions population’.

Qualitatively, the drivers of major city population pressure, regional opportunity and lifestyle preference, are assumed and collectively result in no demographic bias in the ANO 2019 scenarios. Thus, the age structure of the ABS Series B projections is undisturbed by regional population growth in ‘stronger regions population’. Again, using Sydney as a model in that setting, past net internal migration data for Sydney includes all age groups from 0 to 64 – see also observed age structure of net negative internal migration for Sydney since 2006 (Commonwealth Department of Infrastructure and Transport, 2013; ABS, 2017b). The spatial distribution of age groups at the small scale (SA2 boundaries) are not described as the calculation was based on a “non-component” model (see Section 5.4.4) that does not involve age cohorts.

5.4.4 Distribution

Under the ‘low road’ and ‘metro style’ population distributions, Australia’s four largest cities grow 95% to house 27 million people by 2060, lifting their share of total population from 58% to 66%. In 2060, Melbourne and Sydney are each home to over 8 million, while Perth and Brisbane have close to 5 million – similar to Sydney and Melbourne today.

More detailed distributions at the level of SA2 boundaries in major cities (1267 SA2 areas) were created to represent the effect of densification in the ‘metro style’ assumptions, and growth in the centre and urban perimeter in ‘low road’. This was done by applying a profile of multipliers to SA2 densities as at 2016, depending on the respective population density decile rank within all major city SA2s. This profile represents and controls the simulated relative change in population density for SA2 areas as currently ranked in deciles (Figure 5.3).

‘low road’ has an increased density in the already densest areas of the urban core and also a population increase in the outer, least dense areas. ‘metro style’ also has increased density in the urban core but much greater change in the mid-high ranked SA2 areas and no density change in the lowest density areas. Thus, although ‘low road’ and ‘metro style’ have the same total future population in major cities and rest-of-state regions, they have different within-boundary settings of change in density, and consequently population distribution.

Overriding the general calculation of change in density, any specific planned population growth and distribution expectations from the respective strategy documents for the four largest state capital cities were applied[12,13,14,15]. Finally, at each year of the setting, all results for SA2s (N= 2209) were adjusted in proportion to their population to force consistency with ABS population projections in their respective city and non-city regions.

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[12] Greater Sydney Commission (n.d.)

[13] State Government of Victoria (2016)

[14] Department of State Development, Manufacturing, Infrastructure and Planning (2018)

[15] Department of Planning, Lands and Heritage (n.d. b)

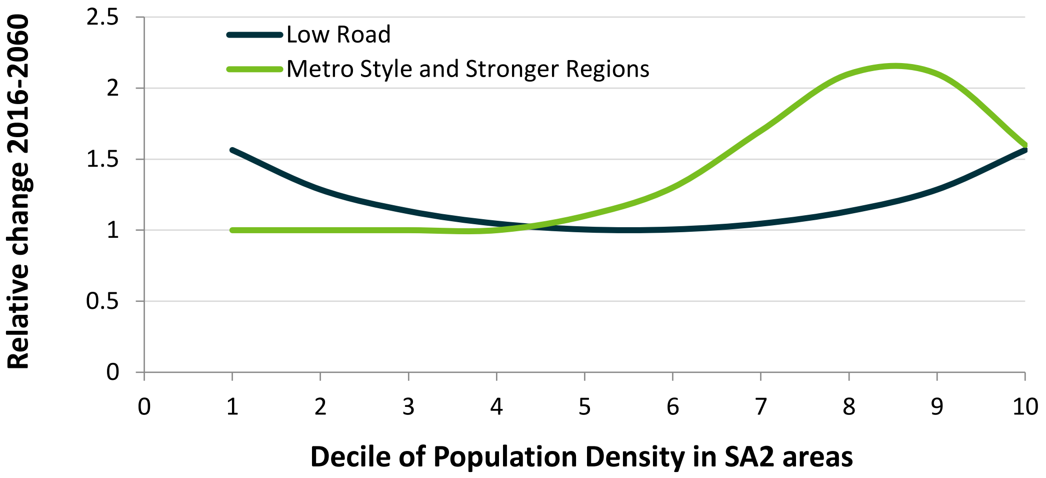

Figure 5.3 Relative change in urban population density for SA2 areas (N= 1267) as they occur in different density deciles specific to each state capital city as at 2016

'low road' sees increased density and consequently relatively more population growth in existing inner areas and the (currently) low-density periphery. Both 'metro style' and 'stronger regions population' assume inner city density growth but relatively more change in the medium-density areas and no or very little change for low-density urban areas.

Outside the major cities, population grows by 40% in 'low road' and 'metro style', with a distribution to SA2 areas in regional cities and rural areas *pro-rata* according to their 2016 proportion of rest-of-state regional population total.

With 'stronger Regions, the distribution of rest-of-state population projections to SA2 is fundamentally the same but over and above that population growth is assumed in regional SUAs[16] so that approximately 5 million of Australia's total population at 2060 live in these areas.

There are approximately 40 'major centres' outside the state capital cities that the ABS recognises in historical population statistics[17]. All of these are considered SUAs and in assessing the potential for growth in these areas these criteria were considered: population greater than 75,000; being within approximately 2 hours of a major capital city; having experienced recent rapid growth, economic diversification; known to be a planned growth area or; connected to planned national connectivity infrastructure. Candidates for population growth outside of major cities satisfy two or more of these criteria and

Table 5.2 expands on the detail of population growth in a selection of these SUA with some notes on justification. The assumed additional rest-of-state population at each year was distributed to SUAs in their respective host state *pro rata* according to that SUA's population.

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[16] 'Significant Urban Area' (SUA) has a specific definition in the Australian Statistical Geography Standard and is constituted from SA2 areas – see ABS (2016c).

[17] ABS (2014)

Regional Cities – growing opportunities

What are the criteria for the selection of identified regional growth centres? Why do we expect them to grow?

Many regional urban centres are diversifying their economies and growing in population at comparable rates to major cities[18]. Programs to accentuate the economic drivers of growth (e.g. Australian Government 'City Deals'[19]) may act as short-term catalysts but policy action cannot work alone. Longer term growth can be expected from at least four sources:

- Increasing productivity in the historical economy of the regional city: growth in agriculture, mining, tourism or logistics can boost regional urban growth.
- Connection to a major city: regional centres that are about 2 hours from a major city can offer lower housing costs without the complete loss of access to international airports, major hospitals, international events, etc. Their growth can feed off the population pressure experienced in the major cities.
- National connectivity projects: these can create new opportunities for newly connected cities or reduce the time to connect between existing centres. Outside the initial construction activity, these projects do not necessarily drive growth, but enable it.
- City size: as regional urban centres grow to a sufficient size [20] there will be a need for services that provide to those people. When more services are available or, in competition, are of a higher standard, this attracts more people and the feedback continues. Ultimately, regional urban centres may be expected to grow by the same dynamic that major cities grow but they are starting from a small base with generally lower wages and land/rent costs than major cities. Although the market size is smaller than in major cities, this presents growth opportunities to small- and medium-sized enterprises (SMEs).

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[18] Pearson et al. (2017)

[19] Department of Infrastructure, Regional Development and Cities (n.d.)

[20] There is no universal definition of what constitutes a 'city' though a comprehensive geographic survey of 4231 cities globally selected only urban areas with a population greater than 100,000 to be identified as cities (Lincoln Institute of Land Policy (n.d.)).

Table 5.2 Current and assumed future population in a sample of 15 Significant Urban Areas of regional Australia under the 'stronger regions population' setting

These SUAs were selected for having one or more of the following qualities: population greater than 75,000; being within 2 hours of a major capital city; having experienced recent rapid growth, economic diversification; known to be a planned growth area or; connected to planned national connectivity infrastructure.

SIGNIFICANT URBAN AREA	2016	2060	ANNUAL GROWTH RATE (%)	NOTES
Newcastle–Maitland (NSW)	436,171	890,628	1.6%	Population >75,000; within 2 hours of a major capital city; economic diversification; connected to planned national connectivity infrastructure
Wollongong (NSW)	295,669	604,499	1.6%	Population >75,000; within 2 hours of a major capital city; economic diversification
Wagga Wagga (NSW)	55,960	147,353	2.2%	Population >75,000; within 2 hours of a major capital city; connected to planned national connectivity infrastructure
Albury–Wodonga (NSW/VIC)	90,576	183,476	1.6%	Connected to planned national connectivity infrastructure (inland rail)
Sunshine Coast (QLD)	317,404	569,303	1.3%	Within 2 hours of a major capital city; having experienced recent rapid growth, economic diversification; known to be a planned growth area; connected to planned national connectivity infrastructure
Townsville (QLD)	178,864	329,606	1.4%	Population >75,000; economic diversification
Cairns (QLD)	150,041	273,015	1.3%	Population >75,000; economic diversification; known to be a planned growth area
Toowoomba (QLD)	114,024	209,230	1.4%	Population >75,000; within 2 hours of a major capital city; economic diversification; connected to planned national connectivity infrastructure
Gold Coast–Tweed Heads (QLD)	646,983	1,170,615	1.3%	Within 2 hours of a major capital city; having experienced recent rapid growth, economic diversification; known to be a planned growth area; connected to planned national connectivity infrastructure
Launceston (TAS)	86,335	295,055	2.8%	Population > 75,000; within 2 hours of a state capital city; economic diversification; known to be a planned growth area
Geelong (VIC)	192,393	972,245	3.7%	population >75,000; within 2 hours of a major capital city; having experienced recent rapid growth, economic diversification; known to be a planned growth area or; connected to planned national connectivity infrastructure
Ballarat (VIC)	101,588	516,193	3.7%	Population >75,000; within 2 hours of a major capital city; having experienced recent rapid growth, economic diversification; known to be a planned growth area or; connected to planned national connectivity infrastructure
Bendigo (VIC)	95,587	480,577	3.7%	Population > 75,000; within 2 hours of a major capital city; economic diversification
Bunbury (WA)	74,113	738,056	5.2%	recent rapid growth, economic diversification; known to be a planned growth area or; connected to planned national connectivity infrastructure
Busselton (WA)	37,596	348,819	5.1%	Recent rapid growth, economic diversification; known to be a planned growth area; connected to planned national connectivity infrastructure
Total	**2,875,320**	**7,522,010**	**2.2%**	

Source: ABS Census (2016), Pearson et al. (2017) AECOM (2011) Infrastructure Australia (2017a) and CSIRO Calculations

The calculation of population distribution is a ‘non-component model’ as migration, birth rates and death rates were not used *at the SA2 level*. The long-term population distribution at the fine scale of SA2 boundaries is based on downscaling regional population projections according to the factors and specifications previously mentioned.

5.5 Land use

In ANO 2019, simulations of agricultural land use are generally handled by the LUTO model (see Chapter 16). However, LUTO does not resolve land use within major urban areas and this is treated separately within the Cities and Infrastructure workstream where observations occur within the metropolitan boundaries, defined by the ABS’s GCCSA.

Two measures of land area are used for different purposes. The first is based on the gross total area of populated SA2 areas used to compute a version of population density, which is an intermediate variable used for distributing future population to SA2 locations (see Section 5.4.4).

A second measure is more precise and is the same as the contiguous developed, urbanised area used to define ‘urban centers and localities’[21] in the Australian Statistical Geography Standard (ASGS). This is referred to as ‘urbanized area’, which is consistent with historical data compiled for 1960 to 1990 (Kenworthy et al., 1999). Within the ‘urbanized area’, different types of land use are known. ‘Urbanized area’ and the associated density are used to calculate total urban land use (see Section 5.5.1).

Data supporting these measures come from historical data on urbanised area sourced from Kenworthy et al. (1999) and ABS censuses between 2001 to 2016, including the detailed data on land uses by Mesh Block boundaries[22]. In 2016 Australia had over 30,000 km^2 of land classified as within urban centres and localities and only 12,000 km^2 of this land was in major cities.

5.5.1 Total urban land use

The ‘low road’ setting for urban land use is coupled directly with expectations for modestly increasing the population density of metropolitan areas (defined by GCCSAs). This entails an incremental evolution of density that refers to the density of previous years. The marginal change for new urban area in future years is conditioned on the recent past of the metropolitan average density.

$$A_t = A_{t-1} + \frac{M_t - M_{t-1}}{\rho_{t-1}} \quad and\ \rho_t = \frac{M_t}{A_t} \tag{1}$$

M_t is the metropolitan population inhabiting a total urbanised area, A_t in the year *t* and ρ_{t-1} is the population density of the previous year. This is modified by the fraction of new development planned to be infill (brownfield development).

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[21] ABS (2016c)

[22] ABS (2016b)

The fraction of new development that a major city chooses to place on *existing* urban land is referred to here as the infill ratio, r_{infill}. Equation 2 calculates total urban land required with the expected population growth of future metropolitan population M_t:

$$A_t = A_{t-1} + (1 - r_{infill}) \times \left(\frac{M_t - M_{t-1}}{\rho_{t-1}}\right) \tag{2}$$

More infill raises the density of the entire metro area and the density of the subsequent year's additional development to accommodate the change in population. More development of greenfield sites (a lower infill ratio), produces a greater increase in total area, and a lesser change in population density. With a 100% greenfield development setting, population density would be maintained. Only if there was an active strategy to create lesser density on greenfield or brownfield development would density decrease. No major city has such a strategy or a 100% greenfield growth strategy. Hence, even under the 'low road' setting there is some increase in population density.

The 'low road' setting assumes a lower proportion of development is infill for major cities (see Table 5.3). Based on expressed aims in metro-strategy documents[23,24,25,26] for infill, land use requirements for new development are attenuated in the 'metro style' and 'stronger regions population' setting.

Table 5.3 Assumed infill ratios

SIGNIFICANT URBAN AREA	LOW ROAD	METRO STYLE AND STRONGER REGIONS POPULATION
Greater Sydney	0.35	0.90
Greater Melbourne	0.35	0.90
Greater Brisbane	0.35	0.80
Greater Adelaide	0.28	0.80
Greater Perth	0.20	0.70
Greater Hobart	0.50	0.70
Greater Darwin	0.50	0.70
ACT	0.70	0.70

Source: assumed values by setting – see also infill settings developed by Infrastructure Australia (2018) for comparison

There are no particular assumed changes to the density character of urban land use outside of the major cities and, with current densities, there is a possible need for approximately an additional 15,000 km^2 under either 'low road' or 'metro style' and over 25,000 km^2 for *Stronger Regions*.

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[23] State Government of Victoria (2016)

[24] Greater Sydney Commission (n.d.)

[25] Department of Planning, Lands and Heritage (n.d. a)

[26] Department of State Development, Manufacturing, Infrastructure and Planning (2018)

5.5.2 Density

ANO 2019 defines ‘urban area’ in common with the urbanised area of ABS‘s urban centres and localities (UCL), which is the ‘second measure’ mentioned earlier in Section 5.5. This is used with the numerator of metropolitan population to calculate average metro density. Long-term trends in population density based on this measure have actually been downwards between 1981 to 2011. An extrapolation of that trend, however, would be misleading. Between 2011 and 2016 there has been a conspicuous upward trend in density connected to apartment building, re-zoning and code-based development approval. The outlook of ‘low road’ is that although this provides Australians with a new ‘normal’ for urban development densities, the availability of land to re-zone and the political tolerance for densification is limited and consequently the recent increase in density is transient.

Peripheral expansion in ‘low road’ results in a modest increase in overall density to accommodate increased population. Density increase is concentrated in the city centres. ‘metro style’ assumes a robust program of infill concurrent with land zoning changes, that sees average density of major cities increase by 80% to 90% and assumes a greater *proportion* of urban populations lives at higher density (not just in the city centres). *Stronger Regions* has the same assumptions about density as ‘metro style’ but assumes relatively smaller populations in the major cities (refer to Figure 5.4).

The profile of population density is as important as the overall average figure. Figure 5.4 shows that ‘low road’ is an accentuation of today’s density profile while ‘metro style’ shifts much more toward the higher end and *Stronger Regions* is in between (see also Section 5.4.4).

Recent research (Coffee et al., 2016) has shown how, historically, density has a reasonably predictable declining relationship with distance from the CBD of Australia’s major cities. With a continuation of that historical trend, it is possible to expect that higher density occurs closer in and lower density areas are further out.

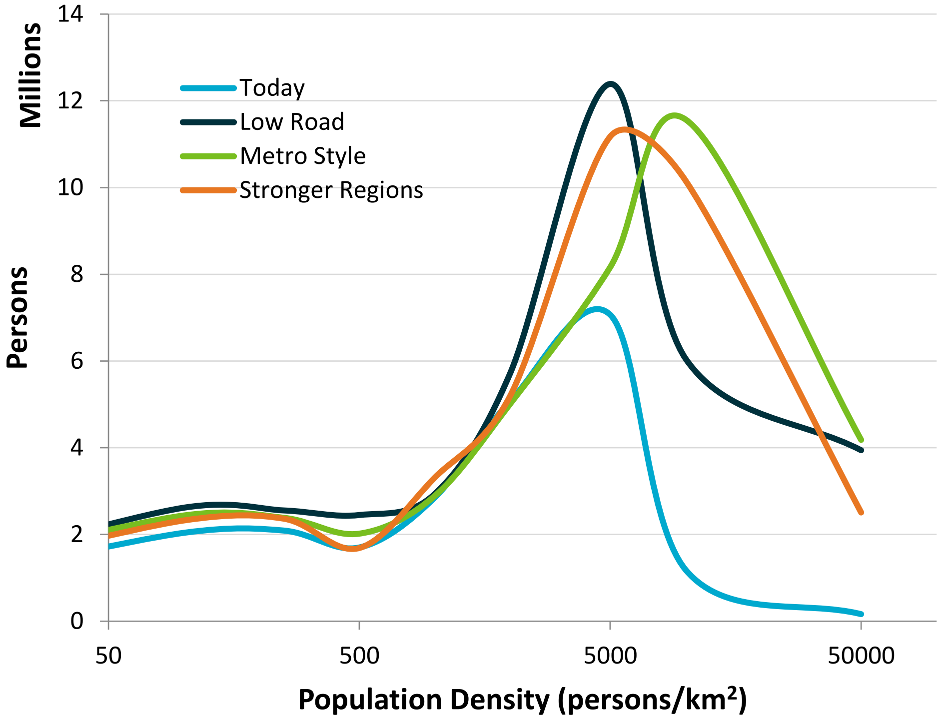

Figure 5.4 Distribution of population over density for all SA2 areas (N = 2209) today and at 2060 under the different setting assumptions

Note the logarithmic scale on the horizontal axis.

In 2016, 16 million Australians lived in developments with low densities of greater than 2000 persons/km^2. By 2060, under both 'metro style' and *Stronger Regions*, this number only increases to 1 million more citizens while 24 million Australians will live in developments of density *greater* than 2000 persons/km^2. Figure 5.5 shows how this distribution compares with international cities.

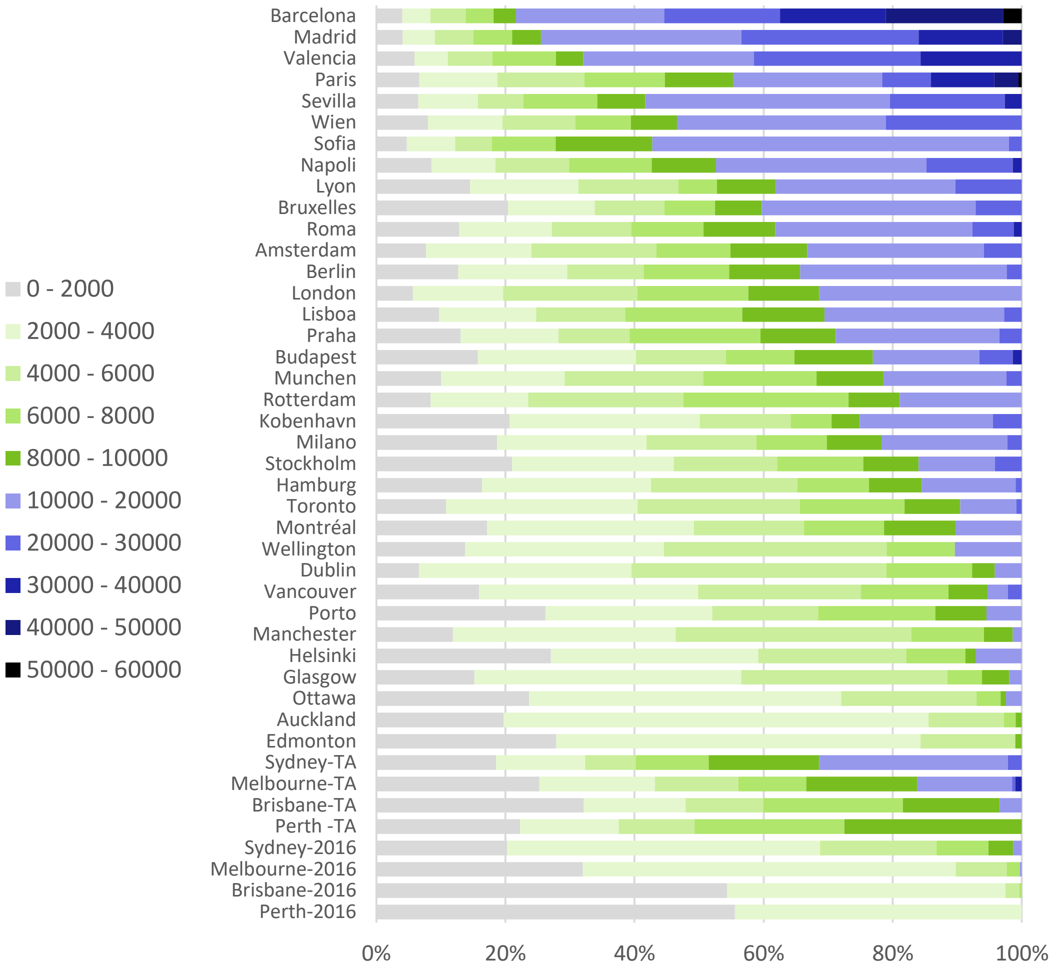

Figure 5.5 Proportion of populations living at different densities in international cities from 2010–2013 compared with major Australian cities at 2016 and at 2060 under the 'metro style'/*Thriving Australia* scenario (TA)

Source: CSIRO calculations, Eurostat, the Australian Bureau of Statistics, Stats NZ, and Statistics Canada and processed by Chris Loader[27] (www.chartingtransport.com)

5.5.3 Destinations and diversity

Creating destinations and places of diverse land use can short circuit several accessibility issues by having places where people need to go, close to where they live. Creating more diverse uses of space, and more employment space, has been found to decrease the need for travel around cities in the USA. (Cervero and Kockelman 1997; Ewing and Cervero 2010).

For each SA2 area seven of the ten types[28] of land uses recorded in the ABS 2016 Mesh Block files[29] were mapped to five categories of land use that summarise qualitatively different purposes for human use:

- Destinations: Commercial, Hospital/Medical and Education land. These represent the end point of many trips for jobs, retail, health and education activities.

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[27] Publicly available at Charting Transport (2015)

[28] Water, transport and agriculture were ignored as land uses because they are sometimes large areas that are not linked to urban destinations and confound the diversity index.

[29] ABS (2008)

- Industrial: although this represents land of important economic value, it is not a strong destination for people.
- Residential: places of habitation and the origin of many of the trips to destinations.
- Parkland: places of environmental capital that are infrequent destinations but important components of liveable communities
- Other: the residual of land not classified above including areas for infrastructure and service lines.

To quantitatively represent the aspect of 'destination' and the lever of creating new hubs of activity, we use the fraction of land for Destinations as defined above. This Destination fraction, f_D is based on the gross measure of total land area within a given SA2 boundary, L_T mentioned in Section 5.5.

$$f_D = \frac{\sum L_j}{L_T} \tag{3}$$

Here L_j is the land area within a SA2 boundary that has uses: j = Commercial, Hospital/Medical, and Education. Using the proportion of land for Destinations as a fraction of total area in each SA2 within Australia's GCCSAs, we found that there were statistical relationships with distance to work data and the uptake of active transport modes reported in the ABS Census data[30] - refer also to Section 5.6. Notably, the Inner, Middle and Outer urban zones have different average f_D values (averaged over respective SA2 areas).

Additionally, fractions of land uses in a given SA2 were used to calculate a Shannon-Weaver diversity index, *H* (Shannon and Weaver 1963). This has been applied broadly in ecology, industrial networks and elsewhere (Pielou 1966; Templet 2004; Lou 2006) and in an analysis of land use diversity of Singapore (Zhong et al., 2013). Its construction is described below:

$$H = -\sum(L_j . ln(L_j)) \tag{4}$$

where *H* is the measure of diversity within a particular SA2, *ln()* is the natural logarithm function and L_j is the fraction of total land area for an SA2 boundary that has uses: j = Commercial, Hospital/Medical and Education, Residential or Parkland. This is used later in characterising 'zones' of settlement that combines with social data – see Section 5.10.

In the 'low road' setting we assume no change to the characteristic mix of land use and prevalence of destinations in urban areas but in 'metro style' and *Stronger Regions* we assume that there is a planned variety of land uses within SA2 areas and those uses are heterogeneously mixed. This concurs with the concept and extent of 'mixed land use' zoning in the existing denser areas of major cities.

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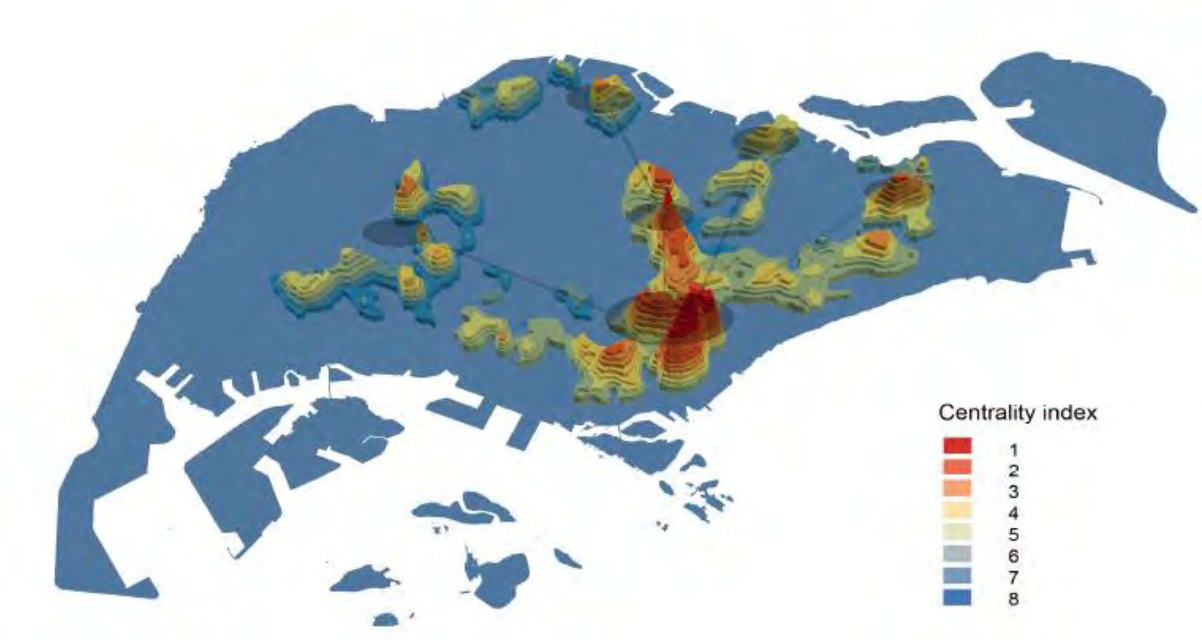
[30] ABS (n.d.)

Creating new destinations – Singapore case study

Part of Singapore's planning strategy for the last few decades has been to create and develop multiple centres for industry, commerce and other activities in addition to the CBD. Importantly, Singapore has created specialised districts: Western (Jurong) that has manufacturing at its heart; Eastern (Changi et al), which has Logistics at its core; and Central (Orchard, Marina) that has Tourism and Retail as its main drivers. These zones are developing as new centres that add to the number of destinations on the island without competing with the activity of the CBD



Polycentricity of Singapore: centrality index of different zones based on a combination of density and land use diversity data (Zhong et al., 2013)

This is guided for example by principles for achieving liveability with higher density (Centre for Liveable Cities and Urban Land Institute 2013) but It is also important to note that a concurrent integrated transport policy is required to connect these centres, otherwise there are risks of isolating potential labour markets from employment centres (Cho-yam Lau 2011).

5.6 Transport

Continuing the same urban design and structure and placement we see in the current built environment, we anticipate a spatial expansion of the major cities. With that expansion we may also expect longer travel distances and most likely congestion ('low road'). Increasing the density and bringing a more transit-orientated style of settlement[31], we can also expect denser cities and as we shall see, a reduced transport task ('metro style' and *Stronger Regions*).

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[31] Cervero (1998)

5.6.1 Total transport task for road

For each state, and for major city and 'rest-of-state' regions, we used historical data on vehicle kilometres travelled (VKT) by road vehicles (BITRE 2015) with concurrent data on population numbers and distribution, urbanised area, income per capita and petrol prices.

In each of the major cities we estimated future VKT based on a production function approach using the historical data to establish exponents from a multi-linear regression analysis:

$$ln(VKT) \approx \alpha.\ln(pop) + \beta.\ln(income) + \gamma.\ln(fuel\,price) + \delta.\ln(area) \leftrightarrow$$

$$VKT \;\approx\; pop^{\alpha}.income^{\beta}.fuel\,price^{\,\gamma}.area^{\delta}$$

(5)

This formulation also connects with the scenario outputs of future income per capita and fuel price from the economic model (VURM), and input assumptions for the transport model (AUS_TIMES).

Outside of major cities, we estimated future VKT based on a similar production function, though we found developed area was not a useful explanatory variable. We suggest that the developed area variable in major cities acts as a reasonable proxy for the span of the city that a citizen may have to traverse (especially new citizens housed at the periphery). However, developed area in regional Australia is less contiguous and more dispersed, and we found it to have poor correlation with VKT.

While retaining the variables (and data sources) of total population, income and fuel prices, we found that the fraction of regional population in Regional Cities, *UR,* is a useful explanatory variable for transport demand in areas outside the major cities.

$$UR = \frac{Population_{Regional\ Cities}}{Population_{Regional\ Cities} + Population_{Rural\ Settlements}}$$

$$ln(VKT) \approx \alpha.\ln(pop) + \beta.\ln(income) + \gamma.\ln(fuel\,price) + \delta.\ln(UR) \;\leftrightarrow$$

$$VKT \;\approx\; pop^{\alpha}.income^{\beta}.fuel\,price^{\,\gamma}.UR^{\delta}$$

(6)

This was the general approach for all vehicle types: car, bus, motorcycles, light commercial vehicles (LCV), rigid trucks and articulated trucks. Previous Australian research has used similar regression analysis for major cities (Rickwood and Glazebrook 2009). The general formulation produces good correlations with VKT ($R^2 > 0.9$) in most cases with the following exceptions ($R^2 < 0.5$): some results for LCV, Motor cycles in regional areas, and articulated trucks in regional Western Australia.

Light Commercial Vehicles: although the regression fit over historical time is reasonable, the derived exponents of the regression produced exponential growth in response to the future parameter changes in the scenarios settings.

Motorbikes: there has been a recent rapid uptake in motorbikes (starting from a low base) that distorts the model and produces extremely high and unlikely estimations for future VKT.

For all exceptions, a simple linear regression over time results in correlations with VKT ($R^2 > 0.7$) without future simulations diverging dramatically from historical values – although there is still an apparent increase in the uptake of motorcycles generally, which is consistent with recent trends – see box below.

Motorbikes – a growing private vehicle alternative

- Overall national motorbike use (VKT) doubled between 2005 and 2015 and in all scenarios we expect further growth.
- Nationally the number of motorbikes has tripled between 1995 and 2015 to nearly 1 million vehicles and the number motorbikes per capita has increased by almost 2.5 times over the same period.
- Particular growth is in NSW, Victoria and Queensland
- Kilometres travelled by motorbike has risen 7% per year for each of the last 10 years in NSW – more growth than any other road vehicle class. This correlates with increases in ownership and registration.

For more information, see BITRE (2015) and ABS (2018a).

5.6.2 Transport mode choice in cities

Transport mode choice is a characteristic of passenger transport and our calculations are more aggregated (and separate) from the calculations of road-based VKT. We may expect that rising urban densities and different urban design can reduce *distances* travelled by car, but it may still be possible that many or most *trips* are taken by car. There is also the likely future expansion of autonomous shared road vehicle modes as an intermediate between cars and mass transit[32].

We categorise all urban passenger transport into three modes: car, mass transit and active. 'Car' may also conceptually include light commercial vehicles, 'mass transit' includes buses, light rail, trams and rail, and 'active' modes include walking and cycling. Data on the number of journey to work trips taken by different modes are available from the ABS Census for 2016 (ABS 2016a)[33]. Our analysis looked at statistical regression relationships based on the basic formulation that the fraction of trips by a given mode, f_{mode} is a function of population density and destination accessibility:

$$f_{mode}[car, mass\ transit, active] = g(density, destination) \tag{7}$$

Both density and destination accessibility have been found to correlate to overall VKT and the uptake of mass transit and active mode choices in US cities (Ewing and Cervero 2010).

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[32] The Economist (2018)

[33] Data extracted from the table available at ABS (n.d.).

Over all the SA2 areas of Australia's major cities, we can see a reasonably predictable response of mode share to increasing density – refer to Figure 5.6.

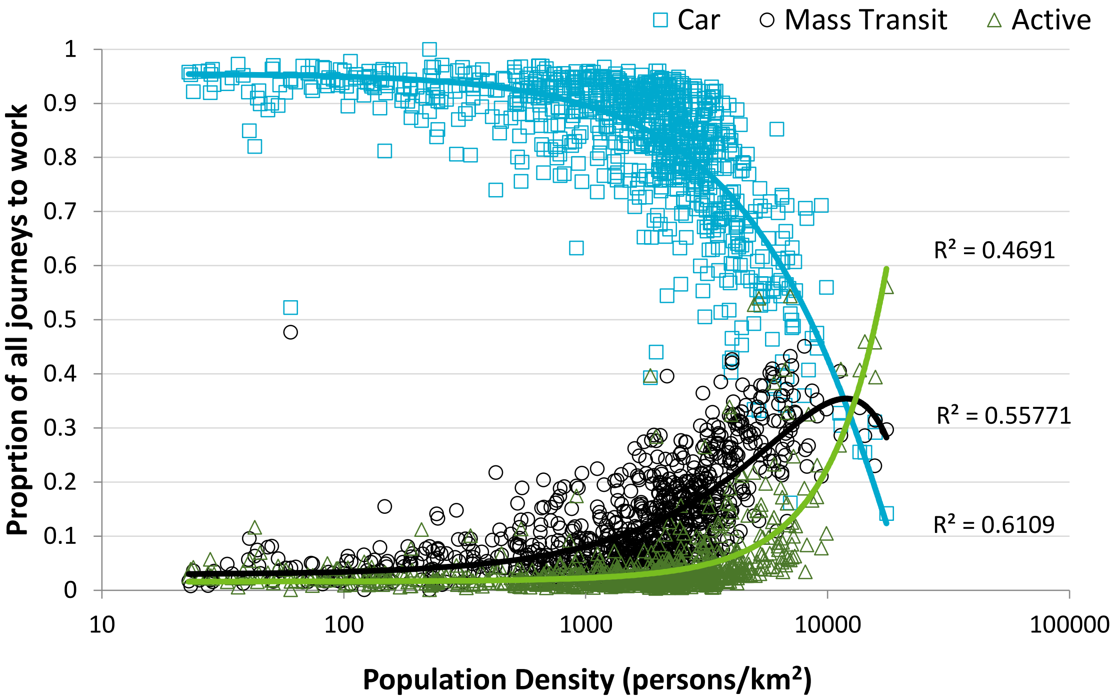

Figure 5.6 transport mode share in the journey to work data for SA2 areas (N=1078) of Australia's major cities plotted against their population density. Fitted curves for all data are second order polynomials

Note the logarithmic scale on the horizontal axis.

Some prior research on transport in Australian cities found density to be one of several key explanatory variables in statistical regressions on mode choice (Rickwood and Glazebrook 2009). The analysis shown in Figure 5.6 uses the population density in the SA2 area of major cities as an explanatory variable for the mode share among three types: car, mass transit (buses, trains, trams etc.) and active (walking, cycling). We attempted regressions with a number of empirical formulations[34] and find the following statistical relations that enable us to anticipate the potential fraction of the passenger transport task undertaken by a mode, f_{mode}, of urban populations, living in a SA2 area, at different densities: $\rho_{SA2}(t)$, at some future date, t.

$$f_{car} = 7 \times 10^{-10} \rho_{SA2}(t)^2 - 6 \times 10^{-5} \rho_{SA2}(t) + 0.9557 \tag{8}$$

$$f_{mass\ transit} = -2 \times 10^{-9} \rho_{SA2}(t)^2 + 5 \times 10^{-5} \rho_{SA2}(t) + 0.0285 \tag{9}$$

$$f_{active} = -2 \times 10^{-9} \rho_{SA2}(t)^2 + 5 \times 10^{-6} \rho_{SA2}(t) + 0.0158 \tag{10}$$

These fractions of mode share in the passenger transport task are referred to as 'potential' because we cannot say for sure how people will behave and how the staging of development will occur. For example, it is entirely possible that new suburbs could be built with density and transit-

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[34] We do not attempt to relate density to mode choice through a theory, only searching for the functional relations with the best correlation coefficient. Functional forms tested include: linear, power law, exponential and logarithmic.

orientated design principles some years or even decades ahead of the construction of mass-transit infrastructure. Naturally, this leaves new residents with little option but to travel by private vehicles despite the potential of the suburb for mass-transit. Such factors are highly contingent on state or federal government strategy and budgets, timing of the approval process and other political priorities, which we cannot anticipate. We can, however, refer to the potential for areas to be amenable to different mode share settings. Similarly there is a relation between the choice of active transport modes and the proportion of land use in an urban SA2 are for 'Destinations' - see Figure 5.7. As the fraction of land use in Inner SA2 areas associated with 'destinations' (f_D, see definition in Section 5.5.3) increases, there is a greater likelihood of the uptake of active transport (see f_{active} in equation (11)). However, the relationship is less pronounced or missing altogether in the Middle and Outer urban areas – refer to Figure 5.8.

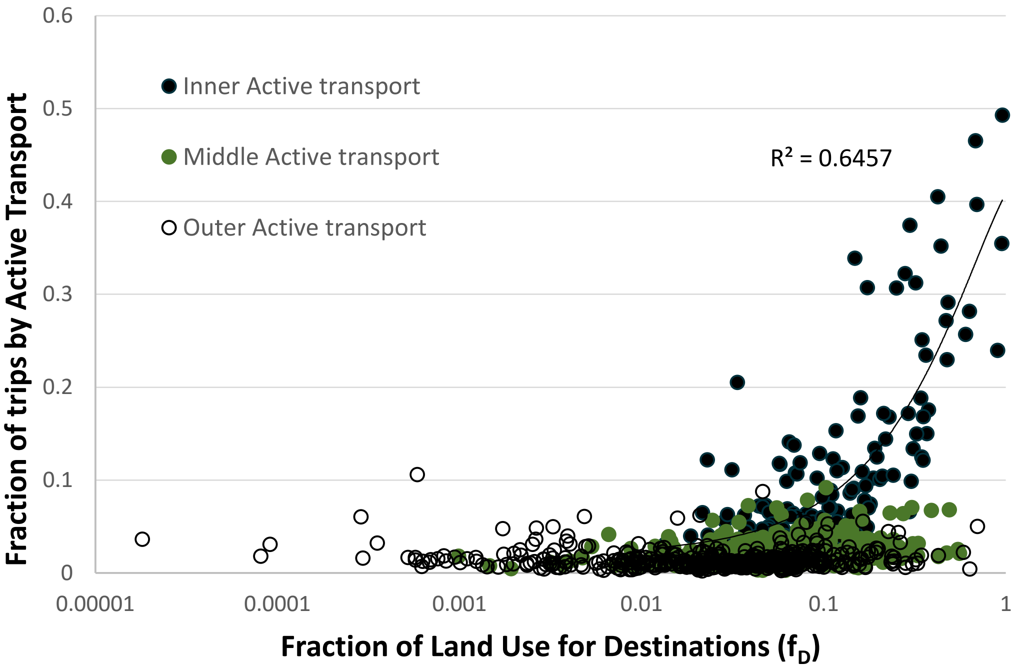


Figure 5.7 Proportion of journey to work trips from the 2016 Australian Census that involved active transport plotted against the proportion of an SA2 area that had 'Destination' land use classes

Note the data is split into zones (see Section 5.10) for inner (N=165), middle (N=428) and outer suburbs (N=485), for all major cities. Note also logarithmic scale on the horizontal axis.

$$f_{active} = -0.2264 {f_D}^2 + 0.615 f_D + 0.0198 \qquad (11)$$

5.7 Housing

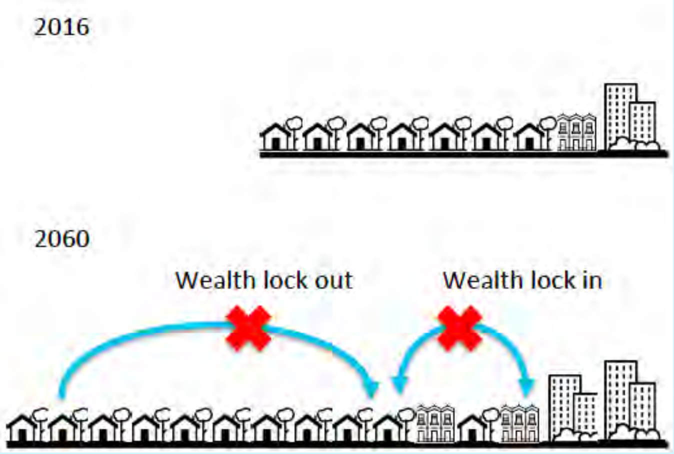
One of the central socio-economic issues of the last two decades and one that is likely to continue for at least another two decades, is the access to quality residential housing(Dodson 2012; Daley et al., 2018). Sufficient access to 'quality residential housing' means (at least) three things: 1) sufficient overall supply of housing to meet population growth; 2) appropriate mix of housing *types* to meet changing requirements for variety in dwellings; and 3) the creation of housing in well-located areas near, or connected by infrastructure, to opportunities (jobs, retail, entertainment, education).

Well-observed problems of housing affordability[35,36] are connected to the supply of quality housing compared to recent and persisting increases in urban populations and the spatial concentration of opportunities in the centre of our major cities. It is also undeniable that housing affordability is intimately related to State and Federal tax regimes, private investment behaviour, perceptions and risk appetite, and the institutional arrangements around rented accommodation (Daley et al., 2018)[37]. This project does not consider changes to all these drivers, and we explicitly do not simulate changes to tax regimes, but we can look at access to housing, how appropriate that is for the current and future demographic structure of society, and the quality of areas in which new development will occur.

Wealth lock out and wealth lock in

- People who aspire to live in higher quality areas cannot afford to because of their income/wealth combination and price of housing closer to opportunities – wealth lock out

People who want to downsize in their area can't because there aren't many options in the current dwelling stock – wealth lock in.



Attitudes of residents, and the local government they elect, also conserve urban form – more wealth lock in[38].

- The path of least resistance is to expand on the periphery, which only exacerbates the wealth lock out effect without providing any more options for the wealth lock-in
- Not everyone can live in well-connected areas because transport infrastructure needs to span a larger city[39].

See – *Future Cities*, Infrastructure Australia (2018), *City Limits*, JF Kelly and P Donegan (2015) and *Housing affordability,* Daley et al. (2018)

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[35] The Guardian (2017)

[36] Anglicare Australia (2018)

[37] Daley et al. (2018)

[38] Infrastructure Australia (2018)

[39] Clark and Moonen (2016)

Responding to the spatial separation of high-accessibility, low affordability areas from affordable locations of lesser accessibility, we consider a conscious change to the housing system that promotes higher densities while also providing heterogeneity in the mix of housing types[40,41] - refer to Figure 5.8.

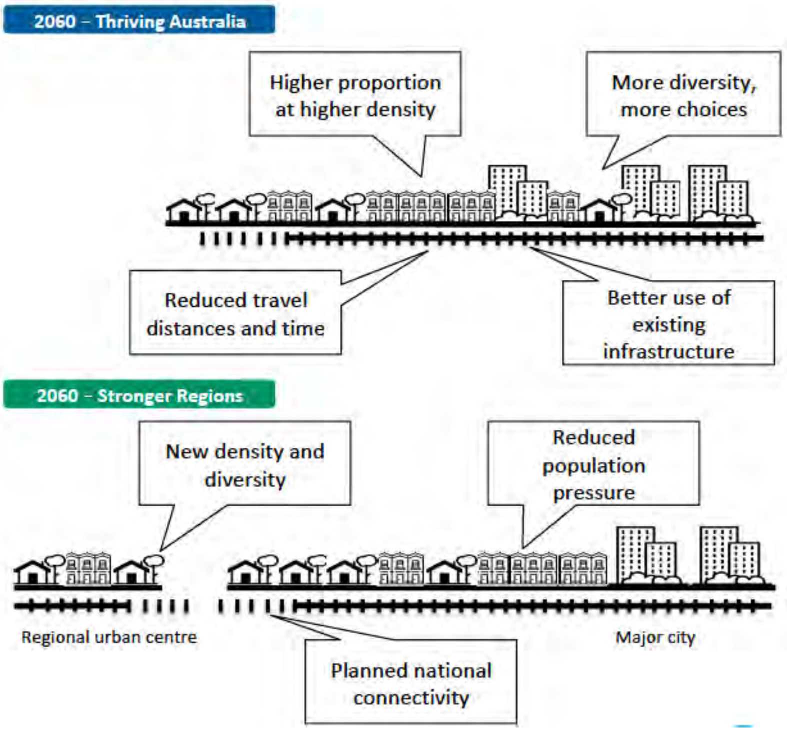

Figure 5.8 Ways that *Thriving Australia* and *Stronger Regions* compare with the 'low road'/*Slow Decline* scenario: more diverse housing options, creating new destinations, connected by infrastructure

Such a planned change to urban form and the ratio of separate dwellings to terraces and apartments occurred between 2001 and 2016 in Vancouver[42]. Importantly, a concurrent 'density bonus' scheme[43] captured value in the development process to provide the funds to restore or expand social infrastructure. This type of process: 1) requires some negotiation with industry[44]; 2) is not a guaranteed way to achieve housing affordability[45] and; 3) needs to be implemented with an infrastructure plan. An example of a formal version of this in Australia is the 'growth infrastructure compact' of the *Greater Sydney Regional Plan*[46].

The key assumptions to the 'low road' setting are that the current short-term trend away from separate dwellings in cities is transient: old industrial land is recycled for medium-high density residential but ultimately this source of easily re-developable land dries up. The institutional difficulties and price of existing residential land reduce the ease and availability of infill development, leading to a return to more greenfield development and the sort of dwelling type

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[40] see Kelly and Donegan (2015)and also Urban Taskforce Australia (2018)

[41] Reserve Bank of Australia (2014a)

[42] Metro Vancouver (2018)

[43] City of Vancouver (2018)

[44] The Australian Financial Review (2018)

[45] Vancouver Sun (2017)

[46] Greater Sydney Commission (n.d.)

mix seen before 2006. This retains the suburban character of cities but also the same density, and growth has to be accommodated mostly on the periphery.

‘metro style’ and *Stronger Regions* share the same assumptions regarding housing in the major cities. Institutional difficulties and planning restrictions are revised to allow for more mixed development and varied housing types with good connectivity, mostly within the current urban areas. The recent short-term trend in apartment construction continues, strongly favouring medium to high-density dwellings to the point where they become the dominant form of habitation in Australia. Melbourne and Sydney experience the transition toward the dwelling mix seen in metro Vancouver[47]. Other Australian cities change more slowly with less population pressure. Rural areas retain their historical dwelling mix.

The quantity of dwellings required, by different types, responds to both the demand for housing through the population projections, state-level average occupancy trends and the settings of change in housing mix, which are approximately a linear function of time.

5.7.1 Assumed housing mix

In the following tables show the assumed housing mixes in different locations in 2016 and the assumed housing mixes in 2060 under the different settings.

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[47] See p2.1 Metro Vancouver (2018).

Table 5.4 Assumed housing mix in different locations at 2016. Note totals may not sum to 100% because of other housing types not represented here

LOCATION	SEPARATE HOUSES	SEMI-DETACHED, ROWHOUSES	APARTMENTS
Greater Sydney	56.9%	14.0%	28.1%
Greater Melbourne	67.8%	16.8%	14.7%
Greater Brisbane	76.4%	10.0%	12.6%
Greater Adelaide	74.8%	16.9%	7.8%
Greater Perth	76.9%	16.0%	6.6%
Greater Hobart	84.8%	6.0%	8.6%
Greater Darwin	63.3%	10.8%	23.4%
ACT	68.4%	14.8%	16.4%
Rest of NSW	84.0%	9.4%	6.6%
Rest of Vic.	90.3%	6.9%	2.8%
Rest of Qld.	78.5%	11.3%	10.3%
Rest of SA	89.4%	8.0%	2.6%
Rest of WA	90.6%	7.3%	2.1%
Rest of Tas.	90.8%	5.7%	3.6%
Rest of NT	77.8%	15.7%	6.5%
Rest of ACT	100%	0%	0%

ABS Census[48]

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[48] Data for 2016 obtained from the ABS Census Table Builder (ABS, n.d.)

Table 5.5 Assumed housing mix in different locations at 2060 for 'low road'. Note totals may not sum to 100% because of other housing types not represented here

LOCATION	SEPARATE HOUSES	SEMI-DETACHED, ROWHOUSES	APARTMENTS
Greater Sydney	60.90%	25.80%	12.80%
Greater Melbourne	72.60%	15.30%	11.60%
Greater Brisbane	79.00%	11.70%	8.50%
Greater Adelaide	77.20%	10.40%	12.10%
Greater Perth	78.60%	9.10%	11.90%
Greater Hobart	82.50%	10.50%	6.40%
Greater Darwin	64.20%	19.80%	12.90%
ACT	72.10%	12.90%	14.70%
Rest of NSW	84.01%	6.59%	9.41%
Rest of Vic.	90.34%	2.78%	6.88%
Rest of Qld.	78.48%	10.25%	11.27%
Rest of SA	89.42%	2.57%	8.01%
Rest of WA	90.60%	2.14%	7.25%
Rest of Tas.	90.76%	3.56%	5.68%
Rest of NT	77.85%	6.45%	15.70%
Rest of ACT	100%	0%	0%

Table 5.6 Assumed housing mix in different locations at 2060 for 'metro style' settings (*Stronger Regions* has the same housing mix assumptions as 'metro style'). Note totals may not sum to 100% because of other housing types not represented here

LOCATION	SEPARATE HOUSES	SEMI-DETACHED, ROWHOUSES	APARTMENTS
Greater Sydney	30.90%	23.30%	45.80%
Greater Melbourne	42.60%	22.10%	35.30%
Greater Brisbane	59.00%	9.30%	31.70%
Greater Adelaide	57.20%	12.40%	30.40%
Greater Perth	58.60%	12.30%	29.10%
Greater Hobart	62.50%	7.00%	30.50%
Greater Darwin	44.20%	16.00%	39.80%
ACT	52.10%	15.00%	32.90%
Rest of NSW	84.0%	8.15%	7.8%
Rest of Vic.	90.3%	3.49%	6.2%
Rest of Qld.	78.5%	9.52%	12.0%
Rest of SA	89.4%	6.66%	3.9%
Rest of WA	90.6%	5.55%	3.9%
Rest of Tas.	90.8%	3.91%	5.3%
Rest of NT	77.8%	10.36%	11.8%
Rest of ACT	100%	0%	0%

5.8 Infrastructure

Analysis of future infrastructure investment and construction activity is highly uncertain. We have proceeded with a best-efforts approach guided by relationships we have identified in historical data on engineering construction (BITRE 2017) and visible major projects reported by Infrastructure Australia[49]. Engineering construction is defined to be non–building construction, classified by major forms of infrastructure: transport (roads, rail, ports, etc.), energy (electricity and gas transmission networks, etc.), telecommunications networks, and water supply and distribution networks. As such, we refer to 'engineering construction' as synonymous with non-building infrastructure.

The general level of construction activity for infrastructure (engineering construction) and building construction relates strongly to GDP (see Figure 5.9). What we have seen in the recent past is a great deal of engineering construction activity especially in the Mining sector[50]. Separately, there has also been a recent rise in residential building construction in the major cities.

Looking over the 45-year future, there are more than 30 priority or high priority infrastructure projects nominally budgeted at $220 billion (in real 2016 Australian dollars)[49]. The list of projects, their budget, priority and subsequent sequencing may change but the magnitude of the

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[49] Infrastructure Australia (2017)

[50] Reserve Bank of Australia (2018)

investment in these major projects should be put in perspective next to the substantive background of infrastructure maintenance, and smaller projects at the local level. In most future years of our scenario analysis this is approximately 10 times the annualised cost of the priority projects – see Figure 5.10.

5.8.1 Baseline total infrastructure investment

We found that the data on construction activity for buildings and engineering (infrastructure) work correlates well with overall economic activity – measured as real GDP ($AUD 2016). This may be interpreted as including development of major new infrastructure and urban areas and the ongoing activity of maintaining extant infrastructure and smaller projects at the local level – see Figure 5.9. We do not have an explicit model of the investment in buildings or infrastructure linked to detailed demand vectors. We use the statistical historical correlation with GDP to anticipate future building and engineering construction activity measured in 2016 Australian dollars.

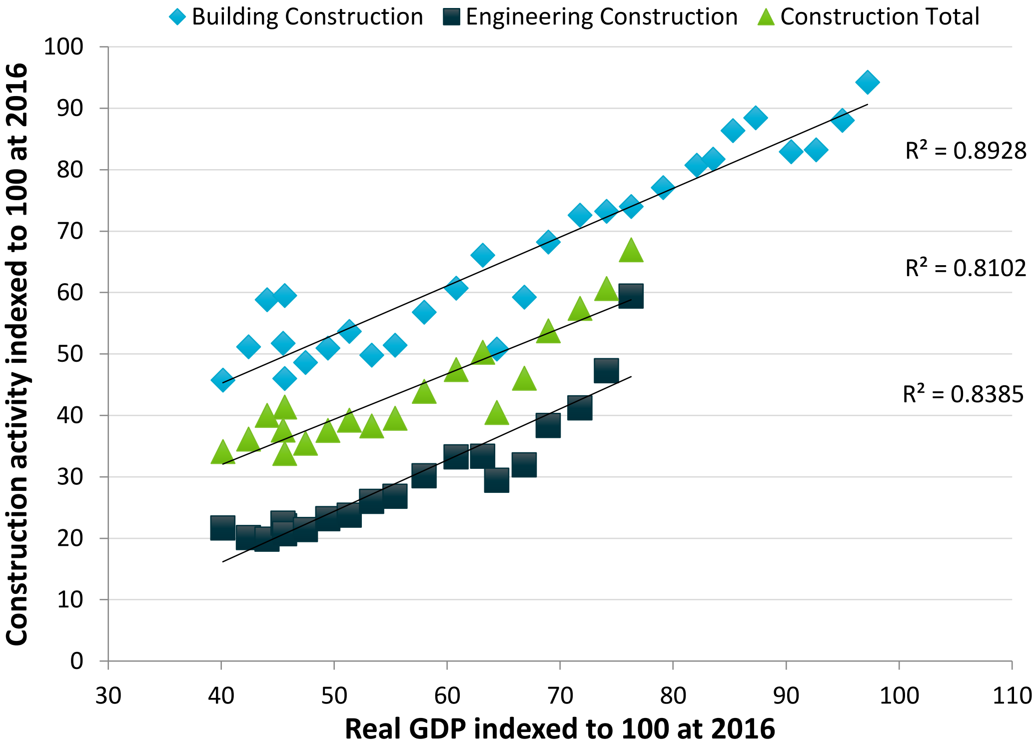

Figure 5.9 Linear regression best fit of historical data (1987 – 2015) on construction activity (monetary value) to national GDP – both measures based on real Australian dollar values (2016) indexed to 100 at the year 2016

Note that for Engineering Construction and Construction Total, we have chosen to exclude the years 2007–2015 to remove the transient effect of the mining boom

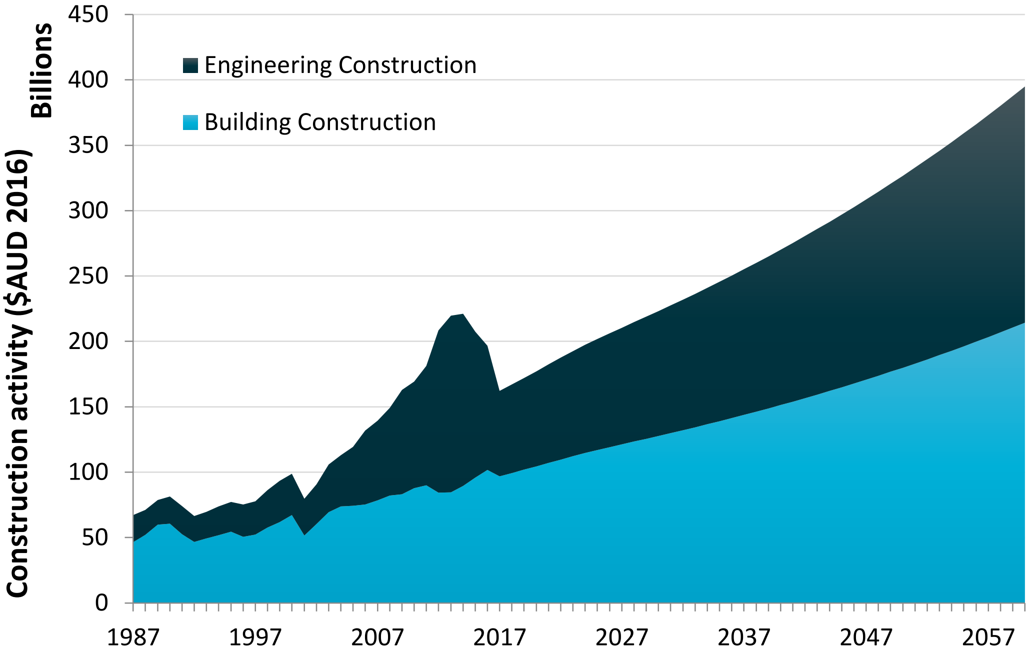

Figure 5.10 Building construction and engineering construction activity in Australia ($AUD 2016) for historical data to 2016 and future expected activity based on national real GDP to 2060 for the *Slow Decline* scenario

Note the transient effect of the mining boom on engineering construction

There is a conspicuous peak and dip in the level of engineering construction between 2004 and 2017 – see Figure 5.10. At the peak of the most recent mining boom (2003–2013), investment from the Mining industry was 8% of GDP[51]. Much of this investment was in new fixed capital and infrastructure, which has now passed the construction phase.

Although data are not yet available for 2017–18, the dip is consistent with current information on infrastructure construction from BITRE[52] and also with prior forecasts from the Australian Construction Industry Forum[53]: "*…a fall of 45% is expected from the peak in Engineering Construction activity in 2012–13 to the expected trough in 2017–18.*" Secondly, there is also a more modest expected drop in residential building construction (from the same source): "*Growth in Residential Building at large is projected to fall to 4% this year (2016–17) and then activity will contract by a total of 16% over the 3 years to 2018–19.*"[53]

We treat the peak of engineering construction activity during the mining boom as transient and use the regression relations of Figure 5.9 to develop future scenarios of building and engineering construction activity in relation to the simulated annual GDP results from the economic modelling (see Chapters 5 and 14). Note that there are well-known cyclical effects in the construction industry that are not simulated, and the trends shown here should be considered as averaged over time.

Under both the *Slow Decline* and *Thriving Australia* major scenarios, we expect an increase in building construction activity to provide for increasing population, and engineering construction

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[51] Reserve Bank of Australia (2014b)

[52] See Figure 12 in BITRE (2017).

[53] ACIF (2017)

activity to expand and maintain the infrastructure that serves that population and the economy. Evaluations for the *Stronger Regions* scenario do not produce a significantly different outcome from *Thriving Australia* and so this scenario is not separately discussed below.

Building construction doubles from approximately $100 billion/year at 2016 to 2060 under *Slow Decline*, and increases 180% ($280 billion/year) by 2060 under *Thriving Australia* (refer to Figure 5.11). Over the same period, engineering construction increases from $65 billion/year to $177 billion/year under *Slow Decline*, and to $245 billion/year under the *Thriving Australia* scenario (refer to Figure 5.12).

The total of construction activity rises from approximately $165 billion/year in 2016 to between $377 billion/year and $525 billion/year at 2060 for the different respective scenarios (all values in 2016 real Australian dollars).

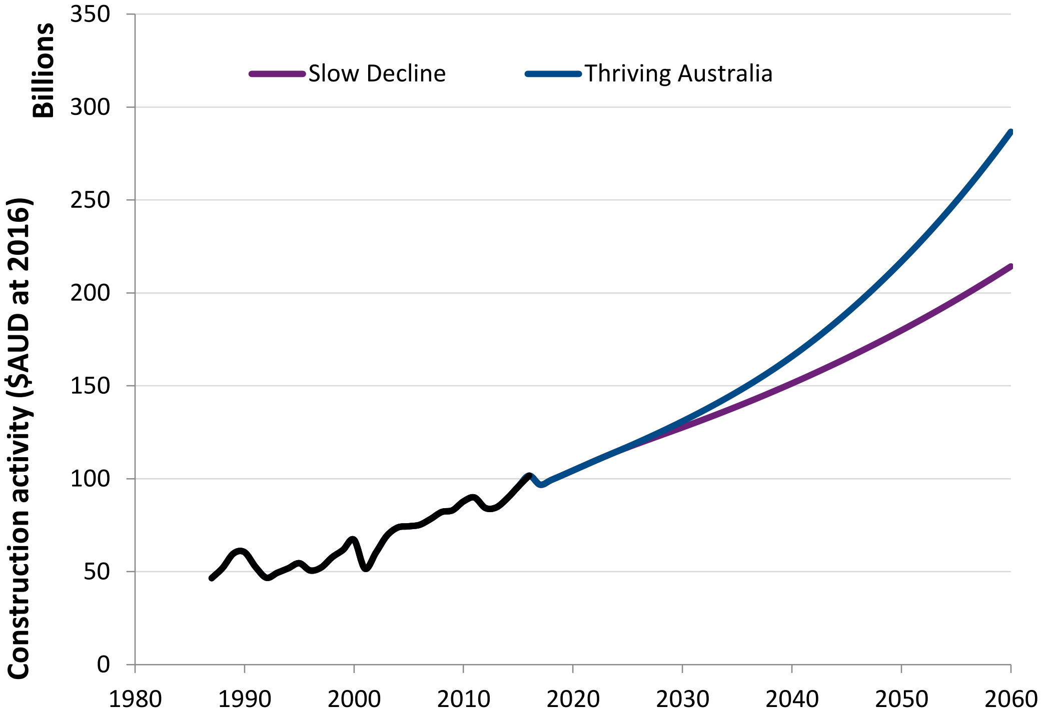

Figure 5.11 National building construction activity: historical data to 2016 and future expectations based on modelling using real GDP ($AUD 2016) simulations from the economic model

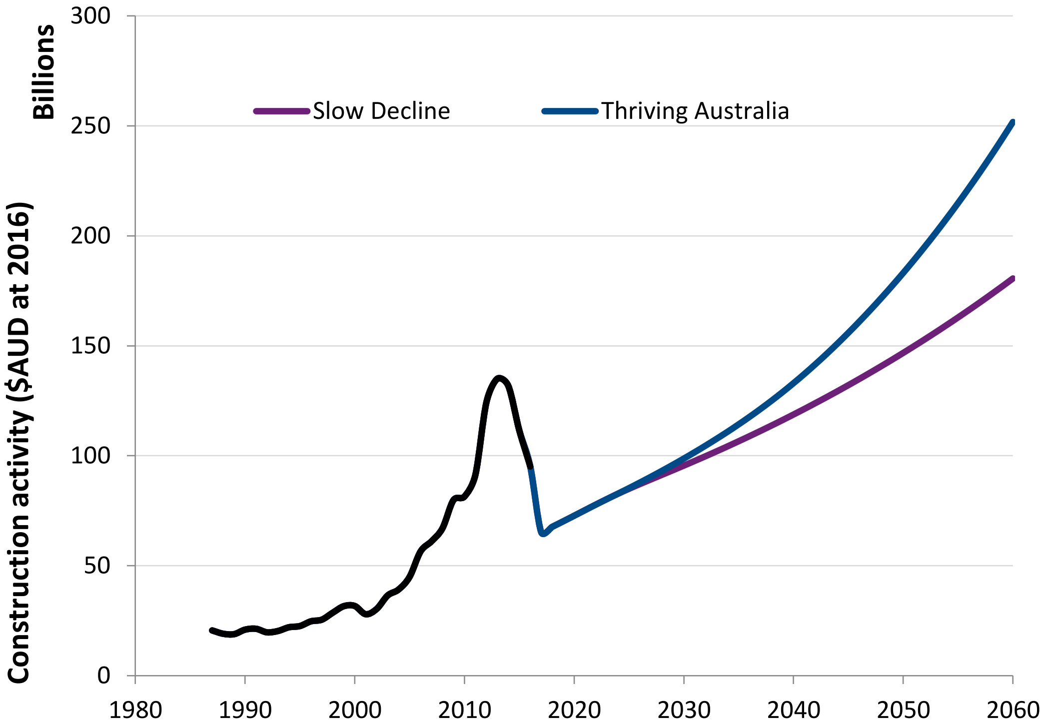

Figure 5.12 National engineering construction activity: historical data to 2016 and future expectations based on modelling using real GDP ($AUD 2016) simulations from the economic model

5.8.2 Identified major projects

There are around 30 major projects identified by Infrastructure Australia at March 2018[54]. The aggregate of the budgets submitted for these projects exceeds $220 billion ($AUD 2016) but that investment is spread over 2017 to 2058. The main point of this section is to put the cost of these singularly large, and sometimes iconic, projects into perspective.

Figure 5.13 provides an indicative time course for investment in the suite of major priority projects. This is based directly on the estimated budgets for individual projects and their planned or anticipated schedule[54]. There are a number of large projects (notably in Sydney and Melbourne) currently underway and expected to continue to the middle of the next decade. However, from 2025 to 2060, the annualised investment on priority projects is around $5billion/year ($AUD 2016).

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[54] Infrastructure Australia (2017b) (note that this list updates as projects commence or complete)

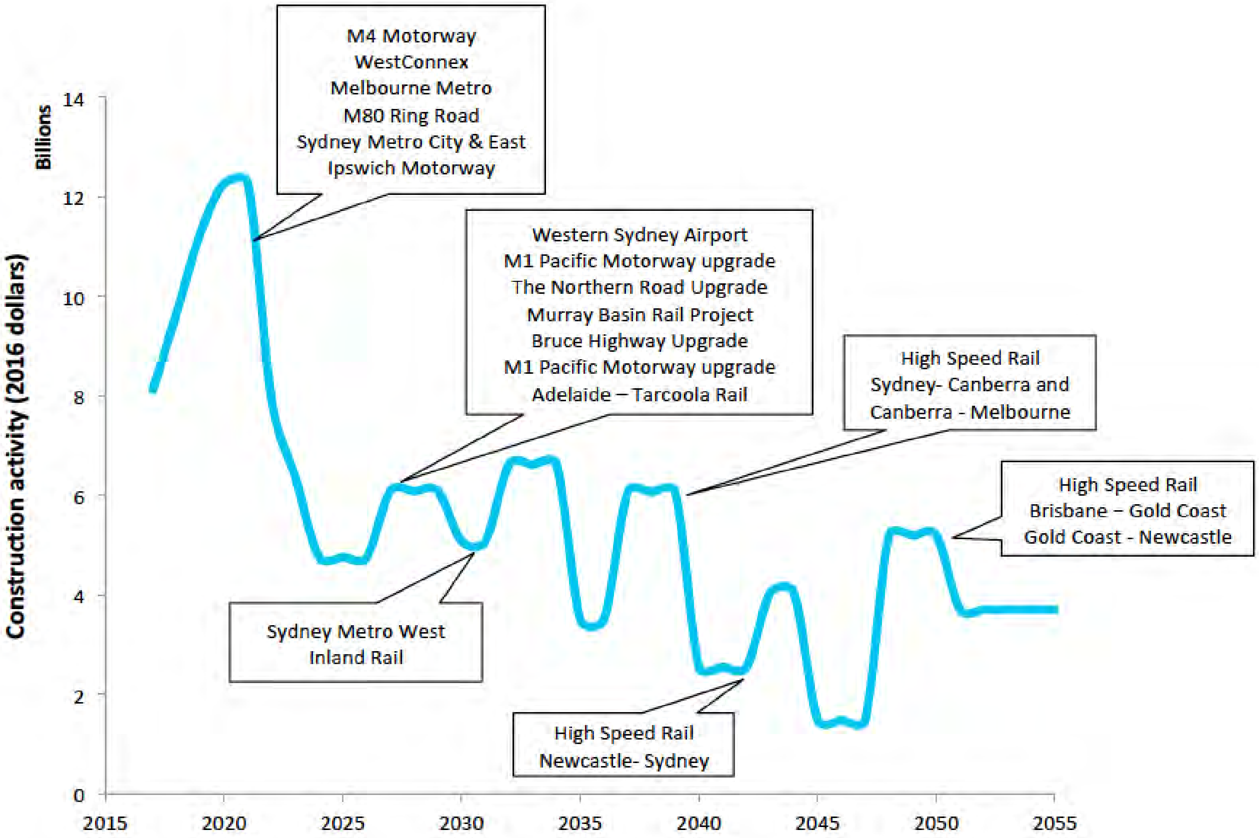

Figure 5.13 Hypothetical sequence, and expected cost, of Infrastructure Australia's priority projects based on budgets ($AUS 2016) and timetables available in Infrastructure Australia (2017a). Names of selected projects are shown

Note the order of magnitude difference from the results in Figure 5.12.

We would expect the construction pipeline to be updated over the period with differential priorities and it is important to note that cost over-runs are common[55] and we may expect that the final costs would be up to twice the budgeted costs[56]. Cost over-runs may already be the case for some current major projects underway[57].

Even if *all* the identified major projects were to experience over-run and cost a total of $400 billion, over 50 years, this amounts to an average annualised figure of $8billion/year ($AUD 2016). By comparison, this is less than 5% of the annual *current* investment in construction of $165 billion/year at 2016, which is expected to more than double under all scenarios (see previous section).

We make no comment on which or whether major projects are the 'right' infrastructure projects[58]. The effect of new major infrastructure can be substantial: airports create new gateways, rail and road enable more productive flows of people and freight and new transport and communications connections engender socio-economic growth and diversity in different locations. Whatever the

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[55] Flyvbjerg et al. (2003)

[56] Terrill M (2016)

[57] Visentin and O'Sullivan (2018)

[58] Flyvbjerg (2009)

relative cost, getting infrastructure right is more about improving the decision-making process and de-politicising prioritisation[59].

5.8.3 A note on water infrastructure

The historical data on construction of water infrastructure clearly shows the sudden additional investment of ~5–10 billion ($AUD 2016) in water-related infrastructure during the Millennium Drought – refer to blue lines of Figure 5.14. This included the construction of new desalination plants, recycled water treatment facilities and pipelines.

It is reasonable to expect that Australia will face another prolonged drought and, with climate change, the frequency and severity of such droughts will increase (Reisinger et al., 2014). Although we have not modelled policy stances on climate adaptation in ANO, under a 'reactive' approach to future drought, we can show indicatively what the response would look like – light green line of Figure 5.14. This involves a continuing-trend investment in water infrastructure, with growing populations and a 'wait and see' stance regarding water infrastructure to deal with water supply shortages.

With a pro-active 'anticipatory' stance on adapting to climate change, the same investment could be initiated earlier and spread over decades – dark green line of Figure 5.14. For example, the current 10-year water plan for Perth involves supplying half the city's water from desalination[60] as well as encouraging water use efficiency and aquifer recharge. In Figure 5.14 we show historical data and create indicative future water infrastructure investment scenarios reflecting these stances with a simulation of a serious drought around 2030 indicating a repeat of a pulse in investment in water infrastructure similar to the Millennium Drought.

Neither of these settings is inherently included or excluded from the major scenarios but we make a note of the basic approaches here. Previous research by CSIRO on adaptation approaches to multiple climate impacts showed that an anticipatory policy generally produced the greatest benefit to cost ratio considering the likely increase in frequency of severe events and a range of potential adaptation investments (Baynes et al., 2013; Wang et al., 2016).

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[59] Terrill and Batrouney (2017)

[60] Water Corporation (2011)

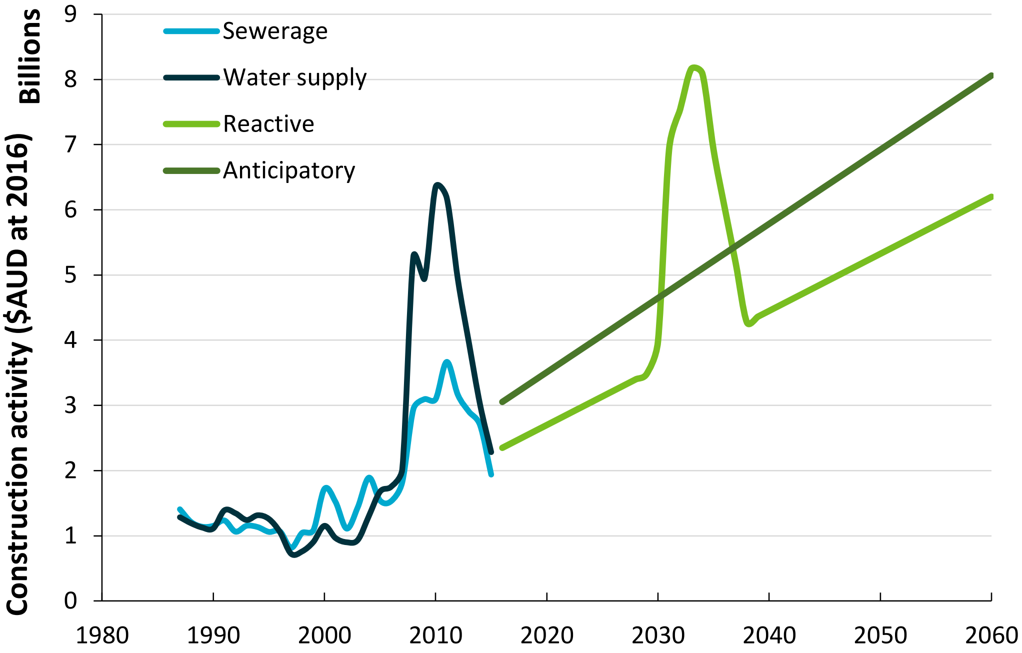

Figure 5.14 Historical investment in water infrastructure from the BITRE Yearbook (2017) noting the peak associated with the reactive response to the Millennium Drought (blue lines). Future investment is contingent on different policy stances – Reactive (light green) and Anticipatory (dark green) – see main text for more explanation.

5.9 Productivity

The expected change in labour productivity due to agglomeration is agnostic of technology change and depends only on the distribution of populations. As the 'low road' and 'metro style' assumption bundles have the same assumptions about population distribution at the regional scale, and only differ in the style of urban form, they have the same labour productivity changes from agglomeration.

In *Stronger Regions* there is a specific distribution to regional significant urban areas, which boosts the labour productivity specifically in those regional areas and very marginally reduces the gain from agglomeration in labour productivity of major cities.

States that gain proportionally more population in regional cities see quite large overall gains in labour productivity as there is a stronger population re-distribution e.g. to agglomerations outside of Perth in WA. States that already have a large proportion of their population in regional cities e.g. Queensland, see proportionally less of a change.

5.9.1 Labour productivity from agglomeration

Our calculations are based on the observations of Sarkar et al. (2018) that there is a scaling to the level of income, $I(t)_{SUA}$ (or the per capita equivalent, $i(t)_{SUA}$) across the set of Australian SUAs, which is proportional to the specific size of the population in a given SUA, $P(t)_{SUA}$ at time, t.

$$I(t)_{SUA} = K.P(t)_{SUA}^{\beta} \leftrightarrow i(t)_{SUA} = K.P(t)_{SUA}^{\beta-1} \quad (12)$$

Here K is a constant and β is the exponent of population scaling. This is a recent, Australian-specific, and more detailed version of the global observations on city population scaling by Bettencourt et al. (2007). We associate this income scaling with labour productivity due to agglomeration.

Implicit in this is the assumption that urban social network effects are present (Bettencourt 2013)and have an effect on wages that drives the super-linear income returns from agglomeration, rather than ownership of capital. This is particularly associated with knowledge-intensive occupations that benefit from co-location with other knowledge-intensive occupations e.g. in finance, accounting, consultants in the CBD; engineers, medical professionals and tertiary institutions in research hubs.

Some occupations experience a neutral effect from agglomeration. For example, with greater population there is a proportionally greater demand for teachers, retail workers and transport workers. There is no especially significant social-network effect that might give effect to labour productivity and, because these sorts of occupations are dispersed across the urban space, there are few economies from co-location that affect wages (although e.g. co-located shared education, retail or transport facilities may have benefits)

Low pay, low skill jobs actually have a negative exponent with agglomeration, meaning that as an urban area increases in population, there are economies of scale that reduce demand e.g. for road maintenance/capita. Bettencourt et al. (2007) observed physical economies of scale in cities whereby per capita requirements for items such as length of road, water supply lines or street lighting, decrease with population size. This is sub-linear scaling with urban agglomeration and we assume that occupations connected to this effect (such as road maintenance) actually have a decreasing per-capita demand for labour (wages) with city size.

Sarkar et al. (2018) analysed the differential scaling of income distributions across income brackets, for more than 100 Australian SUAs with populations greater than 30,000. They found that income from labour scaled with population size and also that the exponent, β, had different values for different income levels.

We have associated their income brackets with 9 occupation categories – see Table 5.7 (from the ASCO Second Edition classification[61]). In order to provide input to VURM, we calculated the year-to-year change in per-capita income (as a proxy for the value of labour) for each of the state capital cities and the other SUA, such as those identified in

Table 5.2 of Section 5.4.4.

$$\frac{i(t)_{SUA}-i(t-1)_{SUA}}{i(t-1)_{SUA}} = \frac{P(t)_{SUA}^{\beta-1}}{P(t-1)_{SUA}^{\beta-1}} - 1 \tag{13}$$

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[61] ABS (2009)

Table 5.7 Values for the β exponent in occupational categories – note that $\beta = 1$ represents a proportional scaling with population, $\beta > 1$ indicates super-linear scaling, and $\beta < 1$ indicates sub-linear scaling – see text for more information.

OCCUPATION	β
MANAGERS AND ADMINISTRATORS	1.05
PROFESSIONALS	1.2
ASSOCIATE PROFESSIONALS	1.1
TRADESPERSONS AND RELATED WORKERS	1
ADVANCED CLERICAL AND SERVICE WORKERS	1.05
INTERMEDIATE CLERICAL, SALES AND SERVICE WORKERS	1
INTERMEDIATE PRODUCTION AND TRANSPORT WORKERS	1
ELEMENTARY CLERICAL, SALES AND SERVICE WORKERS	0.95
LABOURERS AND RELATED WORKERS	0.95

Source: (Sarkar et al., 2018) and CSIRO Calculations

The exponents of the scaling factors for labour productivity in Table 5.7 are due to urban population size based on observations of per capita income scaling with increasing urban population. These were applied to occupations, across all states, as represented in the economic model – see Table 5.8 and Table 5.9. At the national level, the additional effect of agglomeration on labour productivity is modest although some specific occupation classes may see more than 10% improvement by 2060. Factors are common across 'low road' and 'metro style' as they assume the same gross distribution of population in major cities and regions (albeit with different urban density and form). This is compared with the effect of the spatial redistribution of population under *Stronger Regions*.

Table 5.8 relative change in labour productivity 2016–2060 across 9 occupation classifications for Low Road and Metro Style

LOCATION	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
MANAGERS AND ADMINISTRATORS	2.7%	3.2%	3.5%	1.8%	4.7%	1.0%	2.4%	3.1%
PROFESSIONALS	11.2%	13.3%	14.8%	7.5%	20.1%	4.0%	9.9%	12.8%
ASSOCIATE PROFESSIONALS	5.5%	6.4%	7.2%	3.7%	9.6%	2.0%	4.8%	6.2%
TRADESPERSONS AND RELATED WORKERS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ADVANCED CLERICAL AND SERVICE WORKERS	2.7%	3.2%	3.5%	1.8%	4.7%	1.0%	2.4%	3.1%
INTERMEDIATE CLERICAL, SALES AND SERVICE WORKERS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
INTERMEDIATE PRODUCTION AND TRANSPORT WORKERS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ELEMENTARY CLERICAL, SALES AND SERVICE WORKERS	-2.6%	-3.1%	-3.4%	-1.8%	-4.5%	-1.0%	-2.3%	-3.0%
LABOURERS AND RELATED WORKERS	-2.6%	-3.1%	-3.4%	-1.8%	-4.5%	-1.0%	-2.3%	-3.0%

Table 5.9 relative change in labour productivity 2016–2060 for *Stronger Regions*

LOCATION	NSW	VIC	QLD	SA	WA	TAS	NT	ACT
MANAGERS AND ADMINISTRATORS	2.6%	4.1%	2.7%	1.5%	6.4%	0.5%	1.2%	3.1%
PROFESSIONALS	10.9%	18.2%	11.1%	6.2%	29.3%	1.9%	4.9%	12.8%
ASSOCIATE PROFESSIONALS	5.3%	8.5%	5.4%	3.0%	13.3%	0.9%	2.4%	6.2%
TRADESPERSONS AND RELATED WORKERS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ADVANCED CLERICAL AND SERVICE WORKERS	2.6%	4.1%	2.7%	1.5%	6.4%	0.5%	1.2%	3.1%
INTERMEDIATE CLERICAL, SALES AND SERVICE WORKERS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
INTERMEDIATE PRODUCTION AND TRANSPORT WORKERS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ELEMENTARY CLERICAL, SALES AND SERVICE WORKERS	-1.4%	-1.4%	-0.8%	-1.5%	-2.0%	-0.5%	-1.2%	-3.0%
LABOURERS AND RELATED WORKERS	-1.4%	-1.4%	-0.8%	-1.5%	-2.0%	-0.5%	-1.2%	-3.0%

Source: CSIRO Calculations

5.10 Liveability

Summarised, high-level measures of liveability (or other single social metrics) do not represent the range of social outcomes in Australia's human settlements. For example, even when we know there are affordability issues and congestion and social exclusion for some outer suburbs, Sydney and Melbourne appear as among the most ‘liveable cities’ in ratings by the Economist Intelligence Unit[62].

To explore social performance in more detail, we have developed a ‘Spatial Social Database’ that brings together a selection of variables from the ABS Census[63], SEIFA[64], The Social Health Atlas[65], the NEXIS database[66], and our own spatial analysis, to create a spatially specific database for all of

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[62] The Economist Intelligence Unit (2017)

[63] ABS (n.d. b)

[64] ABS (2018c)

[65] Torrens University Australia (n.d.)

[66] Geoscience Australia (n.d.)

Australia – see Figure 5.15 and Figure 5.16. Over 150 variables were collected informed by the choice of indicators presented in prior studies (Deloitte Australia 2015; Arundel et al., 2017).

Selected measures used here and in other results have been collected and harmonised to all SA2 boundaries and 10 in particular we chosen for the "social radar" (see Figure 5.15):

- Need For [Government] Assistance %
- Financial Stress From Mortgage Or Rent (% Low Income Households Under Financial Stress From Mortgage Or Rent)
- Dwellings With No Higher Education %
- Average Distance To Work (Km)
- Population Weighted Distance To Hospital/Medical services
- Education And Occupation Decile (from SEIFA data)- this is both an outcome and a driver of socio-economic (dis)advantage in a feedback arrangement: the lower an individual's socioeconomic position the worse their health, education and economic participation.[67] Those experiencing socio-economic disadvantage attend fewer hours of early childhood education and have lower school attendance.
- Parkland (Land Area Per Capita)
- Jobs-Persons Ratio
- Residential Care Places Per 1,000 Population Aged 70 Years And Over
- Volunteering (% of persons): this is the proportion of persons in an area that willingly gave unpaid help, in the form of time, service or skills, through an organisation or group.
- Employment Land Per Capita (Commercial, Industrial, Hospital/Medical and Education)
- Car use in mode choice for commuting (%)
- Population Density (persons/km^2
- Average Residential Structural Value
- Average Residential Building Footprint (m^2)
- Rent Public Tenure %
- Land Use Diversity Index

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[67] World Health Organization (n.d.)

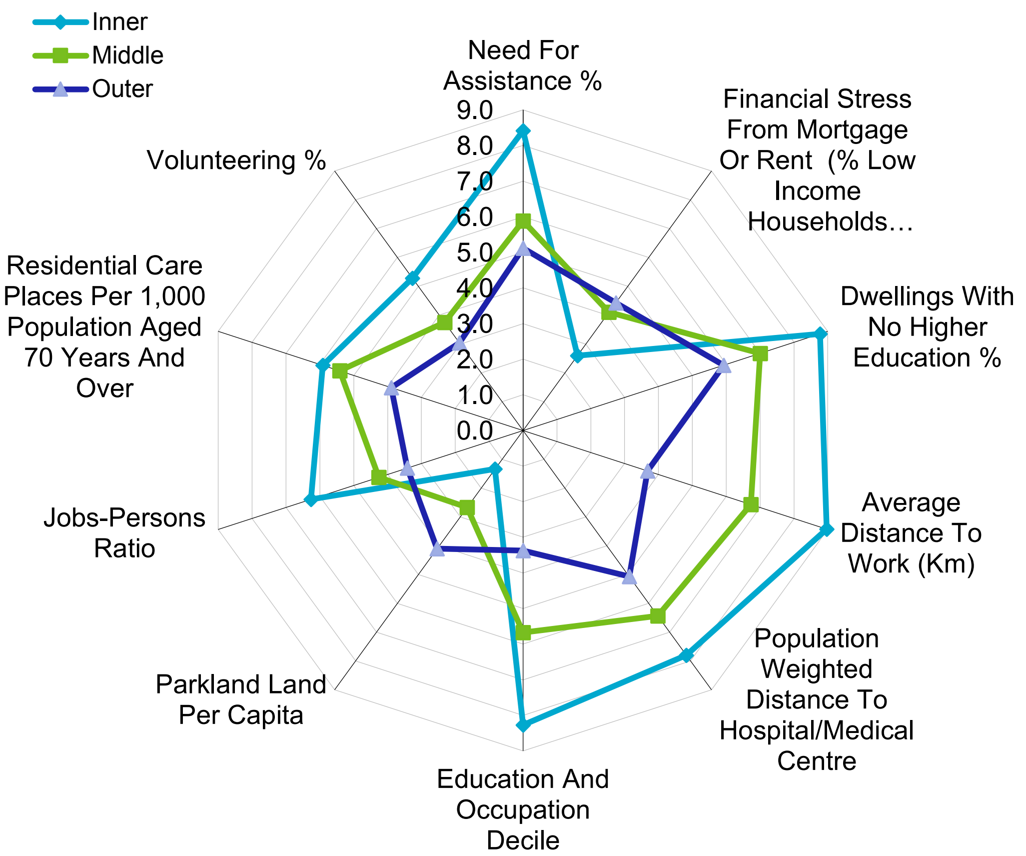

Figure 5.15 the "social radar" for inner, middle and outer suburbs as mean decile rank for performance against 10 metrics of liveability for all SA2 areas in Australia at 2016. For all measures, higher ranking indicates better social outcomes

These measures can be used directly or as proxies to represent social conditions in different zones of habitation in Australia: inner, middle and outer urban areas, and regional cities and other regional areas (small towns and rural) as defined in Section 5.2. See also similar reporting by Deloitte Australia (2015)[68].

Social data have been collected for more than 2200 SA2 locations across all of Australia. Because the indicators are measured in different ways, we have presented the average decile rank across SA2 areas within zones, according to their performance, with a higher ranking indicating a more positive social outcome. For example, a higher ranking of 'Volunteering %' indicates more volunteering, while a higher ranking of 'Average distance to work' indicates *less* travel to work. In general a larger area on the social radar indicates a better overall social outcome.

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[68] Deloitte Australia (2015)

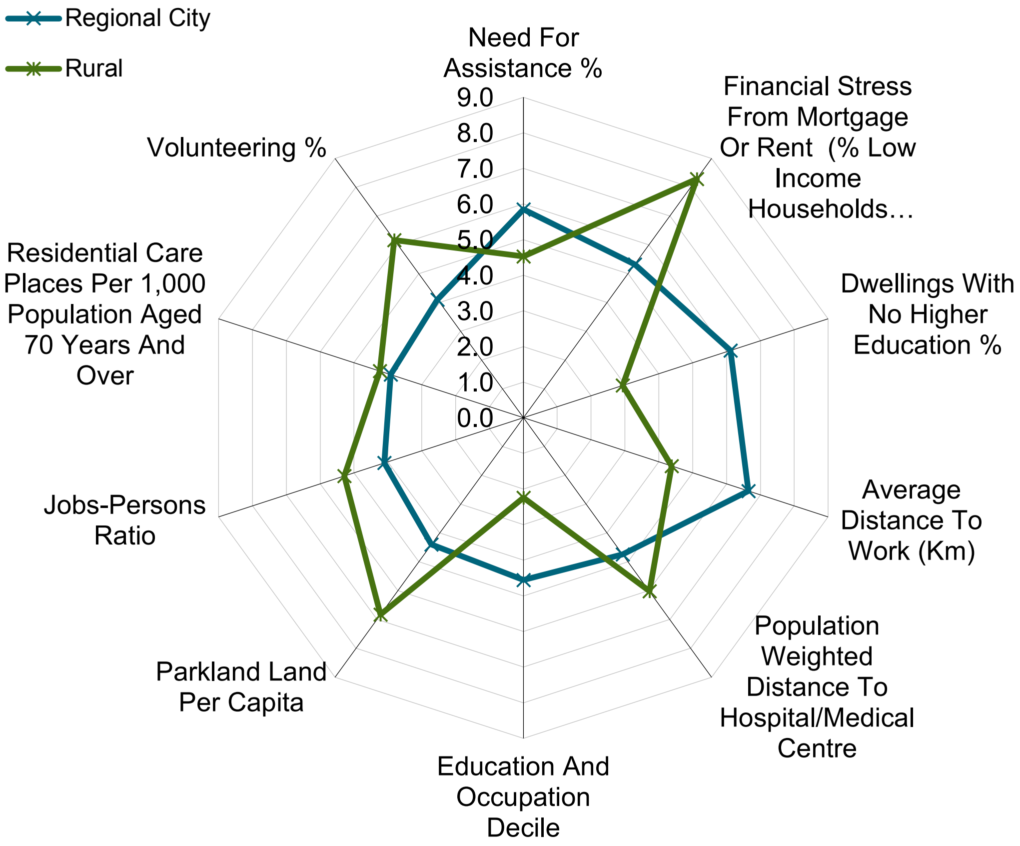

Figure 5.16 the "social radar" of the rural and regional city zones measured as mean decile rank against 10 metrics of liveability. Ranking is across 2210 SA2 boundaries in Australia at 2016. For all measures, higher ranking indicates better social outcomes

While we do not have a formal model of change for these social metrics to integrate with the other urban and economic modelling, we make the association with quality of life in zones now and the future expected population in those zones under different scenarios.

Later, in Table 5.10, we summarise the qualitative changes and outcomes across zones and scenarios and below are more textual insights into the comparison zones as measured in terms of the metrics of the social radar.

People living in inner suburbs travel a third of the distance to work, on average, compared to outer suburb residents who travel comparable distances to Australians living in regional areas. Outer suburbs also rank similarly with regional Australia for indicators of households with no higher education, rental stress, need for rent or government assistance in general. Interestingly, there are higher levels of volunteerism in inner cities and regional Australia than in other zones.

At the same time around 40 % of low income households in inner Melbourne and Sydney are under financial stress from mortgage or rent while the proportion is half that in rural areas. Living in the middle or outer suburbs is about in-between the two levels of housing financial stress.

Residents of the inner suburbs of our major cities have short commutes, higher education attainment and exhibit a high degree of volunteerism but they also have less access to parkland per capita and lower income groups in these areas suffer from financial stress related to housing.

Citizens of the middle suburbs still have relatively short distances to health care, similar access to aged care but more parkland than inner suburban residents, and less financial stress for lower income groups.

Residents of the outer suburbs of our major cities have long commutes, lower job densities and education attainment and they require more government assistance but they also have the lowest housing-related financial stress and better access to parkland per capita than other urban zones.

Rural areas show the highest level of volunteerism and least financial stress from housing of all zones. They rank comparably to outer suburbs in distance to work and access to aged care, but they also have the same need for government assistance. They also have generally lower educational attainment than other zones.

Regional cities rank higher than rural areas in distance to work, education attainment and access to aged care services but exhibit similar levels of housing financial stress for lower income groups as in middle suburbs.

In 2060 under *Slow Decline* there are more than 30 million Australians living in the major cities with more than 12.5 million living in the outer suburbs and more than 10 million in regional Australia.

At 2060 for *Stronger Regions*, there are more than 16 million living in regional Australia and nearly 10 million of those people are in regional cities. Only 22% of the nation (less than 9 million) lives in the outer suburbs of major cities and 11% of Australians will live in the inner suburbs. Middle suburbs account for another 26% but the assumptions of density and urban design in *Stronger Regions* may well make the character of current middle suburb zones more like inner suburbs.

Table 5.10 Qualitative expected outcomes for liveability from the different ANO core scenarios

		Mode choices	Access to Health	Access to parkland	Education	Access to Jobs	Housing Cost
Slow Decline	**Inner Urban**	✓	✓	✗	✓	✓	✗
	Middle	✓	✓	~	✓	✓	✗
	Outer Urban	~	~	✓	~	✗	~
	Regional	✗	✗	✓	~	✗	~
Thriving Australia Focus on expanding social infrastructure, activity and amenity in major cities.	**Inner Urban**	✓	✓	✗	✓	✓	~
	Middle	✓	✓	✗	✓	✓	~
	Outer Urban	✓	~	✓	✓	~	✓
	Regional	✗	~	✓	~	~	~
Stronger Regions critical mass populations in regions to spread benefits of agglomeration.	**Inner Urban**	✓	✓	✗	✓	✓	~
	Middle	✓	✓	✗	✓	✓	✓
	Outer Urban	✓	~	✓	✓	~	✓
	Regional	✓	✓	✓	✓	✓	~

Key	✗ Decline or no change	~ Some improvement	✓ High improvement

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6 Energy

Author: Cameron Butler

6.1 Overall energy use

6.1.1 Current context

Net energy use

Australia's net energy use[1] has historically been dominated by industry[2], electricity generation and transport, together accounting for 83% of total net energy use (6066 PJ) in 2016, while residential and services sectors contribute a relatively small amount (Figure 6.1). Just over a third of all net energy use is derived from oil (37%), with large shares also coming from coal (32%) and gas (25%), as shown in Figure 6.2. Since 2005, total energy from coal use has declined 13%, while gas and renewables increased 51% and 29%, respectively, to 2016. Oil use also increased by around 20% from 2005 to 2011, remaining relatively flat thereafter.

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[1] Total net energy consumption is the total quantity (in energy units) of primary and derived fuels consumed less the quantity of derived fuels produced. Breakdowns of net energy consumption by fuel and sector are provided in Table C and Table E in Australian Energy Statistics (DoEE, 2017).

[2] 'Industry' refers to the mining, manufacturing and construction sectors.

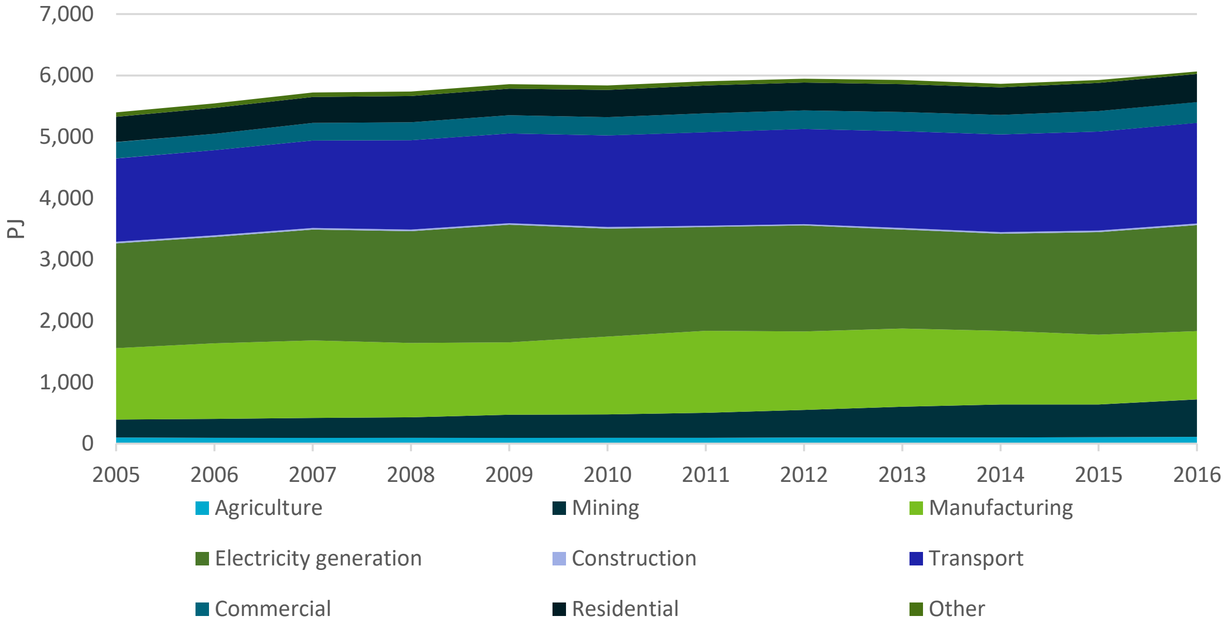

Figure 6.1 Net energy use by sector, 2005–2016

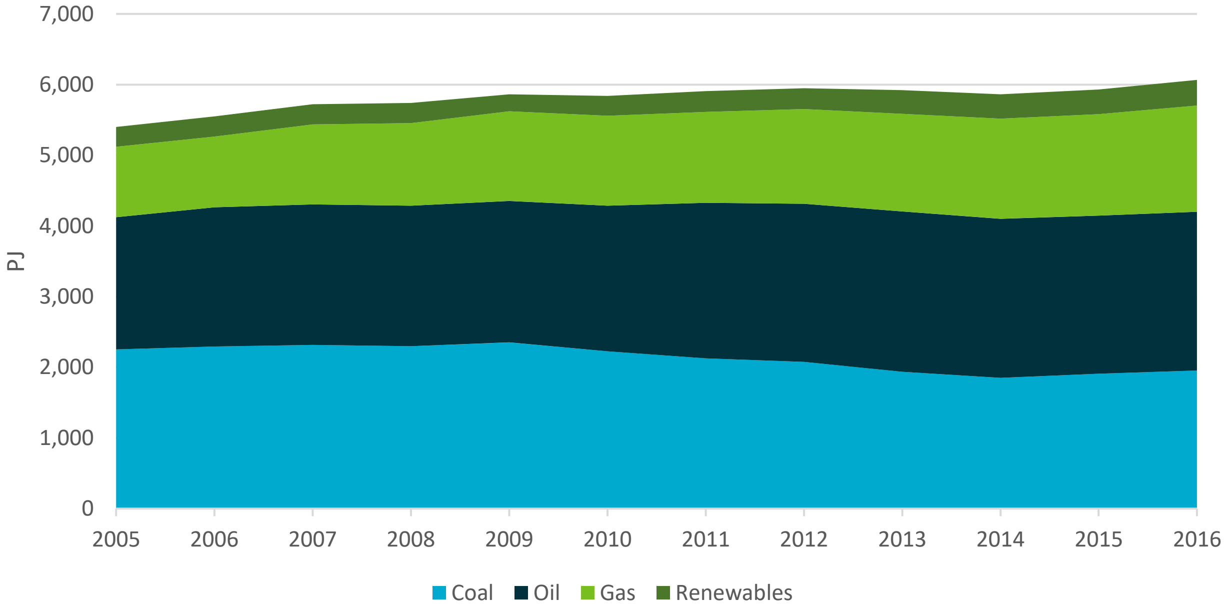

Figure 6.2 Net energy use by fuel, 2005–2016

Final energy use

Total final consumption[3] (TFC) has followed similar historical trends, increasing to 4135 PJ in 2016 (DoEE, 2017). TFC is dominated by transport[4] and industry, which account for 39% and 38% of energy use, respectively, while residential (11%) and commercial (8%) buildings make up most of the remaining consumption (Figure 6.3). More than half of TFC in 2016 was delivered by oil, predominantly consumed in the transport sector, while gas (21%) and electricity (20%) contributed the majority of remaining consumption (Figure 6.4).

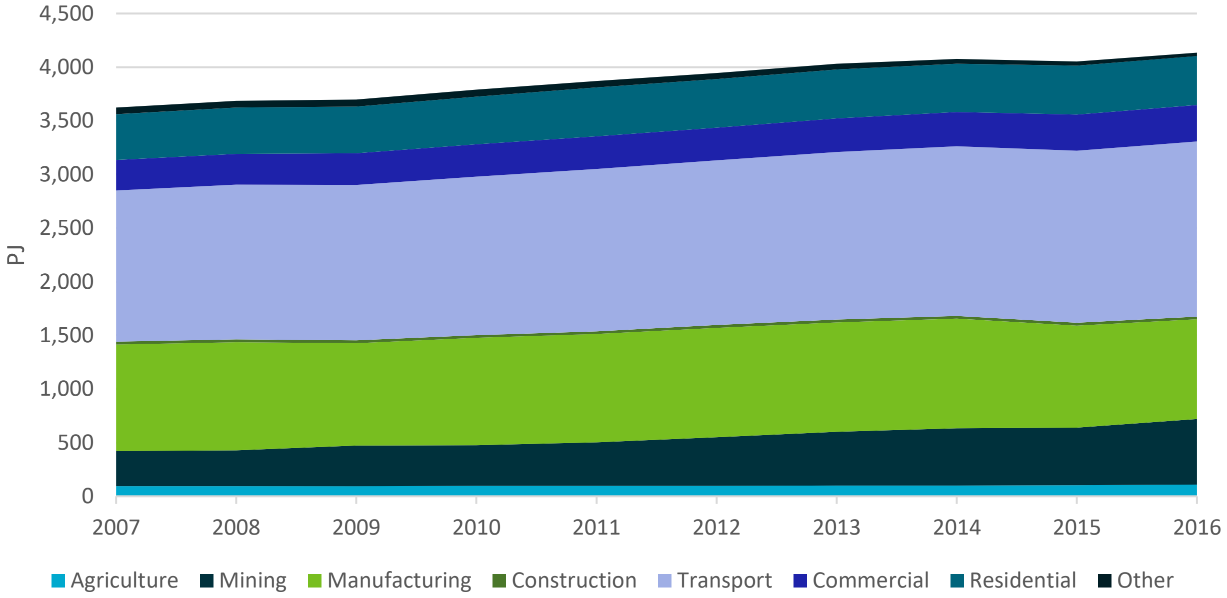

Figure 6.3 Total final consumption by sector, 2007–2016

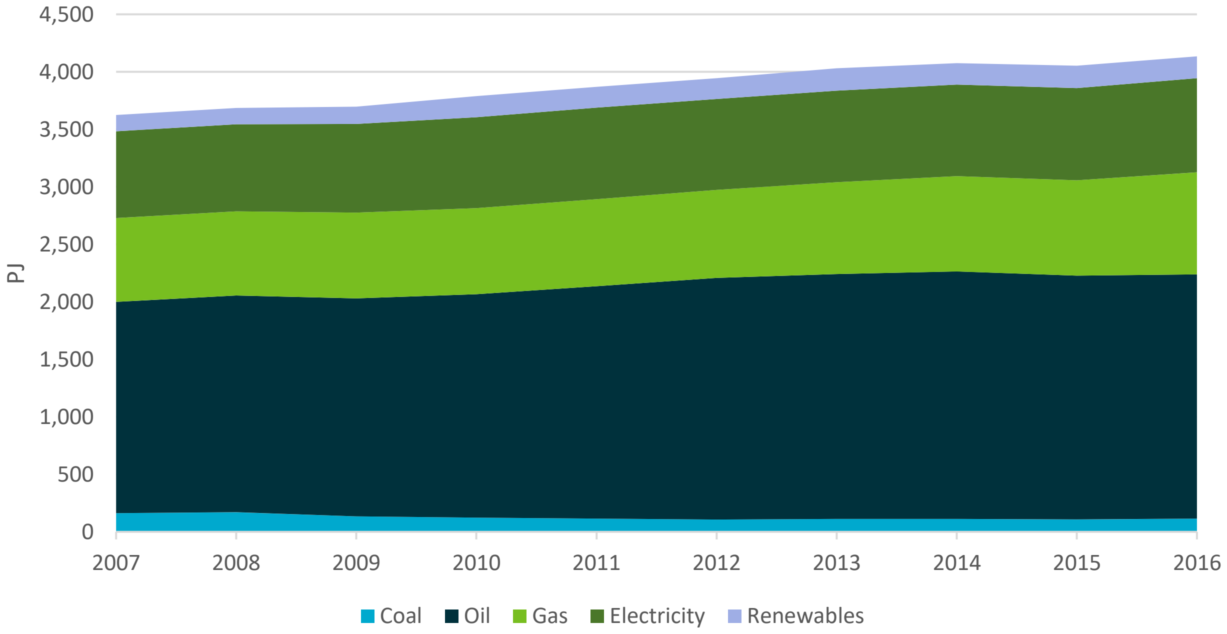

Figure 6.4 Total final consumption by fuel, 2007–2016

Electricity use

As shown in Figure 6.5, electricity consumption was 227 TWh in 2016, increasing 9% from 2005, with the highest consumption in industry (41%), commercial services (30%) and residential buildings (26%). Other sectors of the economy such as agriculture and transport are responsible for the remaining, minor demand for electricity. Most of the rise in electricity use between 2005 and 2016 came from mining (which increased by 80%) and commercial services (14% increase), while electricity use in manufacturing declined by 13% during the period. More detailed analysis of electricity generation will be covered in Section 6.2, while sectoral electricity use is discussed in Section 6.3 to Section 6.6.

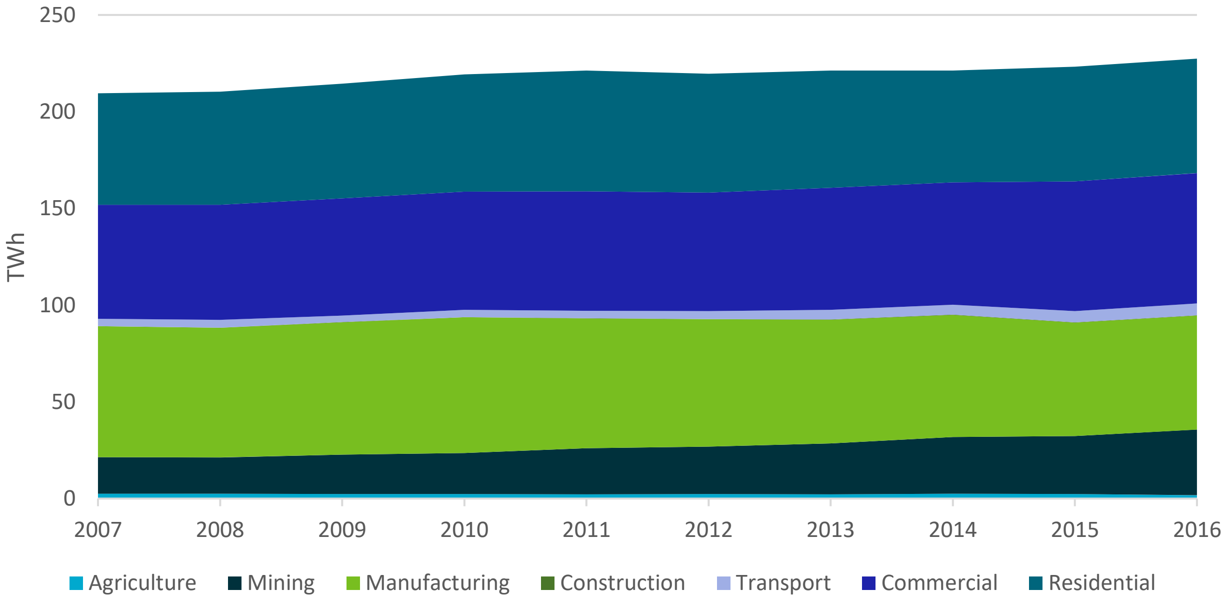

Figure 6.5 Electricity use by sector, 2007–2016

Energy intensity and energy productivity

Energy productivity at a national level is defined as real GDP per physical unit of energy deployed (generally primary energy), representing a measure of the economic value created in terms of energy consumed. Energy productivity can be improved through energy efficiency, fuel switching, improved energy conversion and reduced distribution losses, structural changes in the economy from more energy intensive to less energy intensive activities or through changes in energy supply, including generation of electricity (ClimateWorks Australia, 2015). These efforts to improve energy productivity can have multiple benefits, such as reductions in energy costs and greenhouse gas emissions, while contributing to overall productivity.

Similar to the high rates of energy use per capita mentioned previously, Australia's GDP is energy intensive by global standards, measured as the ratio of TFC per unit of real GDP (IEA, 2018a). This partly reflects the materials-intensive structure of the Australian economy, particularly in the

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[3] Total final consumption is a subset of total energy consumption, and excludes energy used to convert or transform primary energy used into different forms of energy, such as electricity or refined petroleum products. This represents the energy used by the final or end-use sectors.

[4] Above amounts for transport include energy use in international aviation and international bunkers. Discussion of energy use and emissions in transport elsewhere in this report relates to domestic transport only, and therefore excludes these amounts.

extraction of mineral and energy commodities, requiring larger amounts of energy per unit of economic output compared to international peers (Steinberger et al., 2013).

The recent International Energy Efficiency Scorecard (ACEEE, 2018) ranked Australia 18th in terms of energy efficiency out of the countries considered, continuing a recent downward trend from 10th in 2014 and 16th in 2016. While factors such as industry structure and population density contribute to Australia's energy efficiency profile, a number of qualitative metrics such as policy settings against which Australia performs poorly are discussed in this report. Transport and industry, in particular, rated significantly lower than median results, which is significant given these sectors comprise most of Australia's TFC. The ratings in transport and industry were attributed to a lack of energy efficiency agreements, fuel efficiency standards and requirements for audits, as well as low public transport use and investment. Despite aims to increase energy productivity 40% by 2030 through the National Energy Productivity Plan, implementation of strategies has been limited since the plan was established in 2015 (ACEEE, 2018).

Without substantial efforts to improve energy productivity, future energy use can be expected to increase to service a growing economy and the needs of a growing population. Other market, technology and policy factors will also impact on Australia's energy use into the future.

6.1.2 Modelling overall energy use

Note that while the Australian National Outlook 2019 report discusses results under two scenarios: *Slow Decline* and *Outlook Vision*, this report goes into further detail by reporting results for the *Outlook Vision* under two different global contexts: *Thriving Australia* under a fractious global context and *Green and Gold* under a more harmonious global context. It should be noted that both scenarios fall under the *Outlook Vision*. Chapter 2 of this report describes these scenarios in further detail.

The profile of primary energy use differs significantly by 2060 across the modelled scenarios. While total primary energy use increases across all scenarios (Figure 6.6)[5], on a per capita basis, energy use declines by 2060 relative to 2016 (Figure 6.7). Total primary energy use increases by 61% and 28% by 2060 under *Slow Decline* and *Thriving Australia,* respectively, while it remains broadly flat in *Green and Gold* (6% increase). Industry becomes the highest energy consuming sector across all scenarios, displacing electricity generation and transport (see Section 6.2 and Section 6.3 for more detail). In *Green and Gold*, agriculture (including forestry) becomes a significant energy consumer due to productivity and global conditions assumed in the scenario (see Section 6.2 for further discussion).

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[5] Primary energy use modelling for ANO 2019 does not include industrial or residential use of biomass for heating or losses of energy in the processing or refinery of energy or industrial products. As such, both total and proportional sectoral primary energy use in 2016 differ from Australian Energy Statistics figures discussed earlier in this section.

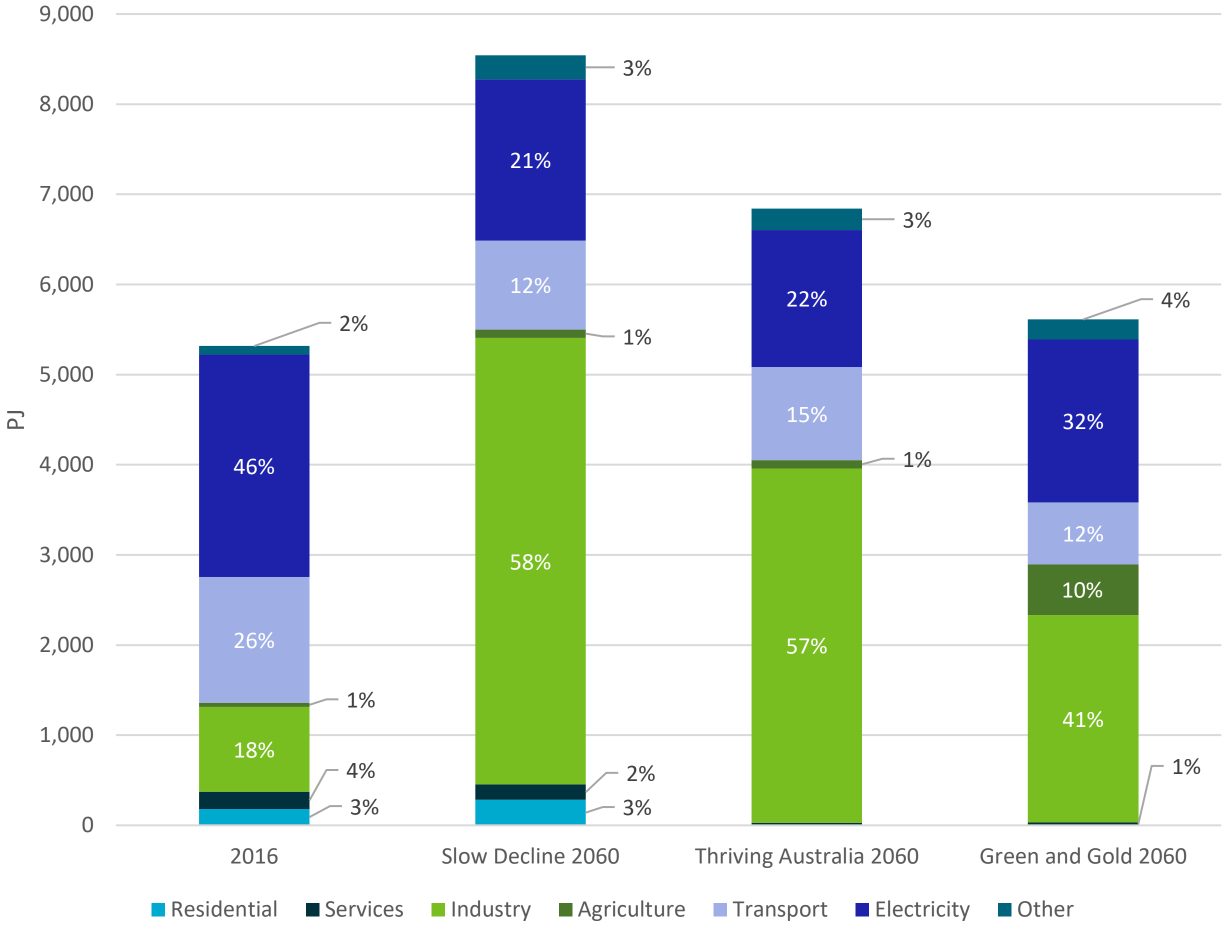

Figure 6.6 Primary energy use by sector, by scenario

Figure 6.7 shows the primary energy use per capita across the scenarios, by fuel type. Coal and oil use decreases by 2060 in each scenario, largely due to the shift away from fossil fuels used in electricity generation and the increased uptake of alternative fuel vehicles, as covered in Section 6.3. There is a substantial increase in renewables (including biofuels) as a primary energy source in each scenario, which rise from 3% to between 22% and 37%, mostly relating to the near 100% penetration of renewables across the scenarios by 2060 (discussed in Section 6.2). Total gas use (shown in Figure 6.7 as per capita) more than doubles in *Slow Decline* and *Thriving Australia*, and increases 27% in *Green and Gold*, largely due to increases in liquefied natural Gas (LNG) production across the scenarios.

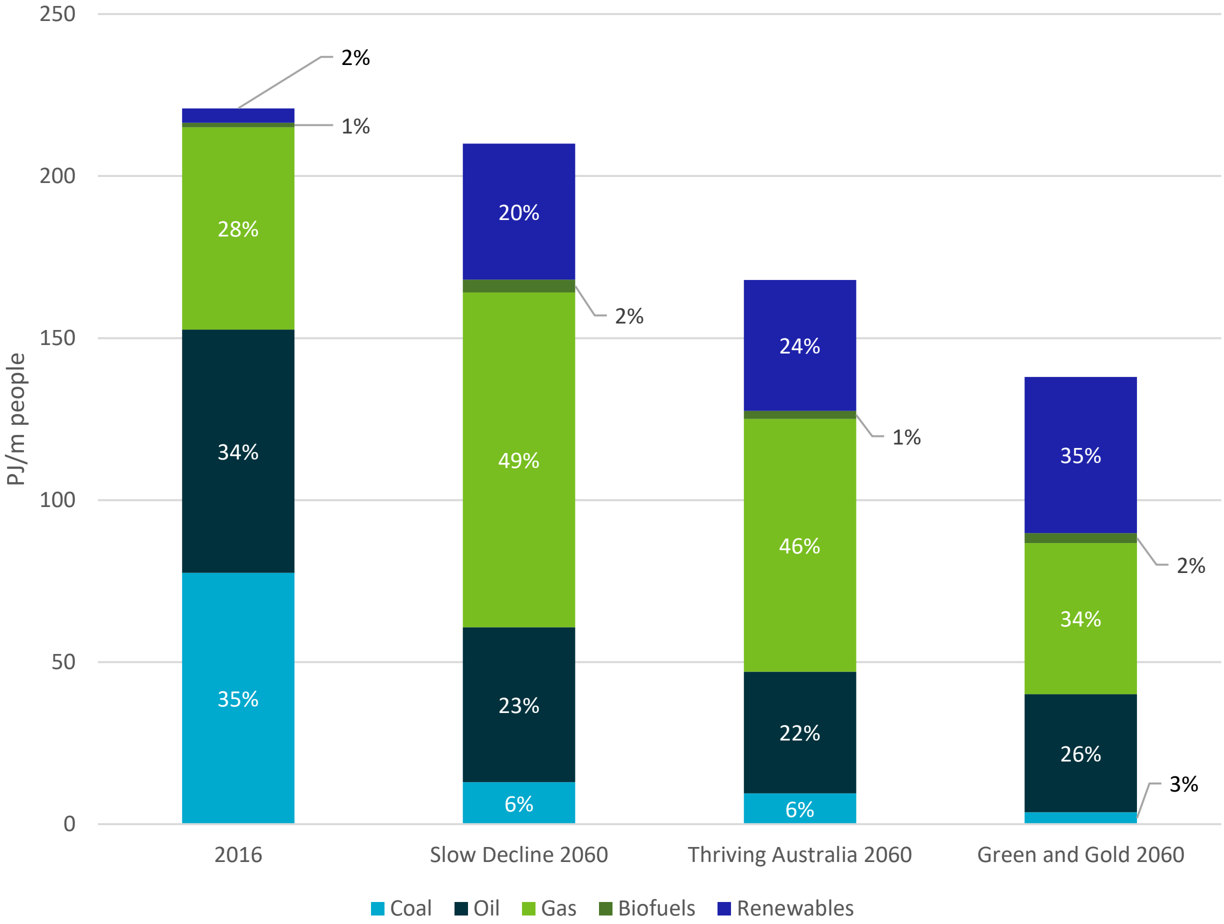

Figure 6.7 Primary energy use per capita by fuel type, by scenario

Energy productivity outcomes differ markedly between each of the scenarios, calculated as GDP per unit of primary energy consumption. This variance across scenarios is the result of changes in both economic growth and energy use trajectories, the assumptions behind which are covered in more detail in Chapter 4 and in the remainder of this chapter. Energy productivity more than triples in the *Green and Gold* scenario, driven by two main factors. Firstly, lower energy demand is achieved through energy productivity measures and a strong shift in electricity generation from renewables. Secondly, strong economic performance relative to the other scenarios drives an increase in GDP, particularly in sectors with a lower energy intensity of production. By contrast, energy productivity in *Slow Decline* peaks at just over 150% on 2016 levels around 2050, gradually declining thereafter, while *Thriving Australia* increases to over 260% on 2016 levels in 2060, driven by stronger economic growth relative to *Slow Decline*.

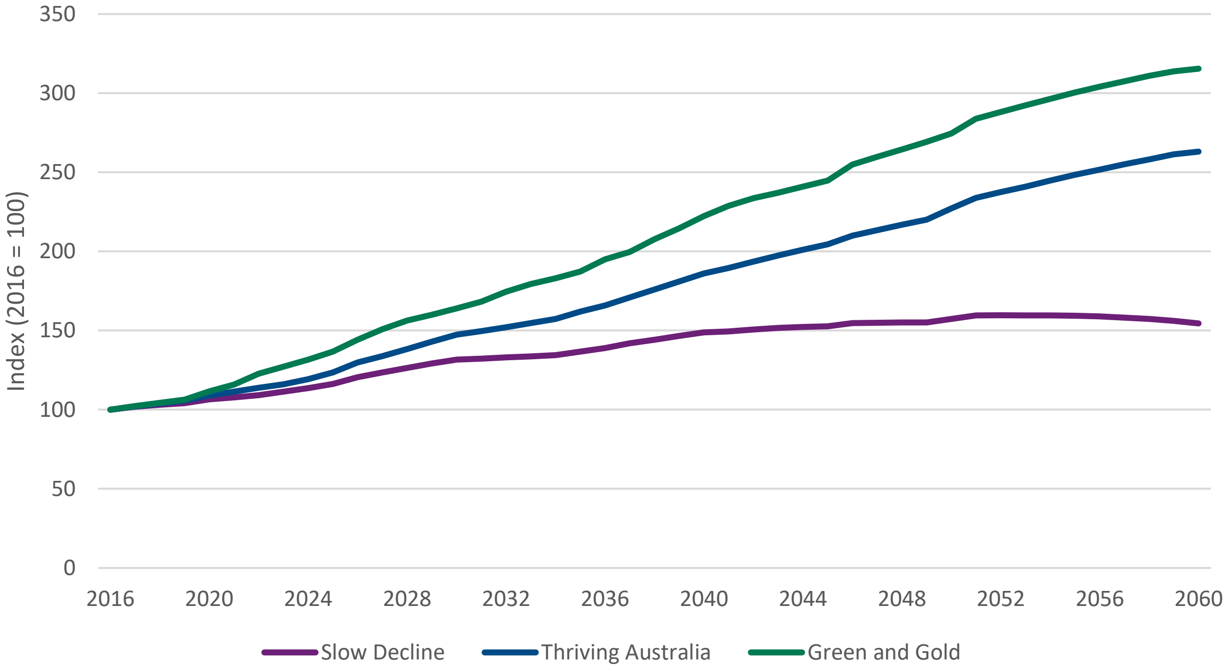

Figure 6.8 Energy productivity by scenario, 2016–2060 (Index 2016 = 100)

At a national level, there are numerous potential drivers of energy performance, including energy intensity improvements, energy efficiency and research and development (R&D) spending, tax incentives and loan programs, energy savings goals and a price on carbon (ACEEE, 2018). Energy productivity is essential to manage increased demand from these sources – by taking advantage of energy productivity opportunities, businesses and households can reduce their overall cost of energy even during potential future increases in the cost of electricity and other energy.

Energy productivity can also alleviate supply constraints, such as potential shortages in the supply of gas. The gas market on the east coast of Australia has changed significantly following the commencement of LNG exports (AEMO, 2018a). To meet future gas needs, a range of undeveloped, contingent and prospective reserves and resources will need to be developed or reserves will need to be diverted from other domestic or international export markets, likely at higher cost (AEMO, 2018a). Gas demand can be reduced substantially through energy productivity, which is the major factor resulting in reduced gas demand in *Green and Gold* compared to *Slow Decline*.

6.2 Electricity generation

6.2.1 Current context

Electricity generation demand and supply

Most of Australia’s electricity is currently generated using fossil fuels, with coal and gas responsible for 63% and 20% of generation, respectively, in 2016 (Figure 6.9). However, the proportion of electricity generated by coal has decreased from 2005 to 2016 and there have been steady increases in the proportion of electricity generated from gas and renewables over the same period.

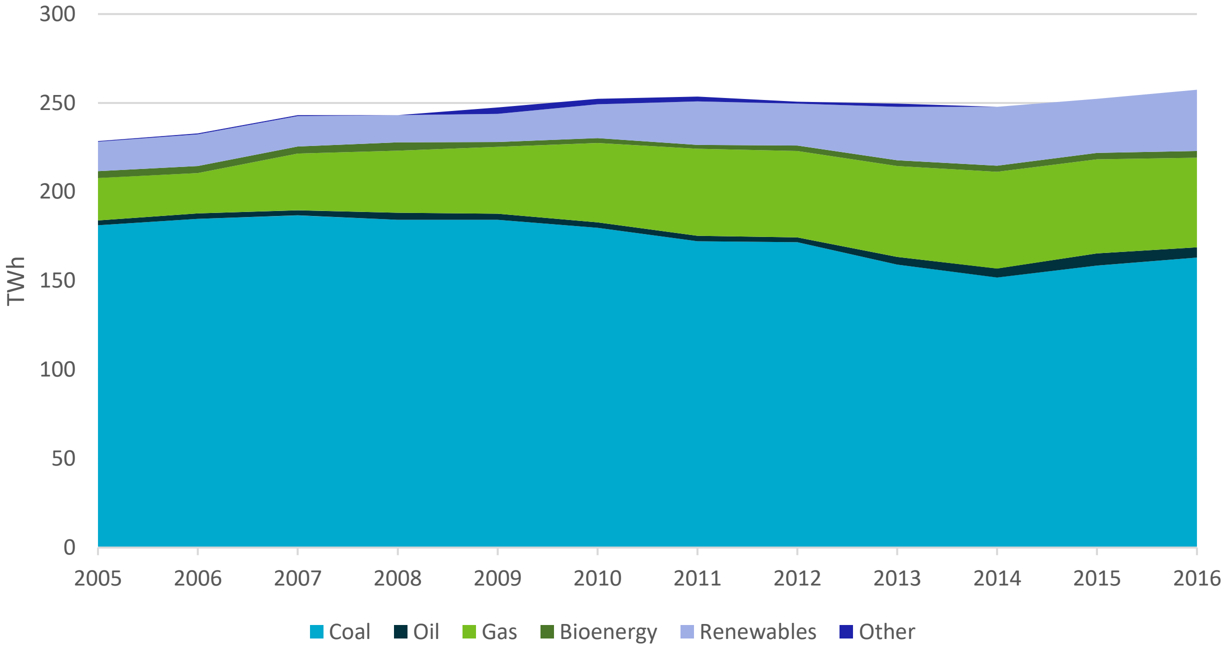

Figure 6.9 Fuel mix in electricity generation, 2005–2016

Costs

As shown in Figure 6.10 (ABS, 2018a; 2018b), retail electricity prices have increased over the past decade, with household electricity prices rising by around 76% percent in real terms from 2008 to 2018. This is far above CPI and wages increases (23% and 32%, respectively) during the same timeframe.

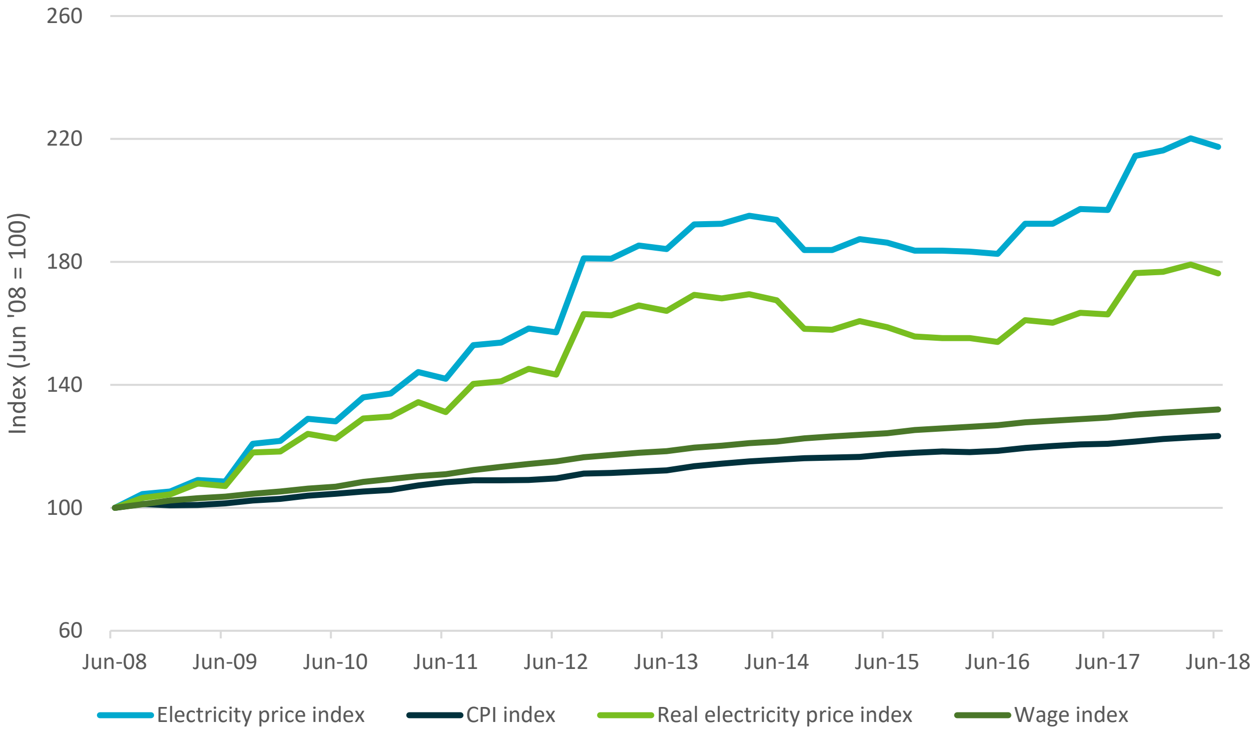

Figure 6.10 Electricity price, CPI and wages, 2008–2018 (Index, June 2008 = 100)

A recent inquiry into Australia's electricity sector (ACCC, 2018) found that while electricity prices charged by retailers rose in the past decade, price increases in residential power bills were slightly moderated by a 13% decrease in average electricity use over the period. This decrease was driven mostly by uptake of solar photovoltaics (PV) (the proportion of solar customers in the National Energy Market (NEM) increased from 0.2% to over 12%), as well as other factors such as energy efficiency and demand response improvements. Of the price increase in residential bills, a large proportion was attributed to recent high wholesale prices, driven by a combination of:

- shifting mix of generators supplying electricity and setting wholesale prices
- rising costs of generation from gas and coal
- current electricity market structure and participant behaviour.

These price increases have contributed to Australia's electricity prices sitting amongst the highest globally (ACCC, 2018). During this period of rising electricity prices, the cost of alternative generation sources such as renewables has decreased substantially, and are currently at or approaching energy cost parity with traditional fossil fuel power sources such as coal and gas. In particular, a recent report from IRENA (2017) showed sharp reductions in the levelised cost of electricity (LCOE) of solar PV and concentrating solar power since 2010, while the costs of onshore and offshore wind continue to improve relative to fossil fuels. Increasing market penetration of generation from variable renewable energy (VRE) such as solar PV will require additional costs to balance demand and supply in the system, which will impact on the relative costs of retail electricity and self-generation.

6.2.2 Future outlook

Traditionally, the demand for electricity has increased over time as a result of population and economic growth. Recently, energy efficiency improvements and installations of behind the meter solar PV has led to slower growth in electricity demand and, in some instances, a reduction or 'de-coupling' of electricity demand with population and economic growth. Future trends that will affect electricity demand include electrification, where electricity is substituted for direct fuels, driven by efforts to reduce greenhouse gases, and technological improvement and structural changes to the economy such as the relative competitiveness of energy intensive industries in Australia.

Electrification in transport, industry and buildings (discussed in following sections) is largely driven by technological advances in electric vehicles, electric heating and a variety of industrial applications. When coupled with renewable energy, this fuel switching presents an effective emissions reduction option. Therefore, domestic and international climate change policy settings are likely to influence the costs and investment certainty of these technologies, which will influence the extent of future electrification and its influence on the electricity demand.

The supply of electricity generation in the future is determined by a number of factors, particularly efforts to reduce greenhouse gas (GHG) emissions and technological trends in generation technologies. There has been a major shift towards investment in renewable energy globally – renewable energy investment in 2018 is already greater than coal and gas combined – with many developing countries among the leading markets for new renewable energy generation (UNEP and BNEF, 2018). This transition is a cost-driven disruption that is well underway and can be expected to continue globally, even without increasing efforts for emissions reductions (CleanEarth Energy, 2018; Henze and Thomas, 2018). Policies for environmental outcomes such as reduced GHG emissions and the certainty of these policies from an investment perspective will play a large role in the extent of renewables in the energy generation mix.

Costs

As discussed previously, the overall costs of electricity generation from VRE sources have declined considerably in recent years. While the costs of balancing the system under high variable renewable penetration will eventually need to be met, under the current low market share renewables are close to cost competitiveness with fossil fuels such as coal and gas facing relatively higher prices, especially if a price on carbon is established (IEA, 2016). The costs of wind energy are already competitive with fossil fuels in many countries, whereas solar costs are expected to continue falling, and will be the lowest cost generation technology in many countries by 2030 (Hayward and Graham, 2017; Lazard, 2017). This transition is also aided by the digitalisation of distribution and transmission networks and reductions in the cost of large-scale and decentralised energy storage, which can reduce the costs of integrating VRE into the grid (CSIRO and Energy Networks Australia, 2017).

Australia has an abundance of renewable energy resources, leaving the country well placed to capitalise on future technology developments, and generate electricity at low cost compared to international peers. Australia has on average the world's highest solar irradiation through central, north and western Australia, some of the best wind resources in the world on the coastal regions of western and southern Australia, and significant geothermal, wave and tidal resources that remain largely untapped (Geoscience Australia and DoEE, 2018). This renewable resource endowment is reflected in Figure 6.11, which shows that Australia, along with a number of other global regions, has more than enough potential for renewable technologies to meet projected energy demand in 2050 (Hayward and Graham, 2017).

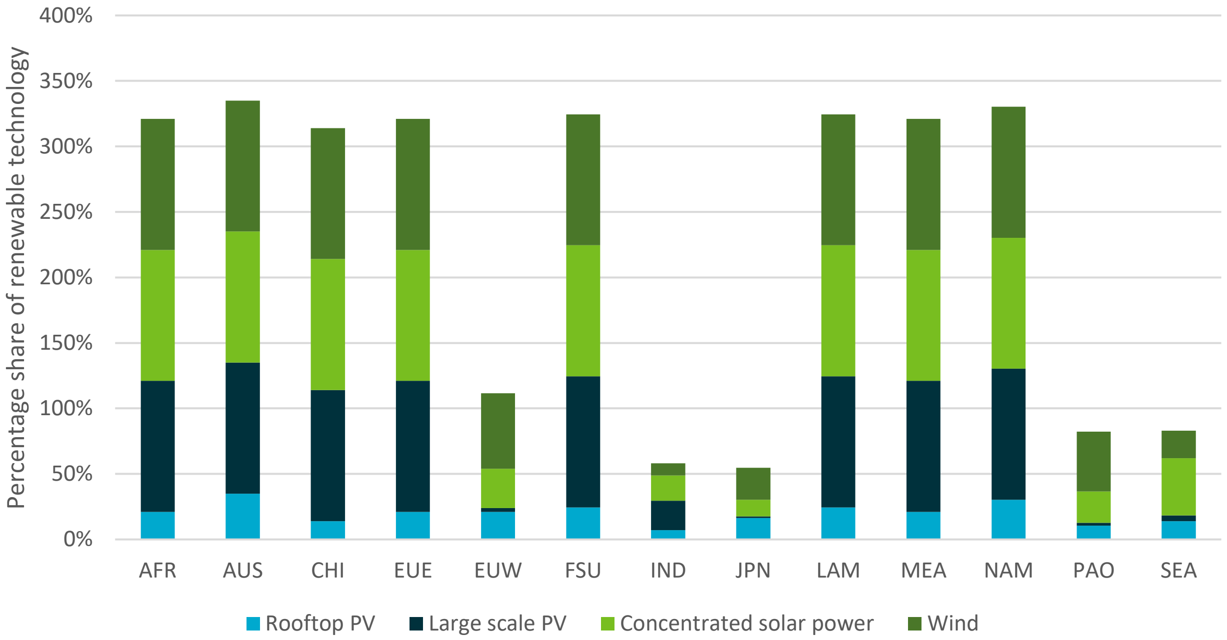

Figure 6.11 Upper limit on percentage of demand met by various renewable technologies in 2050, by region

The availability of resources and relative costs of technologies that draw on them will play a major role in determining the types of generation that will be used for future electricity generation. In the recent AEMO report into improving power system security (AEMO, 2018b), several potential renewable energy zones (REZs) in the NEM[6] were identified through a mapping process based on the following factors:

- resource quality and diversity[7], reducing correlation between different types of renewable generation potential
- location of existing renewable generators
- demand matching, through aligning generation diversity with consumer demand profiles, dependent on technology, location and/or time of day
- relative costs of adapting existing, or building new transmission networks to connect new areas
- ambition of local government to develop jobs and growth in areas, which may improve chances of establishing REZs
- system strength under normal conditions and following disturbances
- network losses through transmission lines and transformers.

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[6] The NEM excludes WA and the NT.

[7] Generation diversity is valuable in producing a more consistent generation output, requiring less energy storage.

Despite the potential advantages and availability of renewable energy resources, AEMO (2017) identified policy uncertainty, social licence, asset stranding risk, and competing state and national priorities as major barriers to the establishment of REZs.

Electricity reliability

Australia's electricity market is currently undergoing a significant transition away from large centralised generation sources such as coal and gas, towards an increasing share of VRE generation, in particular from wind and solar PV (Finkel et al., 2017). As the penetration of VRE grows in next-generation electricity deployment, so too does the issue of maintaining reliability through system and market integration, particularly in responding to disturbances. Maintaining electricity reliability through this transition will require technologies that provide flexibility in matching supply and demand, such as energy storage (e.g. batteries and pumped hydro) and demand response (enabled by smart grid technologies), as well as other approaches such as building excess VRE generation capacity and geographic and technology diversity (Campey et al., 2017).

In addition to maintaining reliability, it will be critical to ensure system security via additional enabling technologies such as synthetic inertia from batteries, wind farms and synchronous condensers. These technologies are expected to be low cost compared with total system spend (Campey et al., 2017). Some existing generation can run in synchronous condenser mode (e.g. some hydro units), which the recent Integrated System Plan (AEMO, 2018b) identified as necessary in SA to supply both system strength and inertia to the region, in conjunction with network upgrades.

If this transition is managed appropriately, renewables have the potential to improve energy security in a number of ways (IEA, 2016), such as through:

- diversification of the energy mix and sources of supply
- potential to localise energy production, reducing import costs
- less complex supply chains and may be fuel free (wind and solar), reducing long-term price volatility.

Electricity supply is also affected by extreme weather events, which have caused major disruptions in recent years due to heat, wind and fire (Climate Council, 2017). Further disruptions can be expected in the future due to the impact of climate change on the frequency and severity of extreme weather events.

6.2.3 Modelling electricity generation

Generation mix

In each of the scenarios modelled, a large-scale transition to electricity generation from renewable energy resources is achieved due to the favourable costs of these technologies. This is demonstrated in Figure 6.12 to Figure 6.14, which show the share of renewable generation across each of the modelled scenarios following a broadly similar trajectory away from fossil fuels such as coal and gas. While outcomes across the scenarios are similar in terms of generation mix, *Green and Gold* sees renewables penetration reach above 90% in 2038, considerably earlier than *Thriving Australia* and *Slow Decline* (which reach 90% in 2051), driven by a higher carbon price assumption. To reach the level of renewable electricity generation suggested by the Australian National Outlook (ANO) 2019 scenarios, the barriers to REZs identified earlier would need to be addressed.

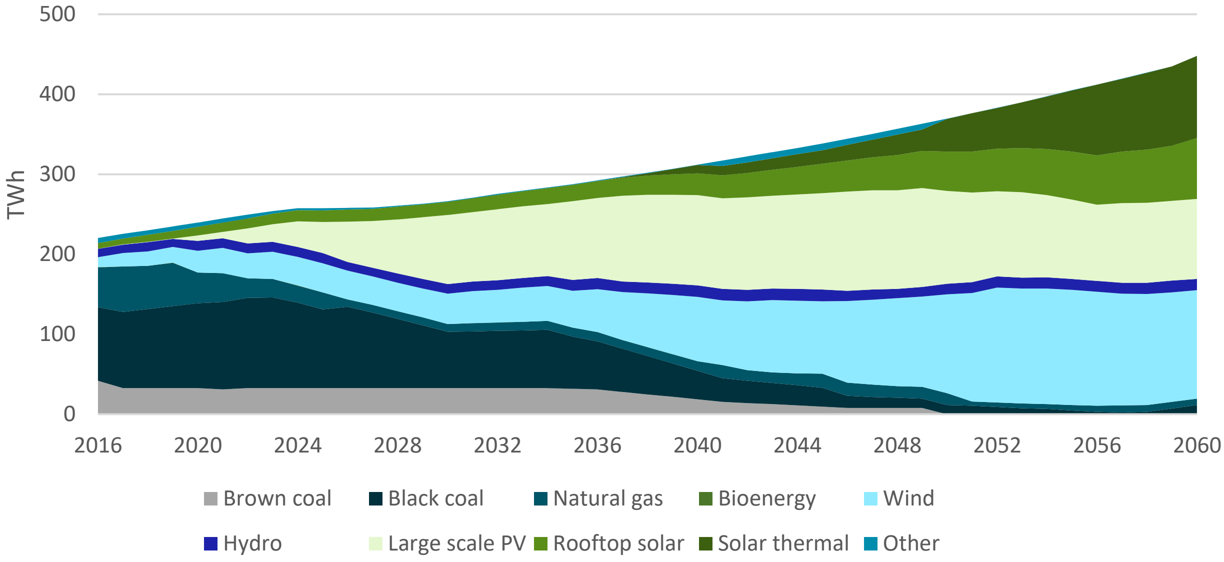

Figure 6.12 Electricity generation fuel mix, 2016–2060, *Slow Decline* scenario

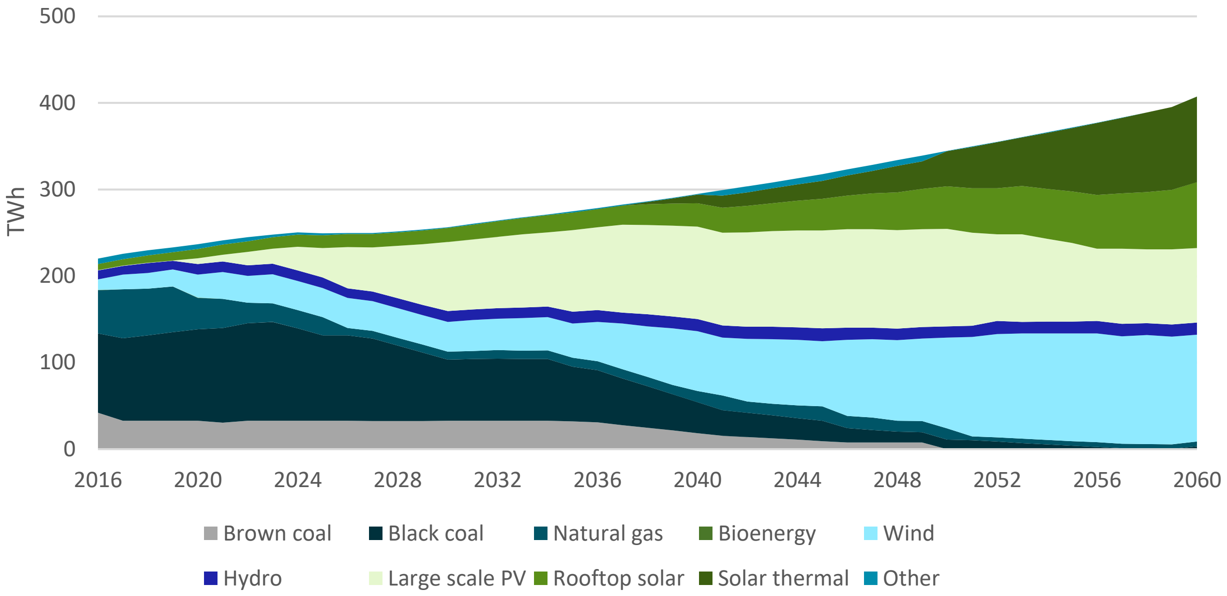

Figure 6.13 Electricity generation fuel mix, 2016–2060, *Thriving Australia* scenario

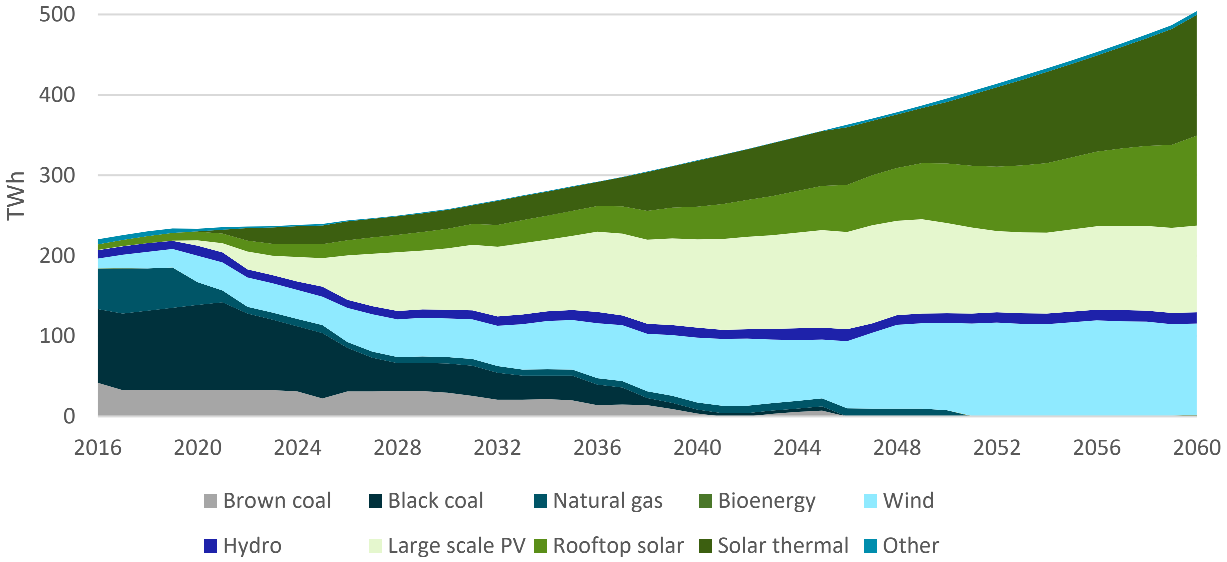

Figure 6.14 Electricity generation fuel mix, 2016–2060, *Green and Gold* scenario

Future electricity costs

While the transition of electricity generation mix is broadly similar across the core scenarios, the modelling results for ANO 2019 indicated there are potential cost implications associated with policy uncertainty at the domestic scale, which can make electricity unnecessarily costly, and reduce Australia's ability to capitalise on renewable resources. When applying higher risk premiums on investment in new electricity generation to reflect policy risk, the costs of electricity relative to other scenarios resulted in significantly higher energy system costs, particularly between 2030 and 2050, as shown in Figure 6.15. These results suggest that uncertainty around climate policy, rather than climate policy itself will be the driver of potentially higher electricity costs in the future. Further detail on the electricity cost implications of different scenarios at the household level is covered towards the end of Section 6.6.

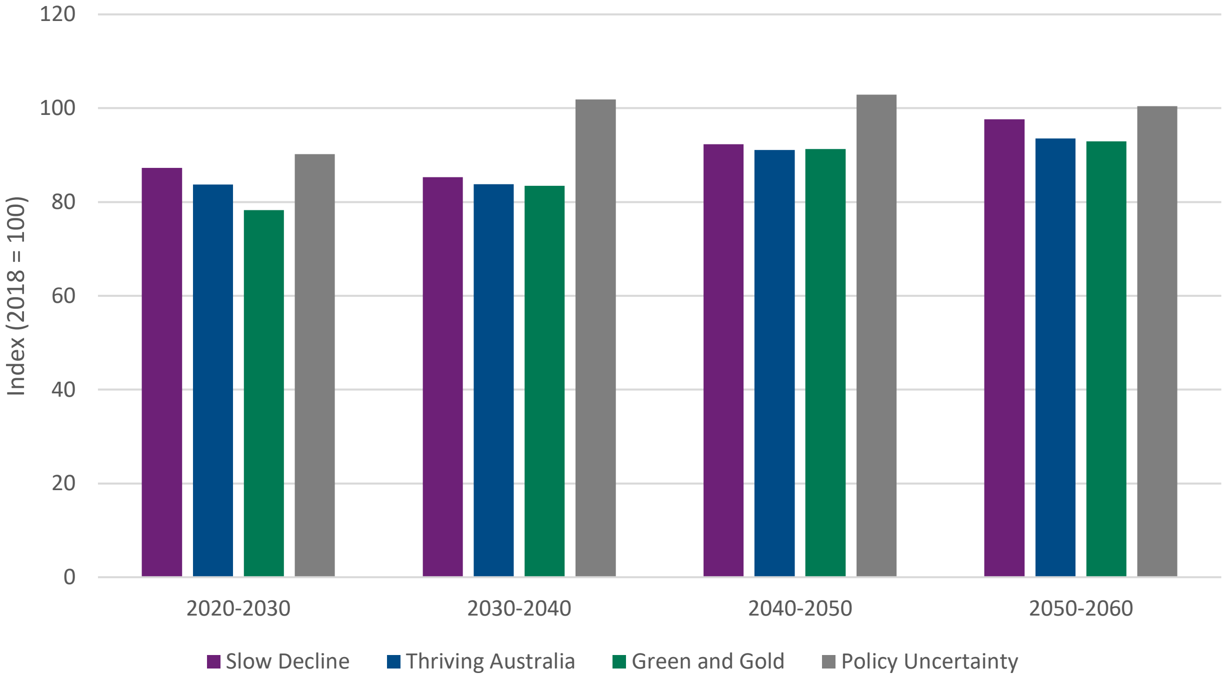

Figure 6.15 Retail electricity delivery system costs, decadal averages

The schematic in Figure 6.16 provides a basic rationale for this result. It shows that the only situation in which a significantly different generation mix would arise is with bipartisan certainty that there would be no future policy (at a state, national or international level) that would place a cost on GHG emissions from electricity generation. The prospect of no future costs on emissions is not consistent with Australia's position within a global context, and the recent momentum for action on climate change generated through the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties and the 2015 Paris Agreement. The possibility of Australia reaching bipartisan agreement to eschew its emissions abatement responsibilities was not considered in the modelling. This rationale establishes the shift to renewable generation of electricity as inevitable, with lack of policy certainty only making the transition unnecessarily costly, as emissions-intensive generators face greater investment risks than low-emissions generators (Jacobs, 2017).

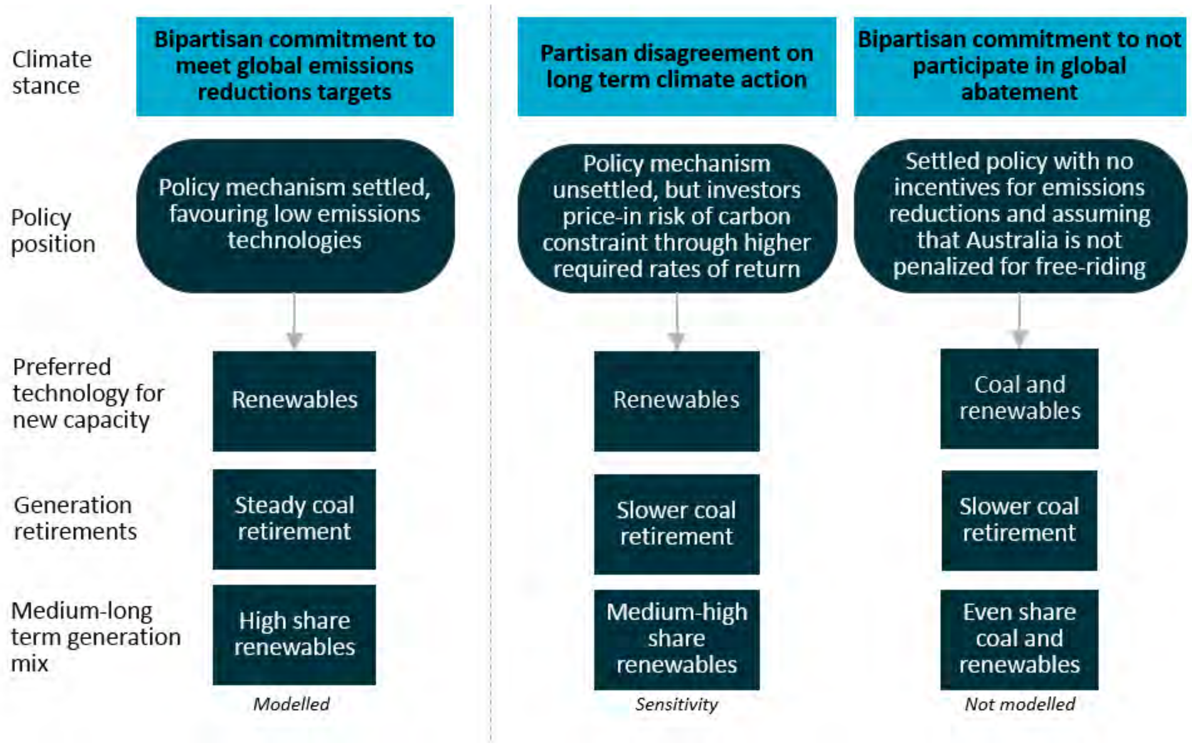

Figure 6.16 Impact of policy settings on electricity generation mix

Future electricity reliability

Figure 6.17 shows the cost implications of the storage and grid support requirements discussed earlier, which were treated as an additional cost of energy supply on top of the costs of variable renewable generation in the modelling. These results show that variable renewables are generally the least cost generation option compared with coal under alternative policy arrangements, even accounting for storage and other grid support mechanisms that are required as variable renewables approach 80% by 2050 (the range is 73% to 81% across scenarios). Even in the absence of a carbon price, renewables are the preferred option after accounting for the increased risk premium for high-emissions electricity generation due to policy uncertainty. This results in similar quantities of renewable generation as in the *Slow Decline* scenario for most of the projection period. Future electricity reliability will also be affected by the increased frequency and severity of extreme weather events due to climate change.

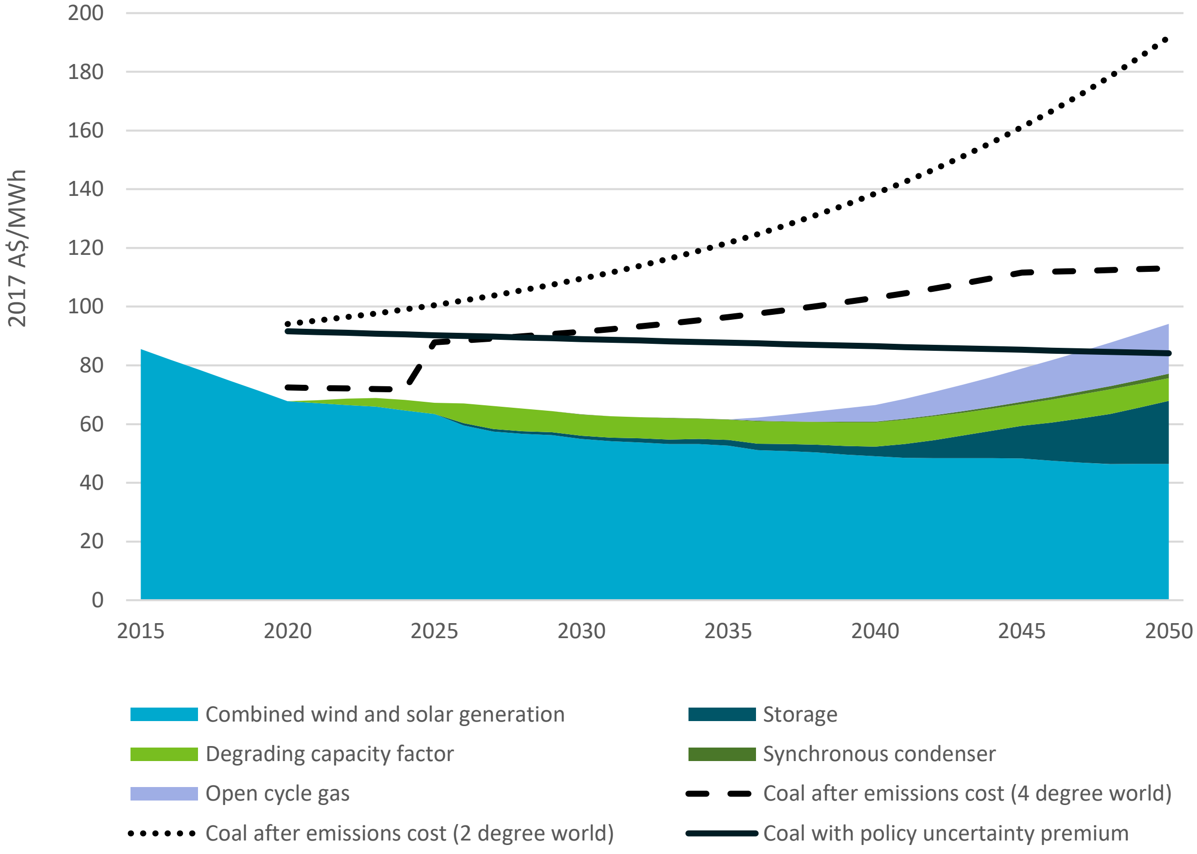

Figure 6.17 Component breakdown of variable renewable electricity generation costs

International competitiveness

When compared to international electricity prices modelled under the same global policy conditions, the rise in electricity prices is shown to be lower in Australia than in other countries in the long run to 2060. Australia's comparative international advantage in electricity generation costs is shown in Figure 6.18, which displays changes in the weighted average LCOE over time, calculated using the GALLM-E model.

This calculation is used as a proxy for the electricity price, and includes the capital charges of existing and new build plant, operating and maintenance costs, fuel costs, carbon pricing and costs of CO_2 capture and storage (CCS) if applicable. Capital charges are amortised over 20 years, beginning when the plant is first constructed in the model. The capital charges for plants that exist at the start of the model are based on an estimate of the lifetime of the plant, given when it was first constructed.

These findings highlight that while Australia's LCOE increases more than its international peers in initial years (reflecting its lower initial cost base), by 2060 Australia's overall LCOE has increased a modest 60% relative to 2016. This magnitude of change in 2060 is roughly on par with Europe, and much lower than that observed in the rest of the world. These findings reflect the potential for Australia to leverage the renewable energy resources discussed previously.

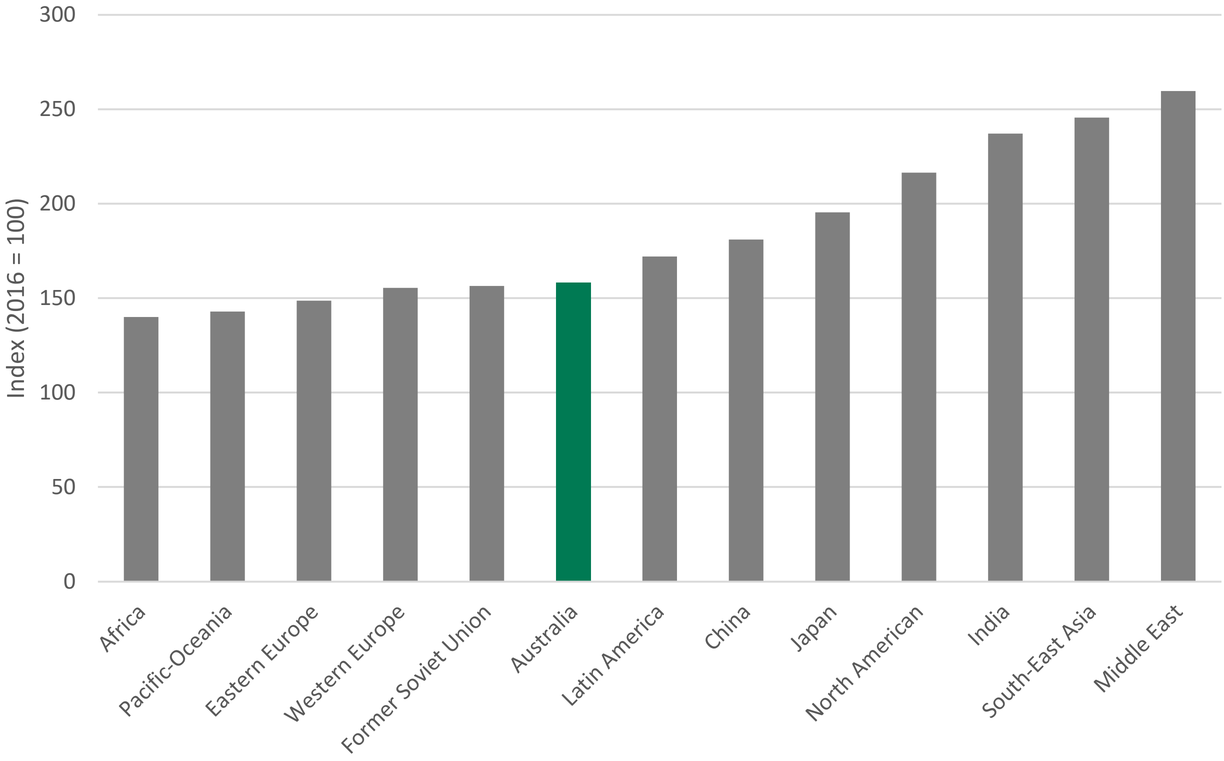

Figure 6.18 Global comparison of levelised cost of electricity in 2060, cooperative global context

6.3 Transport

6.3.1 Current context

Domestic transport is one of the largest contributors to overall energy use in Australia, totalling 1431 PJ[8] in 2016 (Figure 6.19), representing an increase of around 15% between 2007 and 2016 (DoEE, 2017). Most domestic transport energy use in Australia comes from road and air travel, contributing 73% and 19%, respectively, with energy use in both of these transport modes increasing steadily since 2007. Oil accounted for nearly all fuel use in transport in 2016, particularly diesel and petrol (DoEE, 2017). New technologies such as electric vehicles currently make up a very small but growing proportion of transport use in Australia.

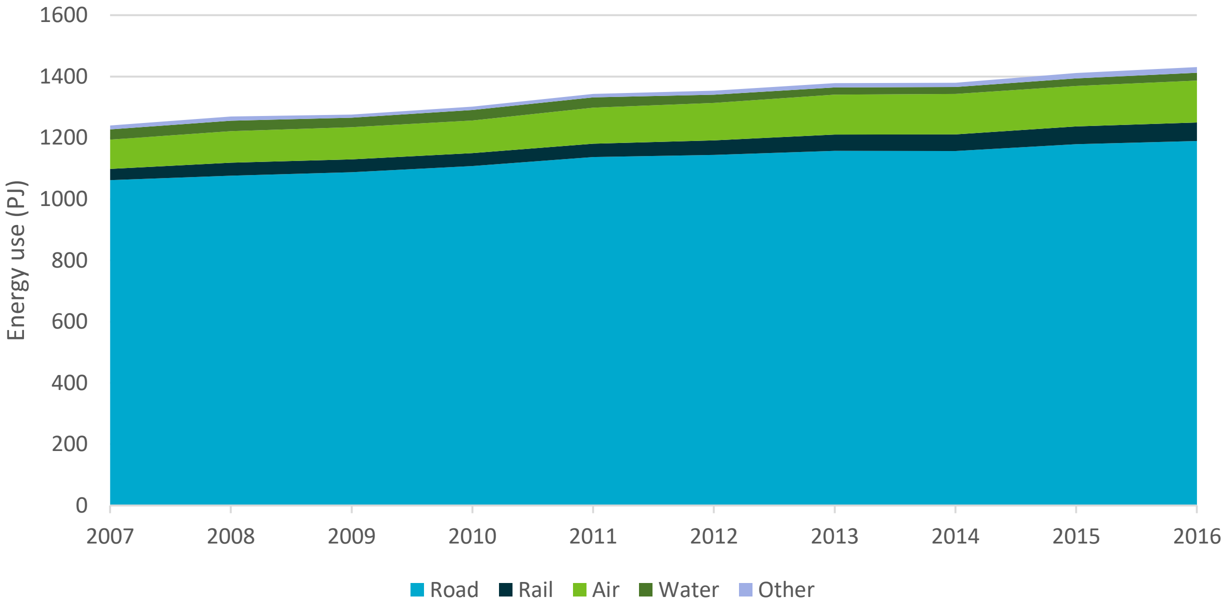

Figure 6.19 Transport energy use by mode, 2007–2016

6.3.2 Future outlook

A growing population and economy will require more transport services for the movement of people and freight. The movement of people, particularly at a city level, will be driven to a large extent by urban design as discussed in Chapter 5. Despite growing needs for transportation, the efficiency or productivity of energy use in providing these transport services can be improved through a number of mechanisms such as shifting from one mode of transport to another, changes to fuel used to drive transport services as well as improvements to overall vehicle efficiency (including efficiency of the vehicle itself, driver behaviour, and road congestion).

Examples of improvements available to reduce energy used in delivering transport services include:

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[8] This amount excludes energy use in international air and international bunkers, so differs slightly from the transport energy share discussed in Section 0.

- improving fuel efficiency of vehicles through light weighting, engine improvements and improved aerodynamics
- switching to alternative fuel vehicles such as electric vehicles and hydrogen fuel vehicles, particularly if coupled with low-cost renewable energy
- information technologies that can improve the flow of traffic and productivity of freight vehicle movements
- behaviour change, through improved utilisation and mix of vehicles, along with shifting to other transport modes that reduce the need for the use of private vehicles
- supporting investment in alternative transport modes such as rail and other public transport
- new business models and technologies, reducing the need for transport.

Key to the future of transport and associated energy use will be the extent to which these different trends and disruptions work together to impact the efficiency of the overall system, which could potentially combine to connect and form shared services (Slowik and Kamakaté, 2017).

Alternative fuel vehicles

Although there is a very small proportion of total road transport vehicles, there are many indications that alternative fuel vehicles will play an important role in Australia’s road transport in the coming decades. Given current and projected costs of batteries (IEA, 2018b), there is no reason why electric vehicles should not eventually reach cost parity (on an upfront basis) with internal combustion vehicles. Currently, electric vehicles (EVs) only lack the economies of scale that come with large-scale manufacturing, which will take several years to achieve with the support of various subsidies and other policies worldwide. Additionally, there is broad consensus that electric vehicles will reach cost parity globally around mid-2020.

The costs of traditional fuels such as petroleum and diesel are modelled to increase under each scenario (EIA, 2017; IEA, 2017). This is driven partly by the assumed costs of carbon, improving the relative cost competitiveness and uptake of alternative fuels such as hydrogen or electricity. Annual fuel costs for electric or hydrogen vehicles are a fraction of the cost of conventional vehicles due to higher end use energy efficiency of electric vehicles. The combination of equality in upfront costs and lower fuel costs means that a cost-driven switch to EVs is expected, particularly from 2025 (hydrogen fuel cell vehicles will be later due to slower manufacturing scale up).

The rate of adoption of EVs in Australia has been very low by international standards. Although over 1.1 million were sold globally in 2017, Australian sales were just over 2000 vehicles (ClimateWorks Australia and Electric Vehicle Council, 2018); however, the rate of adoption in Australia has increased in recent years.

The most significant factors affecting mass uptake of EVs in Australia are limited model availability and high upfront costs compared to internal combustion engine vehicles (ICEs), despite the relatively lower lifetime fuel and maintenance costs of EVs (ClimateWorks Australia and Electric Vehicle Council, 2018). Other barriers to adoption of EVs in Australia include the lack of a supportive policy and regulatory environment (including the absence of vehicle emissions standards), and consumer information gaps and attitudes, such as recharging concerns and ‘range anxiety’ (ClimateWorks Australia and Electric Vehicle Council, 2017).

The rate at which EVs are adopted will depend on a number of factors, with policies playing a significant role, particularly until the purchase prices of EVs are comparable to ICEs. Policy measures to increase uptake of EVs might include vehicle emissions standards, government subsidy of purchase price, reform on stamp duty and registration, or incentives such as priority parking and driving lanes. Any large-scale shift to alternative fuel vehicles such as EVs will also require significant amount of supporting infrastructure, such as private charging in the workplace or household, and public investment in charging stations and electricity networks. In the absence of this infrastructure or domestic market demand, there is a relatively low incentive for manufacturers to sell EVs in Australia or assist in establishing the required supporting infrastructure. Ongoing uncertainty regarding policy and levels of investment in EVs and supporting infrastructure is likely to impact the future rate of EV uptake in Australia.

Another technology change likely to affect the rate of transport disruption includes the potential impact of autonomous vehicles (AVs). While there are currently no commercially available AVs that could be driven on public roads, future uptake and technological advances can be expected to have a range of impacts for vehicle users, transport demand and energy efficiency. These technologies may have a positive or negative effect on energy consumption, as estimated magnitudes vary significantly throughout the literature (Wadud et al., 2016).

Several synergies can potentially be captured by combining developments in electric, autonomous and shared vehicle markets. Examples of this include (Anair, 2017):

- electrification of AVs
- EV battery operation and recharging management through automation
- autonomous management and recharging of shared vehicles between trips
- trip sharing helping to reduce ’rebound’ effects that might arise due to AVs
- widespread trip sharing and use of public transport to reduce vehicle numbers and road congestion
- potential cost savings through shared services to partially offset higher upfront costs of automated EVs.

Although AVs represent a major disruption to the transport sector, due to considerable uncertainty regarding the range of potential outcomes, this was not modelled as part of ANO 2019.

6.3.3 Modelling transport energy and emissions

All transport

Energy use in domestic transport decreases across all scenarios by 2040, and remains relatively flat thereafter to 2060. This energy transition is broadly similar in *Slow Decline* and *Thriving Australia*, which decline by 18% and 16%, respectively, in 2060 relative to 2016, while *Green and Gold* decreases by 37%.

Along with declining overall energy use, the mix of fuels used in domestic transport also undergoes a significant transition. Oil use decreases substantially across each scenario, particularly in *Green and Gold*, where it is 70% lower in 2060 than in 2015, comprising 44% of total energy use, compared to 94% in 2015. As shown in Figure 6.20, the use of biofuels, electricity and hydrogen continues to grow strongly throughout the modelled period, particularly post-2040, with these three fuels combining to supply 53% of energy use in transport in 2060 under *Green and Gold*.

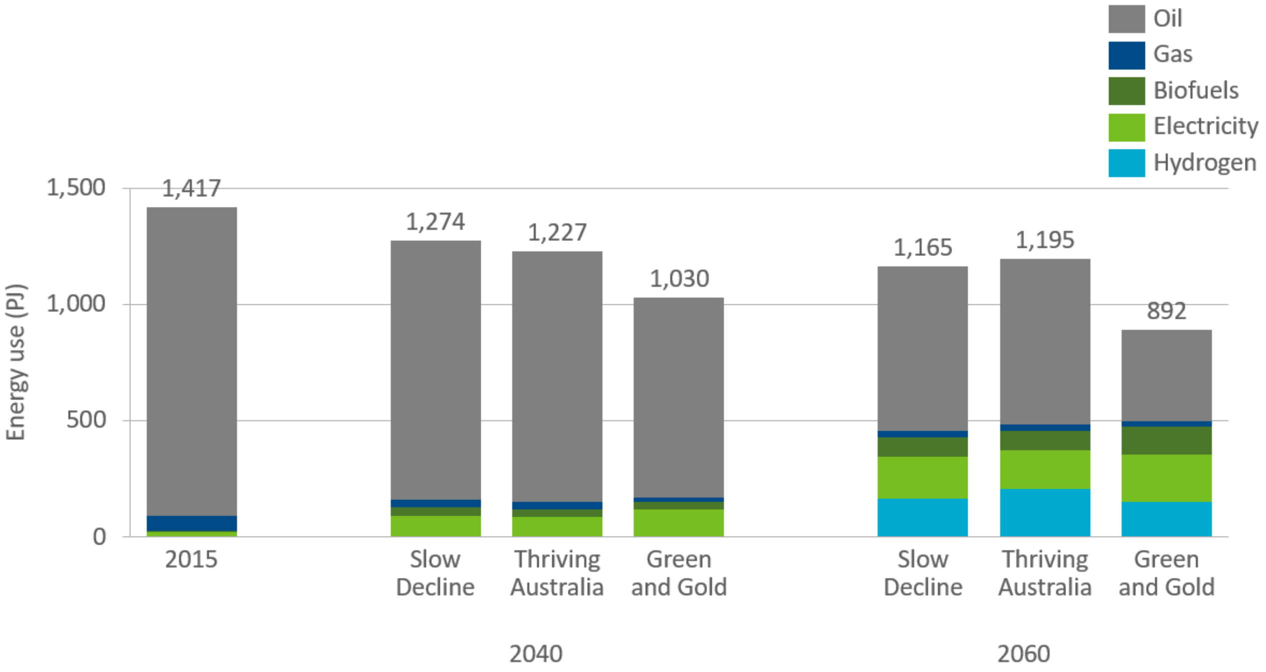

Figure 6.20 Domestic transport energy use by fuel type, by scenario

As shown in Figure 6.21, most of the decrease in energy use is due to reductions in passenger and light commercial vehicles, which together decrease by between 55% and 74% depending on the scenario. Decreases in road energy use are somewhat offset by increases in energy use in aviation, which doubles in *Slow Decline* and *Thriving Australia*, and increases by nearly 90% in *Green and Gold*. As a proportion of domestic transport, energy use in aviation grows to a 28% share in 2060 under *Green and Gold*, compared to just 9% in 2015.

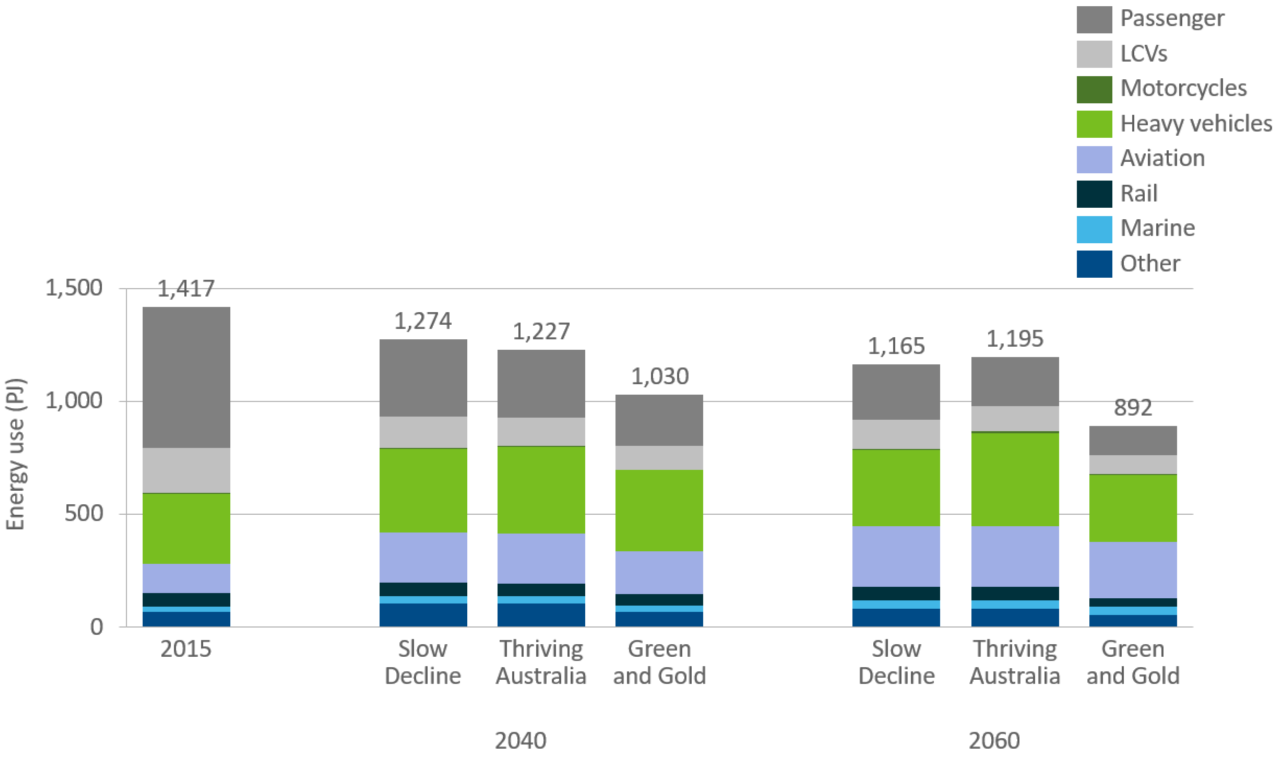

Figure 6.21 Domestic transport energy use by mode, by scenario

LCV = light commerical vehicle

Road transport

Energy use in road transport decreases significantly by 2060 across all scenarios, particularly in *Green and Gold*, where total energy use is 49% lower than 2015. The major factor driving the reduction in final energy use in road transport is the increase in the use of EVs, presented in Figure 6.22. EVs use significantly less energy per kilometre driven due to the efficiency in converting fuel into kinetic energy through the motor system. The modelled reduction in energy use is strongest in the period to 2040 where electricity is beginning to displace some oil use, continuing thereafter with an evolving fuel mix.

From the 2030s and onwards, EVs are the lowest cost road vehicle in all scenarios with cost parity achieved earlier in *Green and Gold* as fuel costs are higher relative to electricity in this scenario. Scenario settings in *Green and Gold* are also assumed to support a higher rate of EV adoption, which is assumed to come through improved infrastructure; for example, such as greater access to both public charging and charging in places of work and residences. These factors are likely to reduce concerns about refuelling, particularly for people living in apartments and for those that take more frequent longer trips.

By 2060, electricity as a proportion of energy use in road transport has increased to around 20% in *Slow Decline* and *Thriving Australia*, while hydrogen has increased to 23% and 27%, respectively. In *Green and Gold*, oil accounts for less than half of road transport energy use in 2060, with electricity (30%) and hydrogen (26%) continuing to grow, reflecting the shifting mix fuel used in road transport.

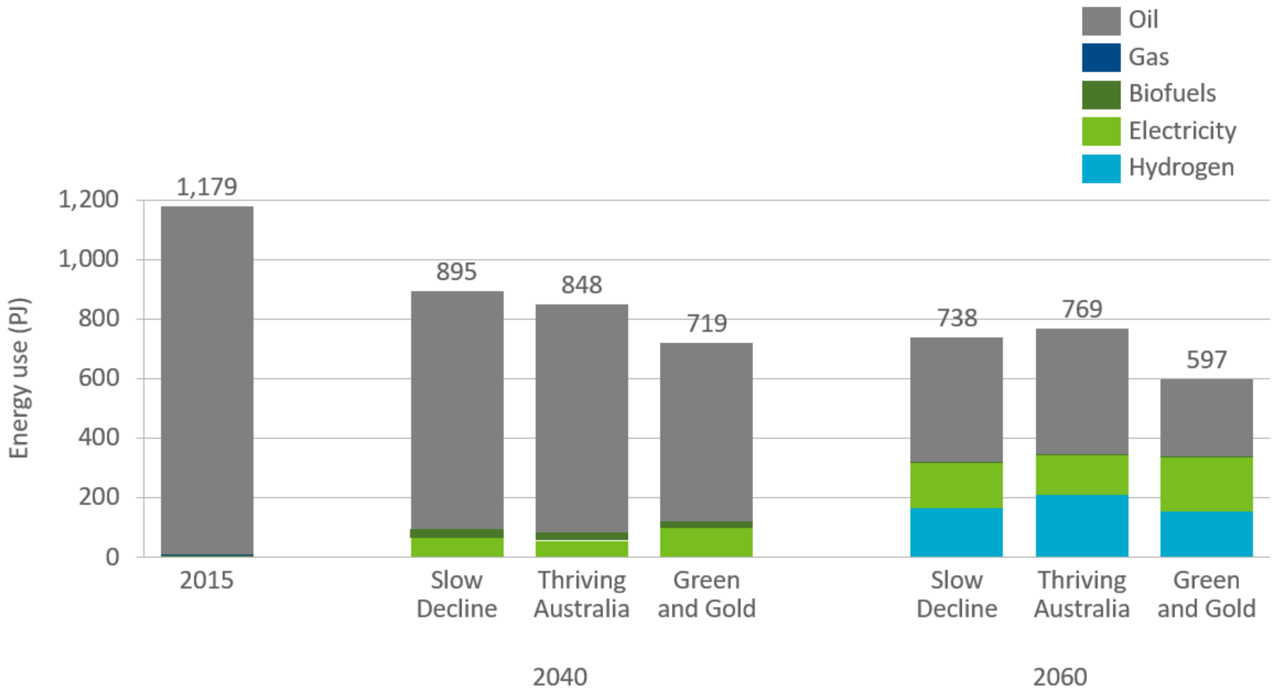

Figure 6.22 Domestic road transport energy use by fuel type, by scenario

Figure 6.23 shows the changing road vehicle mix over time between scenarios, where alternative fuel vehicles such as EVs and hybrids make up the majority of vehicles on the road by 2040. This transition is fastest in *Green and Gold*, due to the favourable cost of these technologies under scenario conditions. Due to the earlier and more aggressive uptake of alternative fuel vehicles in this scenario, ICE vehicles comprise just 13% of vehicles by 2060, far below that of the *Slow Decline* and *Thriving Australia* scenarios.

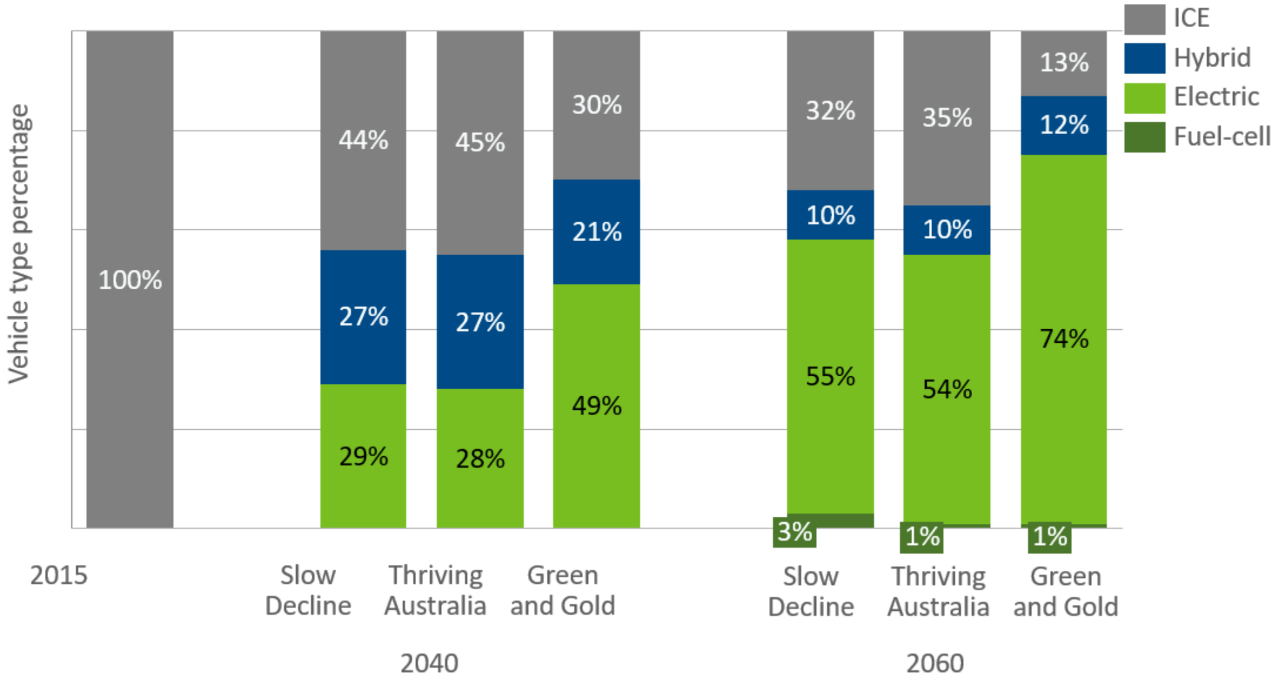

Figure 6.23 Vehicle stock by type

ICE = internal combustion engine

Transport emissions

The changing energy use described previously has considerable implications for the emissions profile of the transport sector, shown in Figure 6.24. In 2015, emissions from passenger and light-commercial vehicles (LCVs) were responsible for 61% of domestic transport emissions. Across the modelled scenarios, energy use decreases in these transport modes, along with a declining emissions intensity due to the transition to lower emissions fuels such as hydrogen and electricity. These trends combine to drive significant emissions reductions in light vehicles. Heavy vehicles, on the other hand, do not experience such decreased energy use and are more difficult to electrify, resulting in much smaller emissions reductions by 2060 in each scenario modelled. Emissions in domestic aviation increase by nearly 80% to 2060 in *Slow Decline* and *Thriving Australia*. However, under *Green and Gold*, aviation emissions increase up to 2040 then decrease by 2060, driven by reductions between 2040 and 2060 due to the higher carbon price and assumptions made regarding biofuel production in this time period.

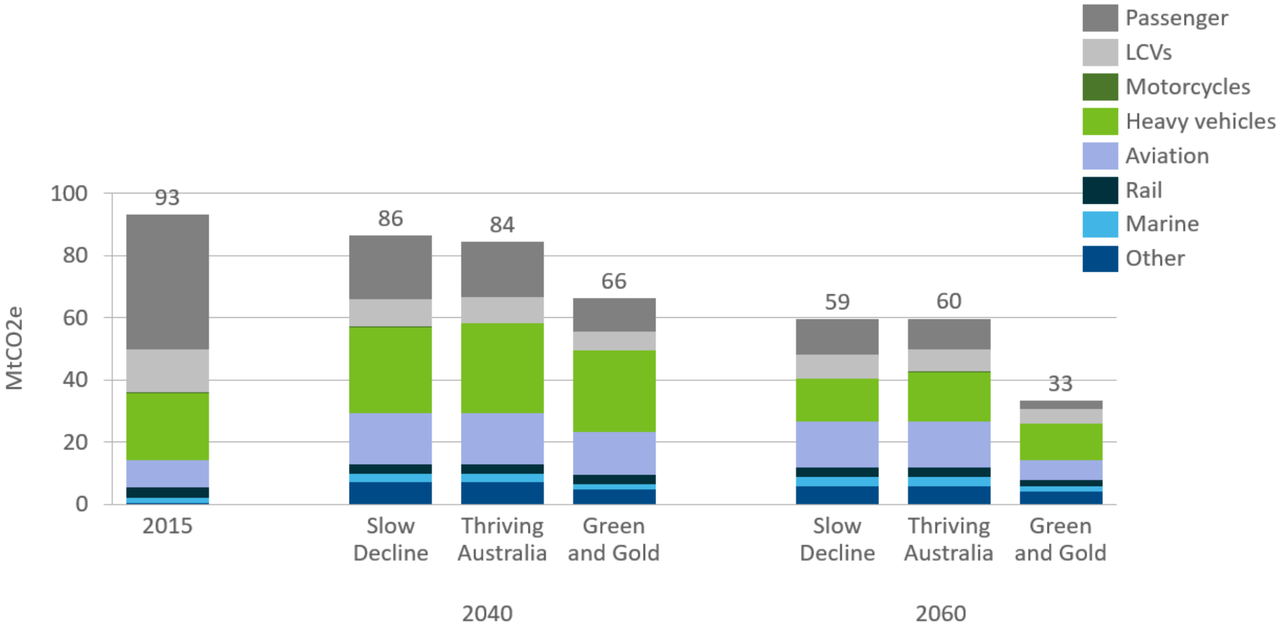

Figure 6.24 Domestic transport emissions by source

LCV = light commerical vehicle

As shown in Figure 6.25, emissions intensity of transport, calculated as emissions per unit of energy use, decreased in each scenario, reflecting the changing profile of the transport sector, particularly post-2040 once alternative fuel vehicles dominate the market. The largest decrease was observed in *Green and Gold*, where emissions intensity decreased 44% by 2060 from 2016 levels. These results demonstrate that the decrease in overall transport emissions is a product of both declining energy use and improvements in transport emissions intensity.

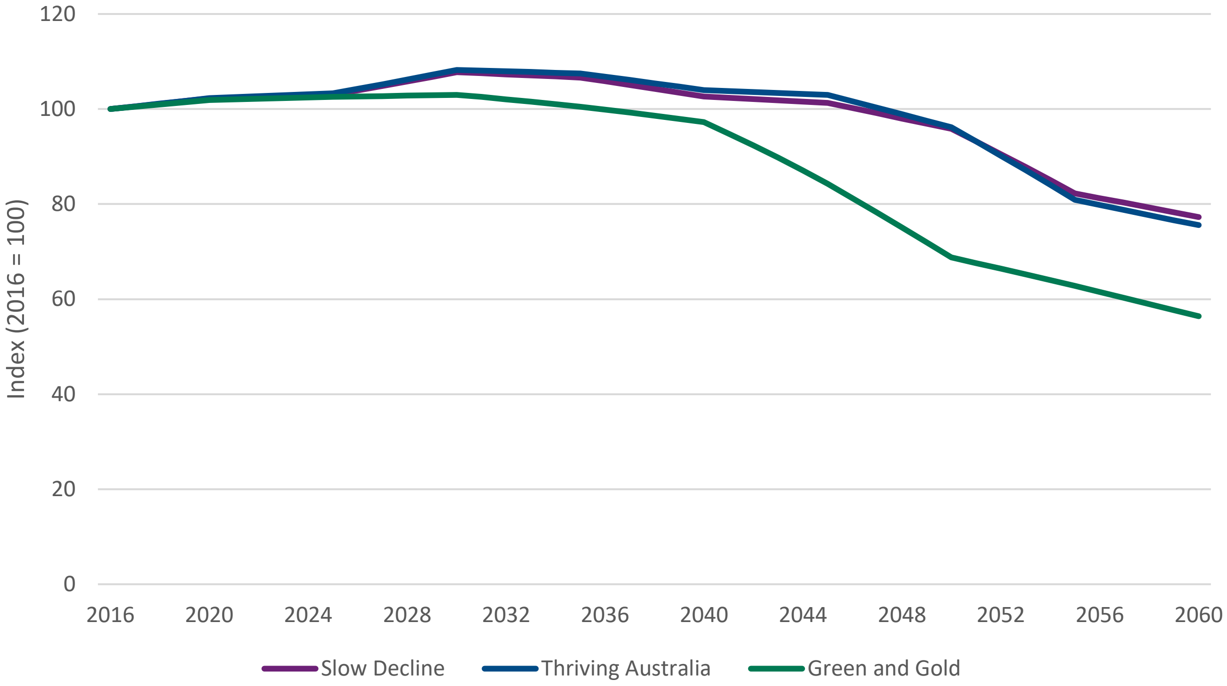

Figure 6.25 Emissions intensity of domestic transport by scenario, 2016–2060, index

As the transport sector is a major contributor to Australia's emissions, changing overall demand for transport and shifting transport modes has significant implications for reducing national emissions. The contribution of emissions reductions in the transport sector relative to other sections of the economy will be covered further in Section 6.5.2.

Alongside the potential reductions in GHG emissions, EVs can have additional co-benefits including local employment opportunities, through sales, infrastructure deployment, and the potential for new manufacturing jobs specialising in batteries; EV components; or charging infrastructure technologies (ClimateWorks Australia and Future Climate Australia, 2016). Uptake of alternative fuel vehicles could be supported through the regulations (particularly in the form of standards), price reform and a range of incentives including:

- support for charging infrastructure
- upfront rebates or tax credits
- discounted tolls and parking fares
- expedited installation of charging units
- stamp duty discounts or tax breaks.

6.4 Industry energy use

6.4.1 Current context

Energy use in industry is predominantly driven by production in key sectors of the economy and the efficiency of energy use in the sector. Over the past decade, manufacturing production remained relatively flat in Australia, while mining activity grew. As such, energy use in these sectors followed similar trends, as shown in Figure 6.26. Over this time, the energy use profile of industry has remained broadly similar, with flat or slightly increasing use across each fuel type (Figure 6.27).

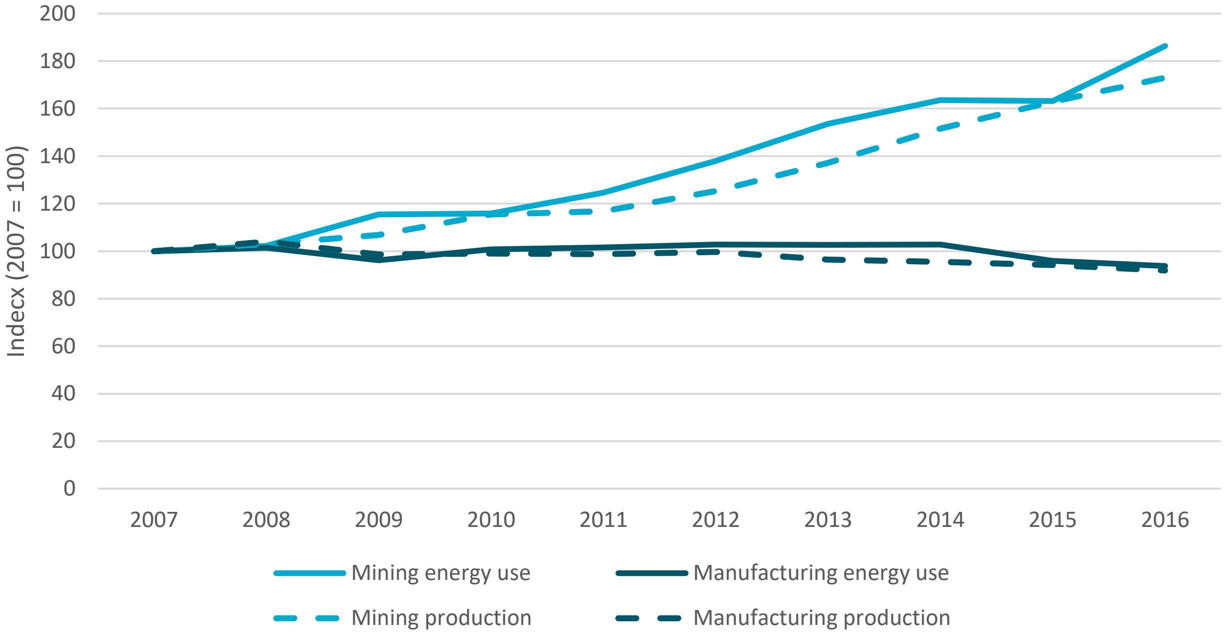

Figure 6.26 Mining and manufacturing energy use, 2007–2016, index

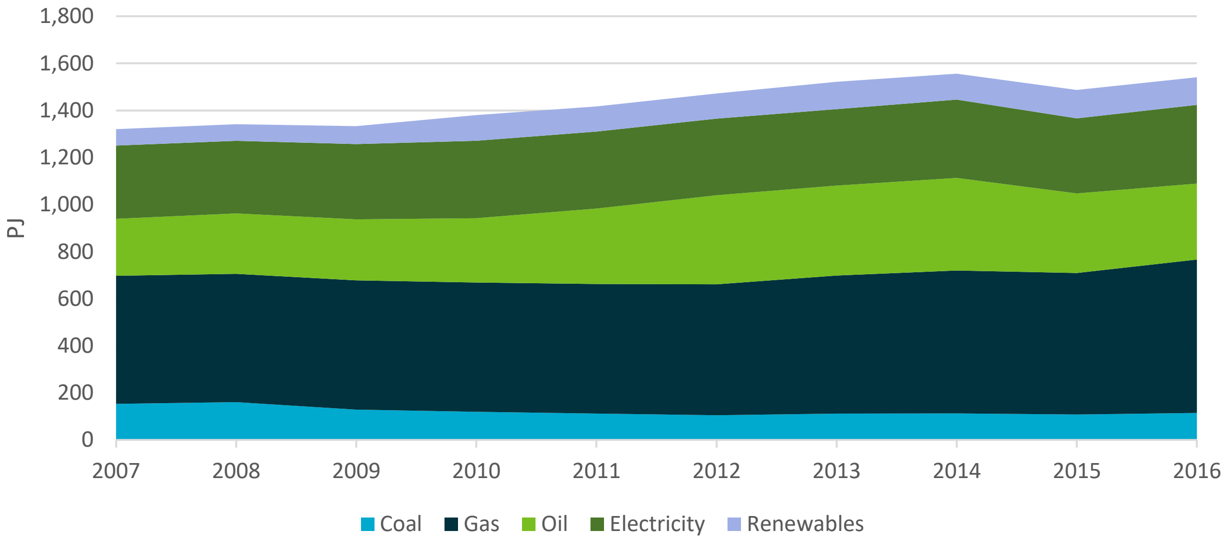

Figure 6.27 Industry final energy use, 2007–2016

6.4.2 Future outlook

Several factors will drive energy use in the industrial sector into the future. These factors can result in changes to energy use through:

- changes to the level of output of industrial sectors, as more energy inputs are needed to produce greater output
- changes to the energy intensity of production, or the amount of energy needed to produce a unit of output.

Several factors will influence the output of individual industrial sectors in the future. Each sector will be driven by a number of supply and demand factors including the global and domestic demand for goods, services and commodities as well the costs of production from labour, energy and materials. International and national policies on emissions will also impact on industrial production through flow-on effects to overall global and national demand for certain energy intensive products, or impact on the relative costs of supply through the impact of a carbon price or the costs of fuels.

Many factors will also influence the energy intensity of production within these industrial sectors. For example, international and national policies on emissions can create incentives to improve energy efficiency and switch fuel types used in industrial production. The recent Intergovernmental Panel on Climate Change (IPCC) (2018) report states that in scenarios limiting global warming to 1.5 °C, industrial emissions reduce by 75%–90% by 2050 relative to 2100, driven by a combination of new and existing technologies, electrification and fuel switching, product substitution, and carbon capture and storage. The cost of energy and the relative costs of substitutable fuels will play a role in driving energy efficiency and fuel switching in industry. Additionally, the cost and difficulty of resource exploration, extraction and processing will impact overall energy intensity. This is expected to increase for fossil fuels such as gas, which may need to pursue unconventional and potentially more costly means of production in the future.

Australia’s relative energy productivity and energy cost competitiveness compared to other economies can be a driver of comparative advantage in industrial production. Therefore, building comparative advantages can lead to greater industrial output in Australia – particularly relevant for energy intensive trade exposed industries seeking markets for lowest cost production.

6.4.3 Modelling industry energy use

The growth in activity by sector is modelled by VURM based on a variety of supply and demand factors mentioned previously, driven by both international and national economic factors. The potential for energy productivity in industry was directly parameterised in the VURM model. These parameters reflect the narrative of the scenario with improvement in line with current trends applied to *Slow Decline.* Improvement in line with a 2 ^{0}C global warming scenario was applied to *Green and Gold.* Energy productivity in *Thriving Australia* was focused on least cost activities, such as energy efficiency, through process improvements and behaviour change rather than higher capital cost activities, such as switching from gas to electricity for process heating and mobile transport in mining. A diverse and often niche range of processes are responsible for energy use across the industrial sector, and there are generally limited publicly available data describing this energy use.

Energy use in mining and manufacturing increased across each of the key scenarios, with the effect of energy productivity assumptions clearly demonstrated in Figure 6.28, with energy use in *Slow Decline* almost twice as high as that in *Green and Gold*.

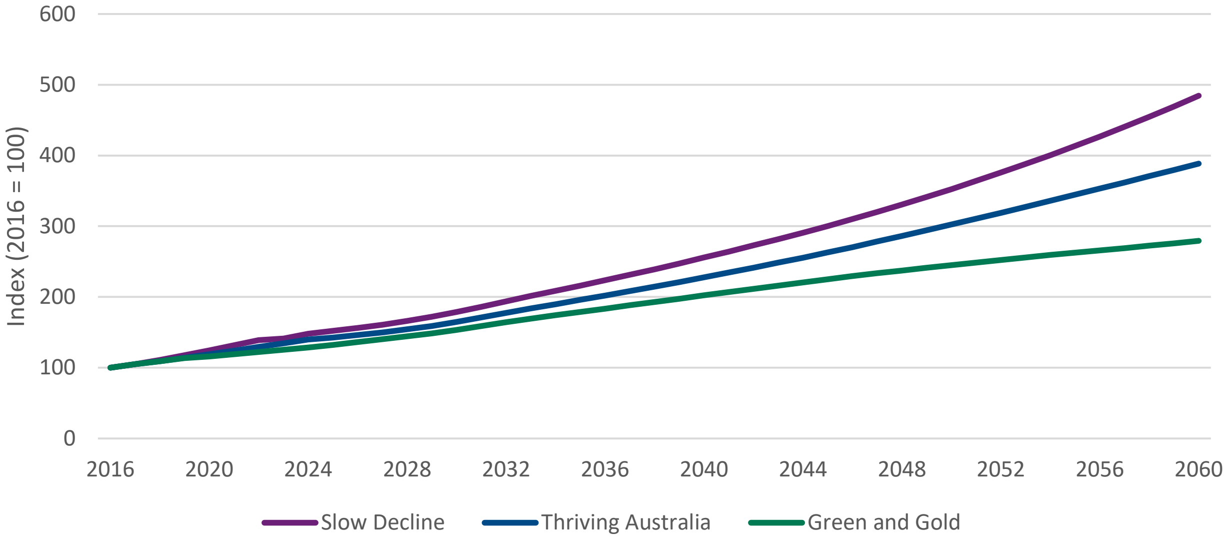

Figure 6.28 Industry energy use by scenario, 2016–2060

Energy intensity modelling assumptions

The assumptions for energy intensity in agriculture and industry are described in Table 6.1.

Table 6.1 Assumed energy intensity improvements in agriculture and industry

Average reduction in energy use per unit output per annum (%)			
Sector	***Slow Decline***	***Thriving Australia***	***Green and Gold***
Agriculture	–0.4%	–1.1%	–1.1%
Mining[9]	0.6%	–0.5%	–0.5%
Energy intensive manufacturing	–0.4%	–1.2%	–1.2%
Other industry	–0.4%	–1.3%	–1.3%

Analysis of historical changes in energy intensity (ClimateWorks Australia, 2013) have shown a long-term trend of energy intensity reducing by 0.4% per year. The long-term trend in energy intensity improvement from this study has been applied across industry, with the exception of mining in the *Slow Decline* scenario. This study also identified an improvement of between 1.1% and 1.3% per annum as a result of a combination of price and policy factors, demonstrating the potential for accelerated improvements in energy intensity across industry. To model this potential in *Thriving Australia* and *Green and Gold* scenarios, rates of improvement at the upper bound of observed historical results have been applied to agriculture, energy intensive manufacturing and other industry, in accordance with results for these sectors.

Energy intensity in mining is the result of two separate factors:

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[9] Energy intensity in mining is assumed to increase by 1% due to reduced ore grades and more remote mining before energy efficiency improvement of 0.4% in *Slow Decline* and 1.5% in *Thriving Australia* and *Green and Gold*. The increase in intensity is based on assessment of energy efficiency from industrial data (ClimateWorks Australia, 2012) and observations of changes in end use intensity (Stanwix, Pham and Ball 2015).

- firstly, an increase in energy intensity of 1% due to reduced ore grades and more remote mining
- secondly, energy efficiency improvement due to improved practices, technologies and behaviours. These energy efficiency improvements are assumed to be 0.4% per annum in *Slow Decline* and 1.5% per annum in *Thriving Australia* and *Green and Gold*.

The increase in mining energy intensity in *Slow Decline* is based on assessment of energy efficiency from industrial data and observations of changes in end-use intensity (Climateworks Australia, 2012). These estimates of potential improvement in energy intensity are also consistent with benchmark levels of energy efficiency improvement rates, provided by the United Nations Industrial Development Organization (2010):

- 1.0% per annum corresponds to business-as-usual
- 1.2% per annum corresponds to Best Practice Technologies (BPT)
- 1.7% per annum corresponds to Best Available Technologies (BAT).

These data focus on developing countries and so may overestimate the potential in developed countries such as Australia.

6.4.4 Electrification

Further energy productivity in industry is achieved by switching from direct fuel use in specific industrial applications to electricity use. As electricity is increasingly delivered by renewable energy in each scenario (see Section 6.2), electrification has the potential to reduce both primary energy use and emissions. Electrification in industry is likely to be driven by three major technology groups (ClimateWorks Australia et al., 2014):

- increase in iron and steel production from electric arc furnace (EAF) technology
- shift to electricity for heating processes
- shift from trucks to conveyors for materials handling in mining.

Iron and steel production

Iron and steel products can be produced through a number of processes, but most commonly with basic oxygen furnace (BOF) or electric arc furnace (EAF). The former uses coking coal to provide heat and a reducing agent, while EAF produces steel from scrap metal using electricity; its use in steel production is expected to grow in the future.

To the extent that Australia can restore energy cost competitiveness, particularly through capturing the renewable energy potential discussed in Section 6.2, it will become an attractive proposition for investment, potentially rejuvenating existing industries such as iron and steel manufacturing, as well as attracting new industries to Australia. Although Australia is currently the largest producer of iron ore (Arrobas et al., 2017), the production of iron and steel is an energy and emissions intensive process. With the introduction of a carbon price or emissions standards, future steel production will need to explore low emissions methods to remain competitive.

As any potential competitive advantage in energy-intensive industries will take time to materialise, it will be important for relevant supply chains and skills to be maintained or established in Australia to capitalise on potential opportunities in the future (BZE, 2015).

Heating

Heating is an essential part of many industrial processes and a major user of direct fuels in the industrial sector. Heating is particularly important for non-ferrous metal manufacturing (alumina and aluminium), chemicals and non-metallic mineral product manufacturing, iron smelting and steel manufacturing, food production, and pulp and paper manufacturing.

Literature suggests that most heating systems will be electrifiable in the future if electricity generation is decarbonised (EPRI, 2009). The effectiveness of technologies to electrify heating processes is largely dependent on the temperature required as well as the specific industrial processes. Campey et al. (2017) classify heating processes into the following categories, each with a range of options for electrification or replacement with renewable heat:

- Furnaces, kilns and electrolytic cells – used for processes with a temperature range over 400 ^{o}C. This includes specific industrial processes such as the Hall–Héroult, Basic-Oxygen Furnace) that can potentially be electrified with electric induction, plasma arc and electrolytic melting
- Ovens – used for processes with a temperature range of approximately 100 ^{o}C to 400 ^{o}C are generally more challenging to electrify or replace with renewable heating within this temperature range. Renewable heating options such as solar thermal can satisfy heating demands as high as 400 °C (IEA-ETSAP and IRENA, 2015). Energy storage is needed for periods of low solar radiation
- Boilers – used for generating steam with a temperature range from 100 ^{o}C. Can be electrified through electric boilers or renewable heat from concentrated solar thermal technologies
- Hot water systems and space heating – mainly residential and non-specialised commercial with temperatures below approximately 100 ^{o}C. Heat pump technologies operate at very high efficiencies to transfer heating from sources to sinks. Prototype heat pumps capable of producing industrial steam have been developed in Japan (Wantanabe et al., 2014). Alternatively, renewable heat such as geothermal can replace the need for direct fuels for hot water and space heating.

Mining

Mining is also an area where electrification could occur at a large scale provided low-carbon electricity can be supplied at reasonable costs. Technologies available for electrification include:

- using conveyors to replace trucks – this is already used in Australian brown coal operations and many underground mines
- trolley-assisted mining trucks, powered with grid electricity when connected to overhead wires (Wolinetz and Bataille, 2012).

Electrification presents benefits for the mining sector, but also challenges. Key considerations for switching to electricity-powered material handling systems include (Wolinetz and Bataille, 2012):

- amount of material to move – electricity is more profitable than diesel when there are large amounts of material to be moved to access the ore; this could lead to a natural shift towards electrification as mines get deeper and ore grades decrease
- productivity improvements – electrification is often associated with improvements in productivity (through automation in particular) and staff health

- reduced energy risk – if renewable electricity can be supplied to the mining site to replace diesel use, then it will reduce the risk linked to fluctuations of fossil fuel prices
- reduced operations flexibility – electricity equipment is often fixed, making changes to mine configuration more costly
- higher upfront cost – electricity equipment often requires setting up more infrastructure upfront, such as conveyors, overhead wires, electricity transmission and distribution.

Further opportunities to electrify mining processes involve in-pit crushing and conveyance of ore and coal, as well as coal drying using microwaves, which improves coal quality (Wolinetz and Bataille, 2012).

6.4.5 Fugitive emissions

Fugitive emissions are emissions from energy supply that arise from non-combustion. Most fugitive emissions in 2016 were from methane emissions from coal mining, and venting and flaring in the oil and gas industry (DoEE, 2016).

Reductions in fugitive emissions are modelled in VURM by applying sensitivities to the assumed carbon price based on the below assessment of potential reductions that would be realised under the high carbon price in *Green and Gold*:

- 77% reduction in fugitive emissions from coal mining through implementation of ventilation air methane (VAM) oxidation technologies in underground gassy mines – a shift to non-gassy mines
- 64% reduction in fugitive emissions intensity of gas extraction through improved flaring practices and carbon capture and storage
- 62% reduction in fugitive emissions intensity of oil extraction through improved flaring practices and carbon capture and storage
- 54% reduction in gas supply through better processes and lower use of distribution networks.

6.4.6 Process emissions

Process emissions are the result of chemical reactions in industrial production. They arise predominantly through cement, iron and steel, non-ferrous metal production and chemical manufacturing. Reductions in fugitive emissions are modelled in VURM by applying sensitivities to the assumed carbon price based on an assessment of abatement opportunities achievable with a high carbon price. Therefore, under a strong carbon price as assumed in *Green and Gold*, a variety of measures are estimated to lead to reduction in the emissions per unit of production as detailed for the sectors:

- 95% reduction in refrigerant gases by replacing hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) with natural refrigerants
- 90% reduction in process emissions from aluminium production through inert anode technology, which can be introduced from 2030
- 75% reduction in process emissions from blast furnace iron and steel emissions through substitution of bio-coke and carbon capture and storage. An overall shift to EAF will further reduce emissions from iron and steel production

- 66% reduction in process emissions from cement through clinker substitution and carbon capture and storage (CCS).
- 65% reduction in process emissions from chemicals manufacturing using catalysts to abate N_2O.

6.5 Energy and mineral commodities

6.5.1 Current context

Australia's mineral and energy resources have been a major source of wealth throughout much of the nation's history. As shown in Table 6.2, Australia has a globally significant natural endowment of reserves, and is a leading producer of many key minerals and metals. These natural resources have historically played a major role in Australia's export economy, in terms of both energy and mineral commodities. Their contribution to the Australian economy is displayed in Figure 6.29, which highlights a significant increase in both resources and energy exports since the turn of the century.

Table 6.2 Australian reserves and production of key minerals and metals

Mineral/metal	Reserves ('000 metric tons)	Reserves (global rank)*	Production ('000 metric tons)	Production (global rank)*
Alumina	–	–	1,650	6
Aluminium	–	–	20,200	2
Bauxite	6,200,000	2	80,000	1
Cobalt	1,100	2	6	6
Copper	88,000	2	960	6
Iron ore	824,000	2	54,000,000	1
Lead	35,000	1	385	2
Lithium	1,500	4	13.4	1
Manganese	91,000	3	2,900	3
Nickel	19,000	1	234	2
Rare earth	3,200	3	10	2
Silver	85	2	1.7	4
Titanium	140,000	2	720	2
Zinc	63,000	1	1,580	2

*Rankings do not include aggregated 'Other countries'.
Source: Adapted from World Bank report (Arrobas, 2017)

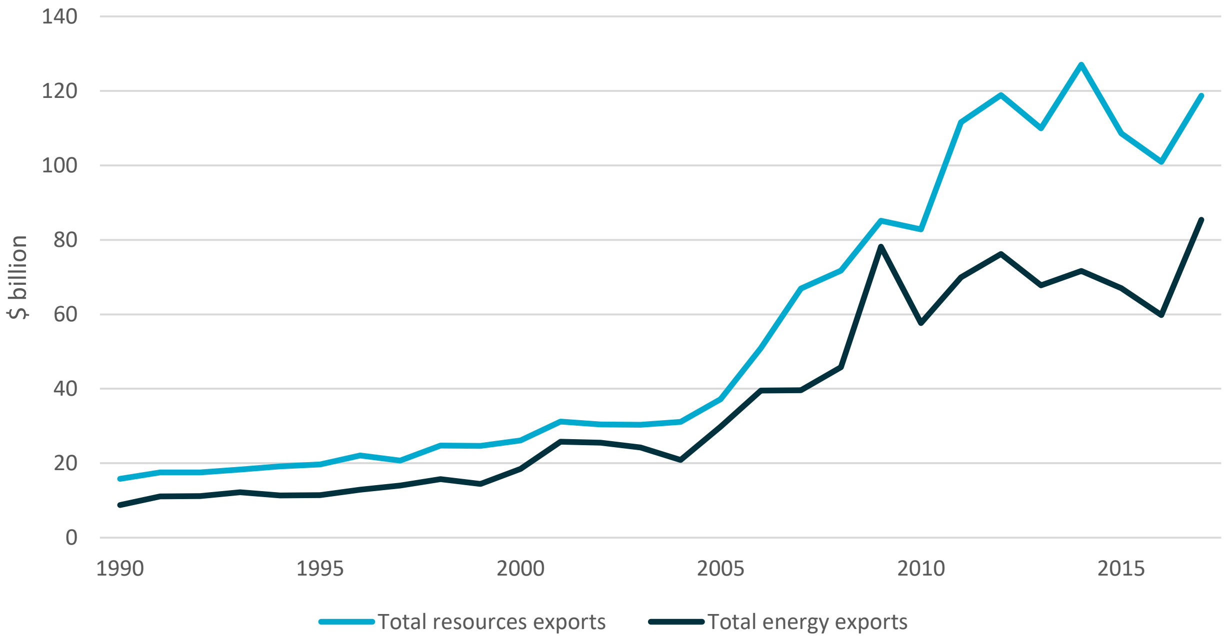

Figure 6.29 Annual resources and energy exports, 1990–2015

6.5.2 Future outlook

The future outlook for Australia's energy and mineral markets will be determined by global demand, offering both risks and opportunities for Australia's international competitiveness. Future global demand for fossil fuels is expected to dampen as the costs of alternative technologies such as renewables become relatively cheaper, especially if a price on carbon is established. In this case, the production of renewable energy commodities such as biofuel, hydrogen and transmitted electricity will be favoured in countries with low-cost renewable energy.

The future is less clear for minerals and metals demand, as different extents and paths towards decarbonisation will require different types and amounts of resources. Due to difficulties calculating transmission network capacity and storage requirements on a global scale, it is difficult to quantify demand for metals and minerals under various future trajectories; demand for metals such as copper and aluminium may benefit significantly from large-scale shift to variable renewable energy or EVs, as might minerals used in energy storage such as lithium. Similarly, the magnitude of these shifts in financial terms is difficult to gauge when considering what benefits or risks might accrue to Australia.

Certain key commodities likely to play a critical role in a high-tech future are available for production in Australia (Skirrow et al., 2013). Significantly, Australia is currently responsible for mining most of the world's lithium, as well as all minerals required to domestically manufacture batteries (Wills et al., 2018). Extensive reserves of hard rock lithium provide a competitive advantage to the Australian lithium industry, as these can be reached with established mining technology in a cost-effective, predictable manner, allowing Australian producers to respond to global demand.

While future disruptions are difficult to predict, this range and quantity of available resources suggests Australia could be well placed from a future energy and minerals commodity perspective, even if the global context shifts towards large-scale decarbonisation in the future.

6.5.3 Modelling energy and mineral commodities

Demand for energy and mineral commodities varies significantly under the different global settings modelled in ANO 2019. As exports comprise such a large proportion of Australian production of energy and mineral commodities, changes in global demand are strongly correlated with fluctuations in Australian production of different commodities.

The projections for global demand of coal and gas are shown in Figure 6.30 and Figure 6.32, respectively, alongside similar scenario analysis by the IEA (2017) and Shell (2018)[10], which are useful to demonstrate a range of possible futures when projecting over such a long time period. As Australian supply of commodities can be expected to respond to global forces, these global demand results were deemed an appropriate benchmark for Australian production of relevant commodities during the modelling for ANO 2019.

Coal

Declining global coal demand to 2060 was projected in both global scenarios modelled in ANO 2019. The 44% decline to 2060 in the GTAP-ANO 4 °C global warming scenario is significantly greater than that suggested by the IEA CPS and NPS scenarios in both 2040 and 2060. On the other hand, results for the GTAP-ANO 2 °C global warming scenario are broadly in line with trends in the IEA SDS and Shell Sky scenarios, decreasing by around 69% by 2060.

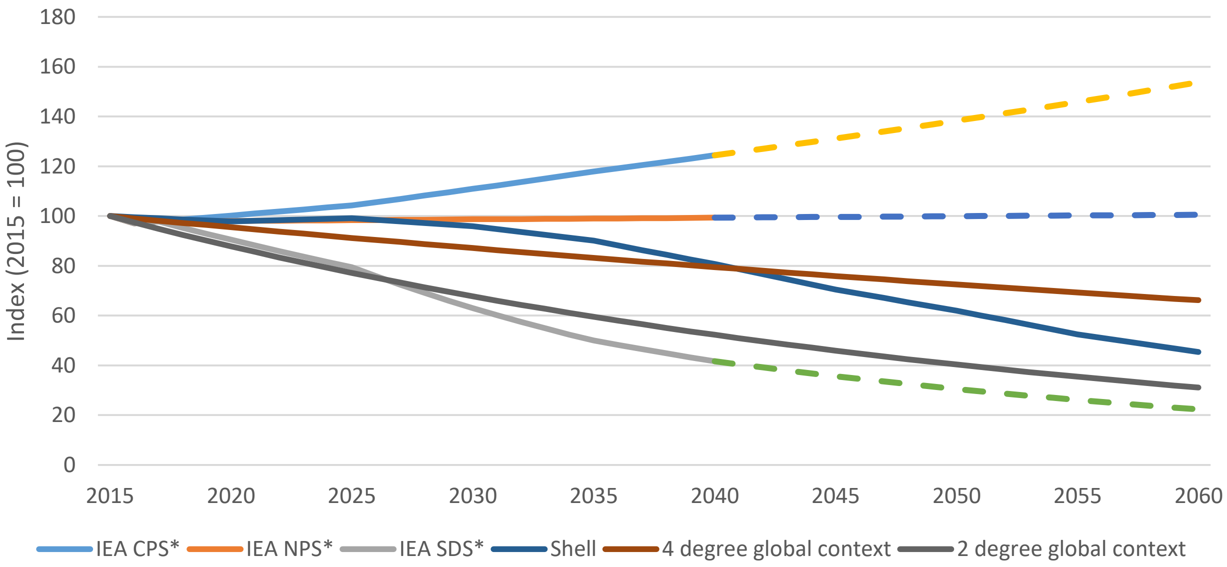

Figure 6.30 Global coal demand projection comparison, 2015–2060, index

* IEA estimates extrapolated from 2040–2060.

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[10] When comparing results between ANO, IEA and Shell, it is also important to note the different timeframes of reports – while Shell's Sky scenario extends to 2100, the scenarios considered by IEA run to 2040. For ease of comparison, IEA results have been projected from 2040 to 2060 based on change rates derived from the report. Therefore, IEA figures for 2060 are intended to be indicative only, and would likely differ based on changing assumptions between 2040 and 2060. The IEA CPS and NPS scenarios are assumed to be the most suitable comparison to the GTAP-ANO 4 °C scenario, while the IEA SDS and Shell Sky scenarios are used to benchmark GTAP-ANO 2 °C scenario.

These global trends are reflected in the national scenarios, which see reductions in coal production to varying degrees across each scenario (Figure 6.31). Coal demand in *Slow Decline* and *Thriving Australia* declines by 26% and 27%, respectively, by 2060, driven by the observed decrease in global coal demand in the 4 ^{o}C scenario. *Green and Gold* experiences a substantial decrease in coal production of 77% by 2060, reflecting the impact of the 2 ^{o}C scenario and a global move away from coal-fired energy generation towards lower emissions energy sources such as renewables.

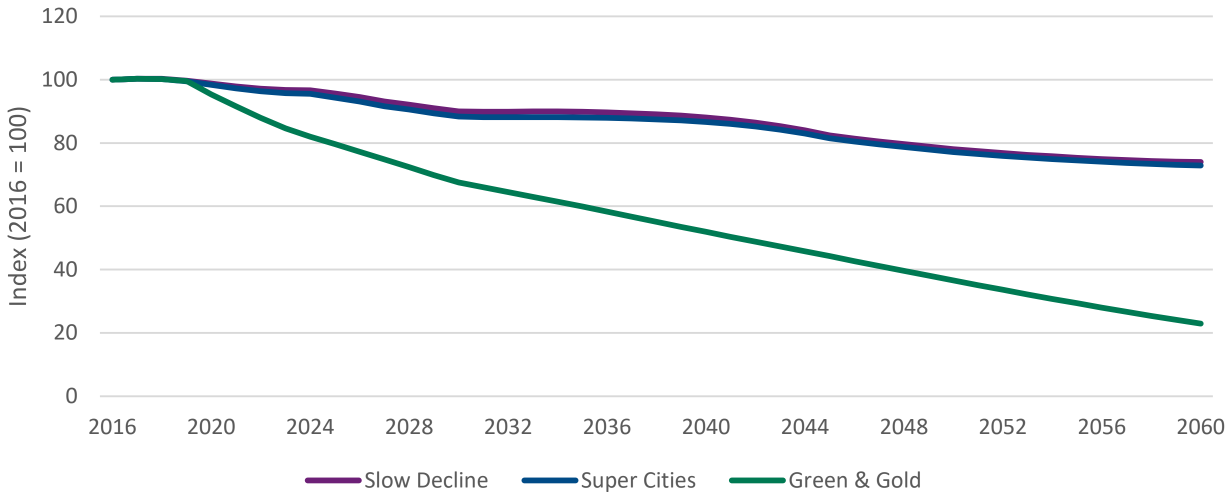

Figure 6.31 Australian coal production projection by scenario, 2016–2060, index

Gas

Global gas supply rises steadily in the GTAP-ANO 4 ^{o}C global warming scenario, increasing to 229% on 2015 levels in 2060, in line with the IEA CPS scenario and slightly above the NPS scenario. In the GTAP-ANO 2 ^{o}C global warming scenario, gas production is flat throughout the period, lower than both the IEA SDS and Shell scenarios at 2040 (which increase by around 20%), before Shell projects a steep decline thereafter to 62% on 2015 levels by 2060.

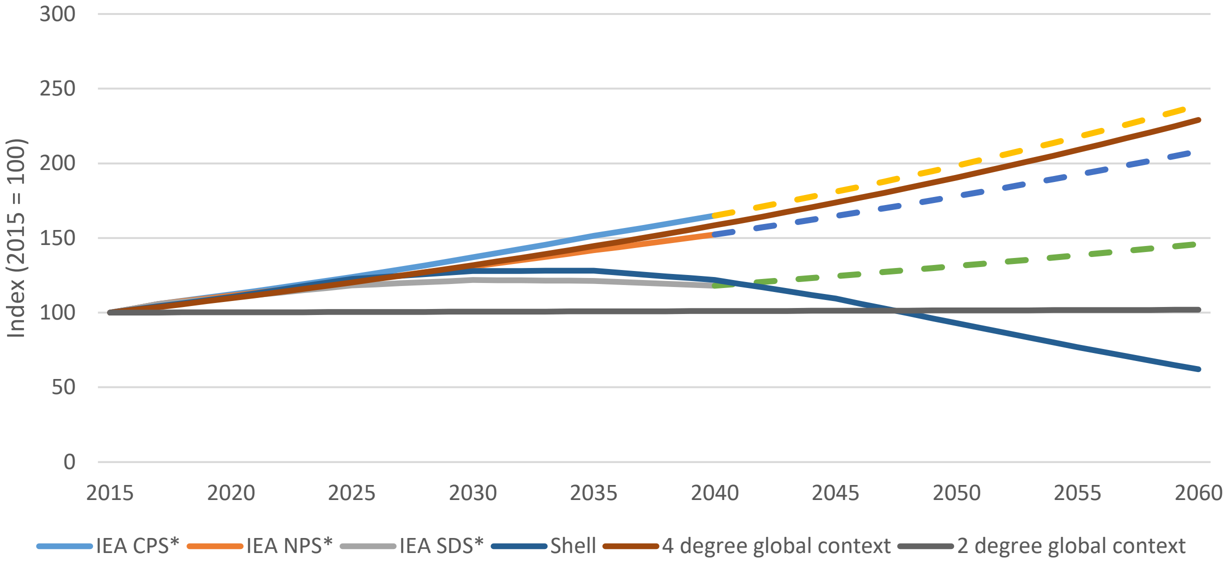

Figure 6.32 Global gas demand projection comparison, 2015–2060, index

*IEA estimates extrapolated from 2040–2060.

Although gas production increases across all scenarios, it is most significant in *Slow Decline*, which more than triples by 2060 compared to 2016, while growth in *Thriving Australia* and *Green and Gold* is relatively lower (Figure 6.33). The trajectory of this growth is relatively linear in the 4 °C scenarios, roughly in line with the global results. *Green and Gold* experiences linear increases to around 2040, before levelling out for the rest of the modelled period – a trend somewhat aligned with Shell's Sky scenario displayed in Figure 6.32, albeit slightly delayed and less pronounced.

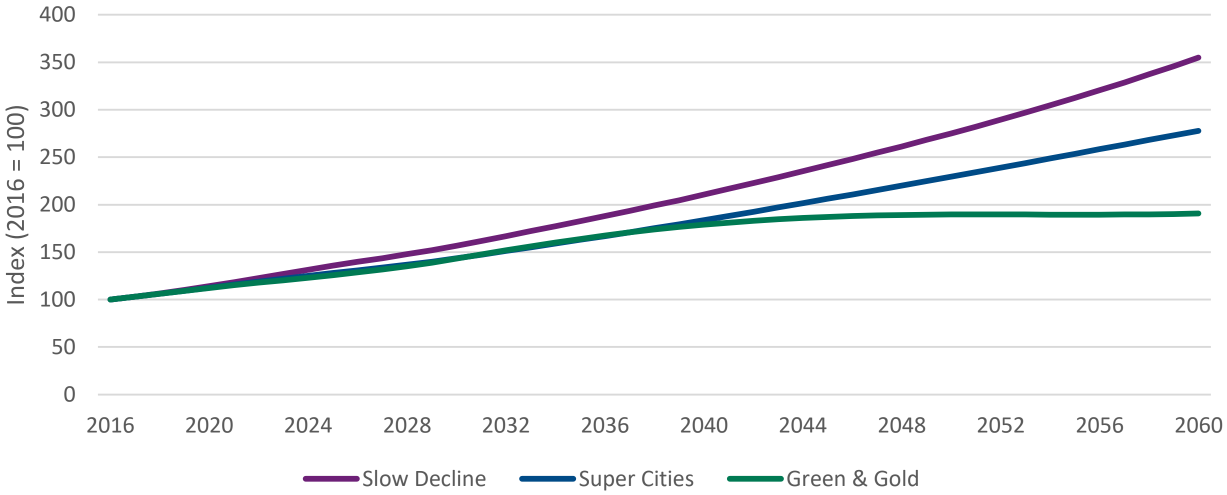

Figure 6.33 Australian gas production projection by scenario, 2016–2060, index

Hydrogen

The production of hydrogen to store and transport low emissions energy may be an effective process to reduce GHG emissions, particularly in the industry and transport sectors (IPCC, 2018). One method of producing hydrogen is through electrolysis which, if generated using renewable energy resources, is a low- or zero-emissions process and can play a role in global efforts to transition to a 2 °C global warming pathway. Hydrogen as a fuel source may be most effective where countries lack the renewable energy resources to produce the required quantities of low-emissions fuels. In this context, Australia could potentially develop an export industry to serve these markets, drawing on the abundant natural resources described previously. The potential for hydrogen as an energy export is considered as a sensitivity to the *Green and Gold* scenario.

As discussed in Section 6.2, as renewables come to dominate the electricity generation mix, Australia is well placed to capture a low-cost advantage that would enable the domestic production of hydrogen for export, particularly into Asian markets. In addition to its natural resource endowment and geographical proximity to key markets, Australia has other enabling qualities well-suited to producing clean hydrogen domestically, such as established industrial capacity and supply chains, pre-existing infrastructure and political stability (ACIL Allen Consulting, 2018; BZE, 2015; Bruce et al., 2018; Campey et al., 2017). It is assumed that in a 2 ^{o}C global warming scenario, hydrogen could be used as a substitute for LNG or coal exports, with the potential to repurpose or redesign existing infrastructure, such as that being used for LNG exports in the Pilbara region of north-western Australia, with the Upper Spencer Gulf region of SA also being identified as a potential hydrogen export hub (Forcey, 2015).

Modelling in GALLM-E projected the cost of producing hydrogen from electrolysis, compared to that of producing LNG under the assumed carbon price of the *Green and Gold* scenario. Due to the uncertainty around key factors such as capital intensity and labour factors, hydrogen production was not modelled as an industry in the modelling, but rather, assumptions were made around the potential for hydrogen to capture some of the projected growth in other energy export commodities such as LNG. As shown in Figure 6.34, hydrogen reaches cost competitiveness with LNG towards 2040, suggesting hydrogen could become a viable substitute from a cost perspective after this point.

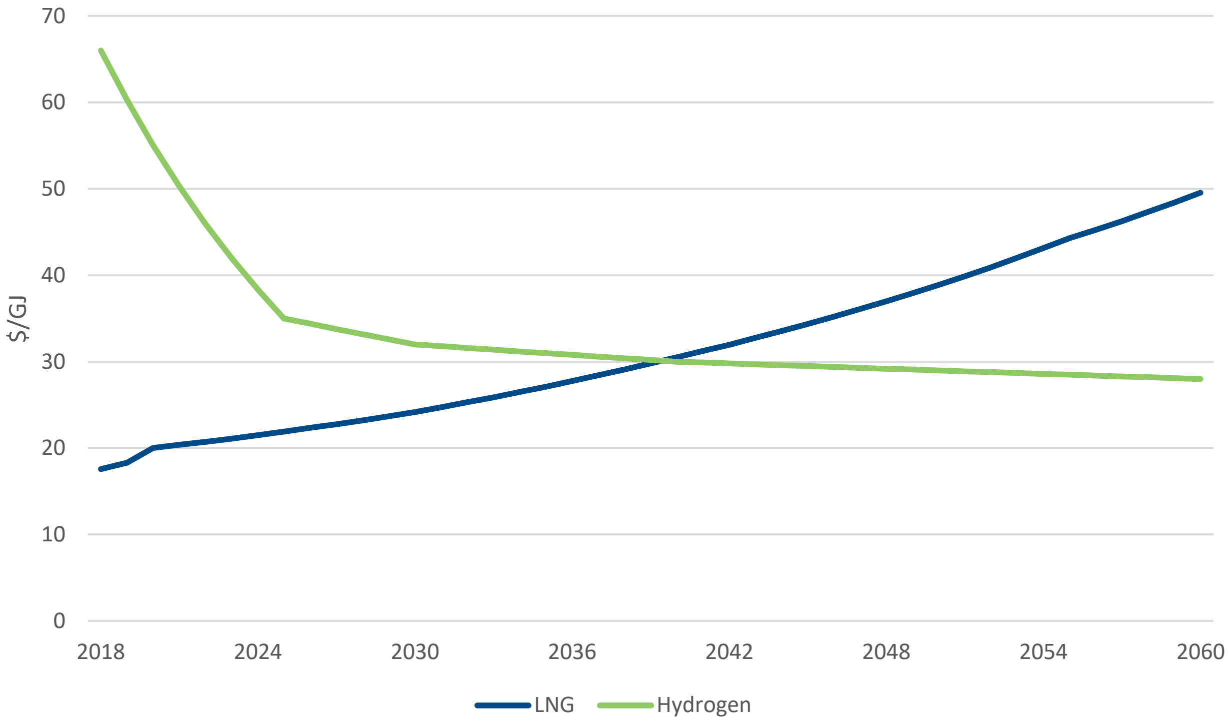

Figure 6.34 Cost comparison of producing liquified nitrogen gas (LNG) and liquid hydrogen, 2015–2060, *Green and Gold* scenario

Methodology for hydrogen modelling

The potential quantity of hydrogen exports from Australia was inferred from previous long-term modelling. The impacts of this potential export volume has been presented as a sensitivity to the *Green and Gold* scenario. Projected quantities of global demand and Australian exports from 2025 to 2040 were taken from the ACIL Allen 'Low' scenario (ACIL Allen Consulting, 2018), which was deemed the most appropriate comparison with *Green and Gold* due to the specific scenario settings, alignment with the IEA SDS scenario, and the fact that the global demand in 2040 is broadly in line with that projected in Shell's Sky scenario. As the ACIL Allen report only assesses hydrogen potential from 2025 to 2040, global demand was indexed to Shell's Sky scenario growth from 2040 to 2060 to match the modelling timeframe for ANO 2019.

Similarly, potential demand for Australian exports of hydrogen was taken from ACIL Allen between 2025 and 2040, after which point Australian exports as a share of global demand was assumed to be constant (at approximately 4%) and calculated using the indexed global demand. This quantity of hydrogen in tonnes was converted to petajoules (PJ) using a low-heating value (LHV) factor, for consistency with the approach undertaken in the ACIL Allen report (ACIL Allen Consulting, 2018). All hydrogen exported from Australia is assumed to be produced via electrolysis, minus the approximated 770 tonnes per day produced at the Kawasaki Heavy Industries (KHI) project from 2025 using brown coal gasification. All exported hydrogen was then assumed to replace LNG exports on a 1:1 PJ basis, so that combined quantities of LNG and hydrogen remain consistent with LNG production quantities in the VURM outputs for *Green and Gold*. Although this commodity displacement is somewhat simplistic, and hydrogen may instead compete with coal exports in the future, the ANO modelling chose to peg the hydrogen outlook sensitivity to LNG due to the strong association in terms of transportation and their end uses, along with the cost comparison of liquid hydrogen and LNG outlines in Figure 6.34.

Results for hydrogen modelling

The potential displacement of hydrogen for LNG exports is shown in Figure 6.35, demonstrating minimal uptake before 2040, which accords with the relative cost profile of production in Figure 6.34. Under the assumptions discussed previously, hydrogen increases exponentially to just over 800 PJ in 2016, accounting for approximately 14% of the combined LNG and hydrogen export market. Given the need for further R&D, vessel construction and commercial demonstration at scale, this modelled profile of Australian hydrogen production and export was deemed reasonable, with any meaningful Australian hydrogen exports before 2025 considered ambitious.

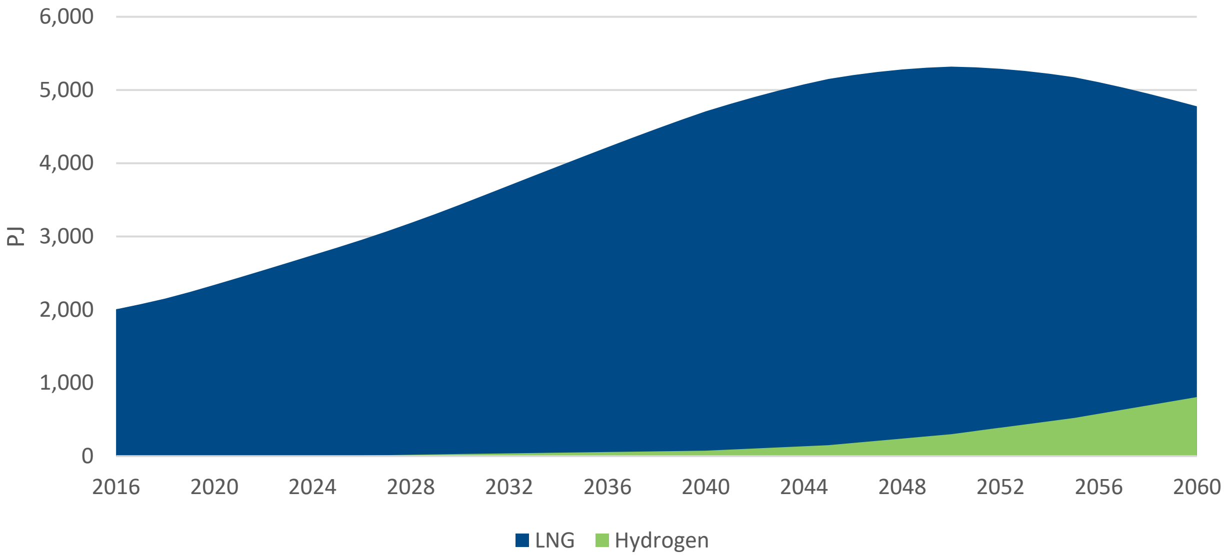

Figure 6.35 LNG and hydrogen export projections, 2016–2060, *Green and Gold* scenario

The additional electricity required to produce this quantity of hydrogen via electrolysis is assumed to be produced with off-grid renewables, so was not integrated within any of the other models used in ANO 2019. This additional load is shown in Figure 6.36, adding a further 290 TWh of generation, which is assumed to be zero emissions. While electricity generation on this scale would require considerable land, renewable resources, investment and infrastructure, this was not explicitly modelled in this hydrogen sensitivity analysis.

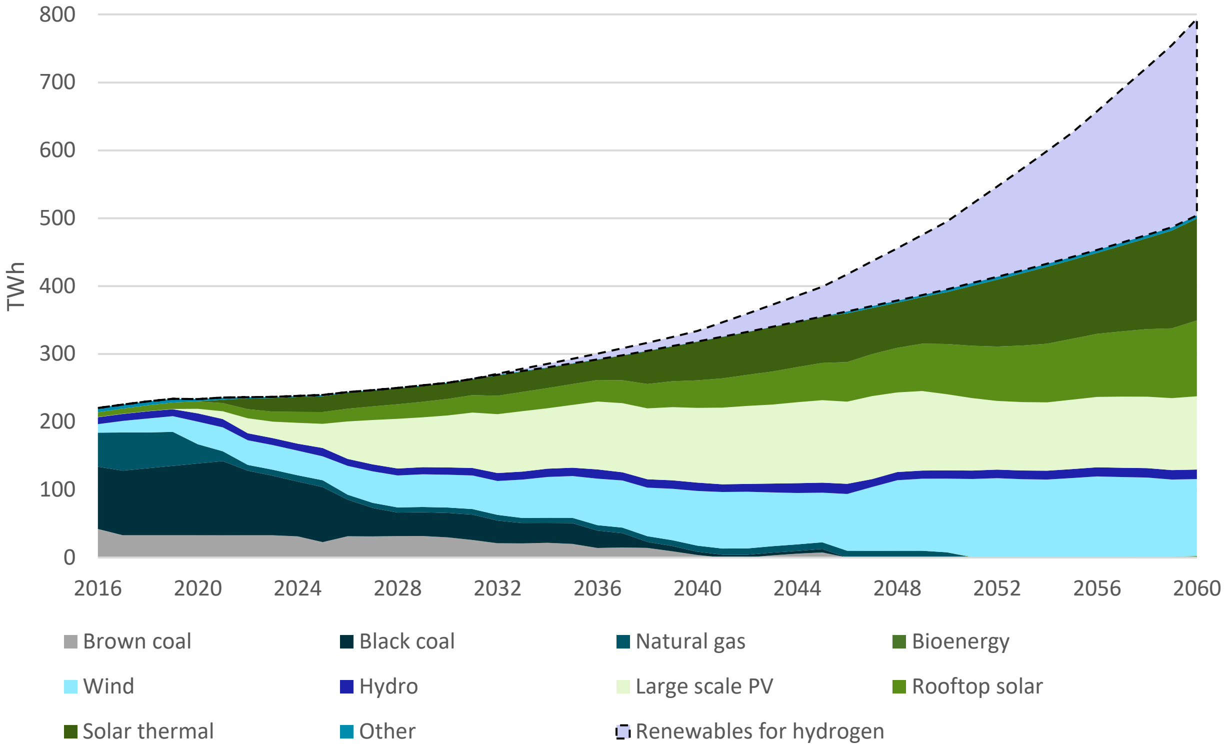

Figure 6.36 Electricity generation fuel mix including hydrogen production, 2016–2060, *Green and Gold* scenario

PV = photovoltaics

Mineral commodities

While not a focus of ANO 2019, there are likely to be substantial changes in the global market for mineral commodities, with implications for Australian industries such as iron and non-ferrous ore mining, and iron and steel manufacturing, in particular. There would be value in further work to identify the potential for Australia to capitalise on new opportunities for minerals from future high-tech innovation and trends.

Given the range and size of domestic mineral and energy deposits, it seems likely that many of the commodities required in any future global context will be available in Australia, suggesting a potentially competitive commodities market in both a 2 and 4 ^{0}C world. As it is unclear which global context will eventuate, it will be important for Australia to avoid 'lock-in' to export markets that might be highly susceptible to shifting demand, and to build optionality to capture opportunities if and when they arise, particularly if the world moves towards decarbonisation in the future.

As mentioned, lithium is an example of a commodity expected to experience substantial growth in demand, as it is a key component of battery storage used to support VRE and EV uptake. Although Australia is the largest producer of lithium in the world, the industry is primarily focused on the mining and processing stages of the value chain, suggesting that while Australia will continue to benefit from lithium mining, significant economic value across the rest of the value chain may not be captured (Wills et al., 2018). This may cause Australia to see a decline in its share of the total market, face a negative balance of trade due to re-importing value-added products (Godfrey et al., 2017), and miss opportunities for innovation and commercialisation through R&D, high-tech manufacturing and cross-sector synergies. The implications of Australia extending further throughout the supply chain of key minerals and metals such as lithium was not included in the modelling for ANO 2019.

6.6 Buildings

6.6.1 Current context

Energy use in all buildings, for both residential and commercial uses, was modelled using the same approach. Commercial and residential buildings have different energy use profiles. Most energy in commercial buildings is consumed by heating and cooling and lighting systems, although energy use is highly variable across the sector depending on the specific building use. In residential buildings the main energy uses are space conditioning (particularly heating), water heating and appliances and equipment. As numbers of in-home appliances and equipment proliferate, it is expected that the share of household energy consumption associated with appliances and equipment could increase, particularly if standby power consumption is not dramatically improved. Despite an uncertain policy environment, improvements in energy efficiency, along with a range of government policies, have delivered benefits to the building sector (ASBEC, 2016).

Overall energy use in residential buildings has increased slightly over the past decade to 457 PJ in 2016, primarily delivered by electricity (54%), gas (42%) and renewables (14%) (DoEE, 2017) (Figure 6.37). Similarly, commercial building energy use has increased steadily to 339 PJ in 2016. Electricity provides the majority (71%) of energy consumption in commercial buildings, with the remainder coming from gas (17%) and oil (10%) (Figure 6.38).

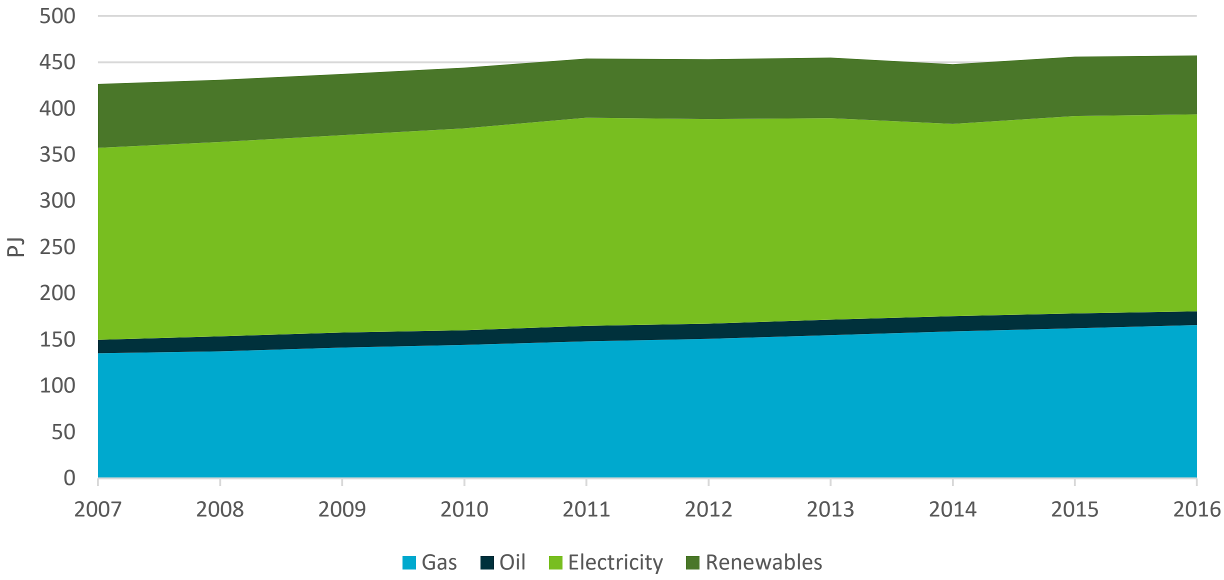

Figure 6.37 Residential building energy use by fuel type, 2007–2016

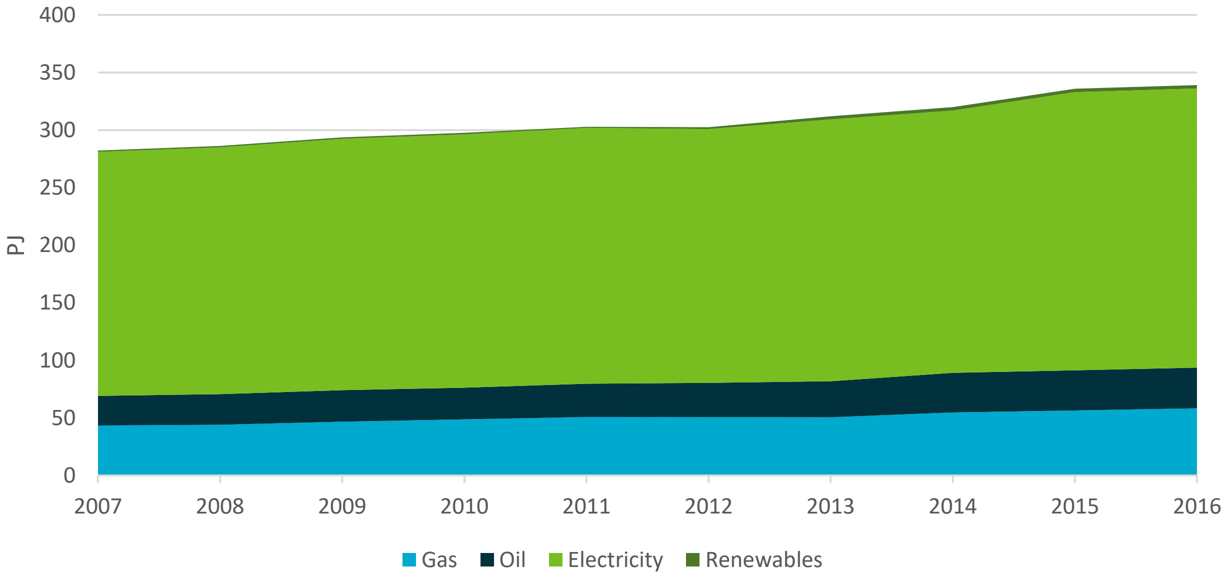

Figure 6.38 Commercial building energy use by fuel type, 2007–2016

In the broader context of rising prices, the stress of household energy expenses has potential substantial economic and social implications, particularly for those Australians least able to afford it. Australian households from the lowest income bracket spend around five times more on electricity than those from the highest income bracket as a proportion of their household disposable income (ACCC, 2017). Large Australian families on low incomes are most at risk of energy poverty, where there are currently around 42,000 large households with five or more persons and on a low-income of less than $650 per week (KPMG, 2017). The risk of energy stress or poverty is also higher for pensioners, people living in poor quality housing or in rental properties, Aboriginal and Torres Strait Islander people, single parents and their children, newly arrived migrants and refugees, and people with a disability (ACOSS, 2017).

Although the average household is getting smaller and becoming more energy efficient, household spending on domestic energy has increased from $32.5 per week per household in 2009–10 to $40.9 in 2015–16, and now accounts for 2.9% of household income (KPMG, 2017)[11].

Retail electricity prices are also forecast to increase over the near term, due to recent supply constraints (e.g. closure of Hazelwood power station) and rising gas generation fuel costs, before prices stabilise or decline slightly over a longer horizon between 2020 and 2030 (Jacobs, 2017). Without improvements to household efficiency or usage rates, higher prices will translate to greater energy expenses for households, with this pressure more significant for families and individuals on lower incomes.

The risk of energy poverty is also more pronounced for these cohorts as many are financially constrained in their options to reduce their long-term household energy expenses (KPMG, 2017). Pensioners, newly arrived migrants and single parents, for instance, may avoid energy efficiency improvements such as solar panels, double glazed windows, insulation and energy-efficient appliances due to significant upfront costs and as they prioritise other essential living expenses instead (Jacobs, 2017). Similarly, many renters are also unable to access these improvements as such incentives are often split between the tenant and landlord – a particularly significant factor as renters account for about 30% of the population, with many on lower household incomes (ACOSS, 2017).

More broadly, the proportion of weekly household spending on essential goods and services has increased from 56.6% in 2003–04 to 59.4% in 2015–16 (ABS, 2017). This reflects rising pressures across essential living expenses such as housing, food, fuel, healthcare and transport. Such challenges are likely to remain over a broader horizon if healthcare spending grows with Australia's ageing population, housing affordability continues to deteriorate and overall income inequality persists (Productivity Commission, 2013; QBE, 2016). These pressures can reduce the available budget households have to meet energy costs and increase the risk of energy poverty.

6.6.2 Future outlook

The overall trends in energy use in buildings will be driven by the growth in new building stock, turnover of existing building stock and equipment, and the energy efficiency of these buildings and equipment used.

There are several ways by which energy efficiency might be improved in buildings, with the most significant opportunity during design, construction and fitout of new buildings, and at the point of replacement of existing appliances, equipment and refurbishment of existing buildings (ASBEC, 2016). Fuel switching of appliances such as those used in heating and cooking was also identified as an effective means of altering the energy use and emissions profile of buildings – particularly through electrification.

Much of the energy productivity potential in buildings is already profitable; however, several barriers prevent the adoption (ClimateWorks Australia, 2010). One of the most prominent barriers

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[11] The average number of people per household has fallen from 3.0 in the 1980s to 2.6 in 2016.

Source: Hugo (2001)

Source: ABS 2011 & 2016 Censuses – Time series Profile (Census No. 2003.0) in buildings is the ‘split incentive’, where building owners are responsible for capital improvements to buildings but tenants are required to pay energy costs, therefore, the decision maker is not incentivised to improve energy efficiency. ASBEC (2016) identified the following impediments to decision makers implementing energy efficiency improvements in buildings:

- capability – access to appropriate data and information, skills, services and products, or capital or finance
- attractiveness – potential commercial immaturity or lower financial returns of more efficient technologies, amplified by market distortions such as discounted energy pricing
- motivation – range of internal and external factors such as lack of awareness, energy comprising a small share of total expenditure, or split incentives.

Supporting measures can help overcome the barriers to the adoption of energy efficiency in buildings, which include (ACEEE, 2018):

- residential and commercial building codes
- appliance and equipment standards and labelling
- building retrofit policies
- building rating disclosure
- energy intensity improvements in residential and commercial buildings
- improved building management, such as monitoring and optimisation of appliances and equipment.

6.6.3 Modelling energy use in buildings

Energy use in buildings draws upon modelling of housing density and dwelling numbers described in Chapter 5. The energy use in buildings has been modelled in VURM (see following section) with parameters to reflect energy efficiency and electrification opportunities and adjusted to ensure (i) that the model did not apply rates that were stronger than can be justified by technical analysis and (ii) that results reflect appropriate levels of potential productivity based on available reports.

Energy intensity modelling assumptions

Rates of improvement in energy efficiency and electrification in *Slow Decline* are assumed be consistent with a business as usual as identified in ASBEC (2016). This report also provides assessment of achievable, economic potential in improved energy efficiency and electrification which was applied to *Thriving Australia* and *Green and Gold* scenarios. The rates of improvement in energy efficiency of buildings is presented in Table 6.3 below.

Table 6.3 Assumed energy intensity (energy use per unit output) improvements, residential and commercial buildings

Average reduction in energy use per unit output per annum			
Sector	***Slow Decline***	***Thriving Australia***	***Green and Gold***
Existing residential buildings	−0.60%	−1.9%	−1.9%
New residential buildings	−1.50%	−2.6%	−2.6%
Existing commercial buildings	−0.30%	−2.4%	−2.4%
New commercial buildings	−0.60%	−3.6%	−3.6%

Further energy productivity improvements are achieved by switching direct fuel use in buildings (particularly gas) to electricity. As a carbon price is imposed on emissions and the emissions intensity of electricity generation decreases (see Section 6.2), switching from gas to electricity in buildings can significantly reduce emissions and lower energy costs in buildings. Electricity is already a cheaper alternative for many applications in buildings and improvements in technology, particularly heat pumps and induction cooking are forecast to improve the competitiveness of electricity use to gas in many buildings applications.

Previous work (ClimateWorks Australia et al., 2014) suggests that buildings could be almost completely electrified by 2050 as a method of reducing emissions. The potential switch from gas to electricity use in the modelling was compared to (ASBEC, 2016) as an indicator of technical potential. This report identified that for residential buildings, over 93% of direct fuels were assumed to be able to switch to electricity by 2050 cost effectively with this rate of switching extrapolated to 2060. For commercial buildings, 40% of direct fuels were assumed to be able to switch to electricity by 2050, starting in 2030, primarily for heating and hot water. In commercial buildings, one unit of electricity is assumed to replace between 1 and 7 units of direct fuel, depending on the application.

Electrification is likely to be stronger in new buildings where there is the potential for avoided connection costs to gas networks. Improvements in technology are likely to result in reductions in the electricity use required to replace gas in an equivalent use. Based on previous assessments of potential for electrification in buildings, electricity is assumed to replace between 2 and 3 units of gas before 2030 depending on the type of usage. After 2030, technical improvement is assumed to result in up to 7 units of gas replaced for one unit of electricity for some applications due to improvements in heat pump technology. This assumes that best in class technology (IEA, 2011) becomes standard by 2030.

Residential buildings energy use

The different profiles of residential energy use are shown in Figure 6.39. In *Slow Decline*, energy use in residential buildings increases by 50%, maintaining a relatively consistent proportion of electrification compared to the use of other direct fuels (predominantly gas). Conversely, *Thriving Australia* and *Green and Gold* experience declines in total energy use by 66% and 79%, respectively, with this energy delivered almost exclusively via electrification.

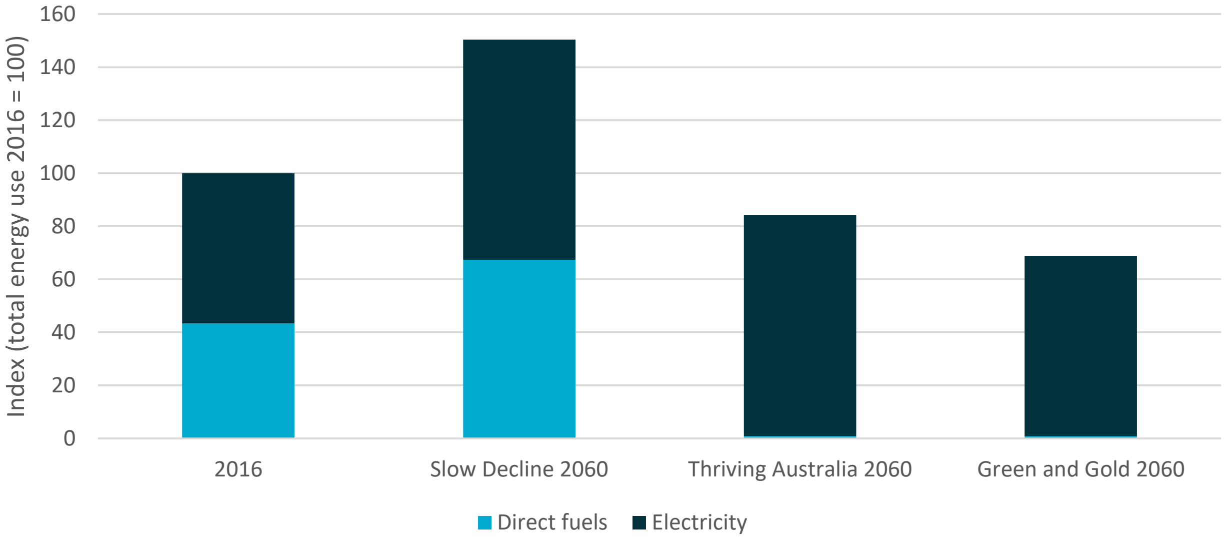

Figure 6.39 Residential energy use by fuel type, by scenario[12]

Residential electricity affordability

Electricity affordability was identified as an important aspect of the energy system affecting social outcomes. Although energy costs were not modelled relative to a distribution of wages, the average energy costs relative to average wages can be inferred and therefore the directional impact on energy as a proportion of wages, which is one dimension of energy poverty. Relative to 2018, each of the scenarios experiences a reduction in average electricity costs per capita relative to wages by 2060, with this reduction strongest in *Green and Gold* where spend as a proportion of wages decreases by around 64% (Figure 6.40).

The reduction in electricity costs relative to wages is a product of changes to retail electricity prices, energy efficiency improvements (through a reduced demand for electricity) and wage growth. Figure 6.41 shows the relative contribution of these different components in the *Green and Gold* scenario. Here, improvements in energy efficiency per capita and wage growth account for nearly 90% of the change by 2060, with the remainder due to slightly lower retail prices relative to 2018.

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[12] As the VURM model does not contain a bioenergy category, it is not included in the projections for residential energy use.

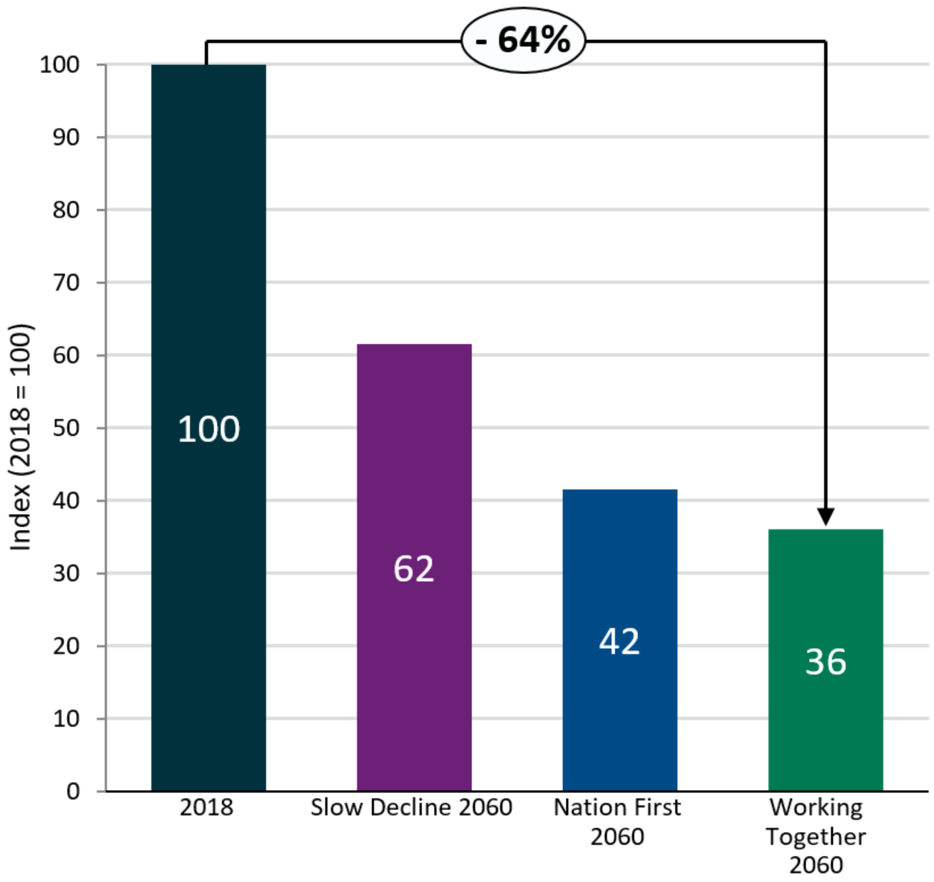

Figure 6.40 Annual electricity spend per capita as proportion of wages, index (2018 = 100)

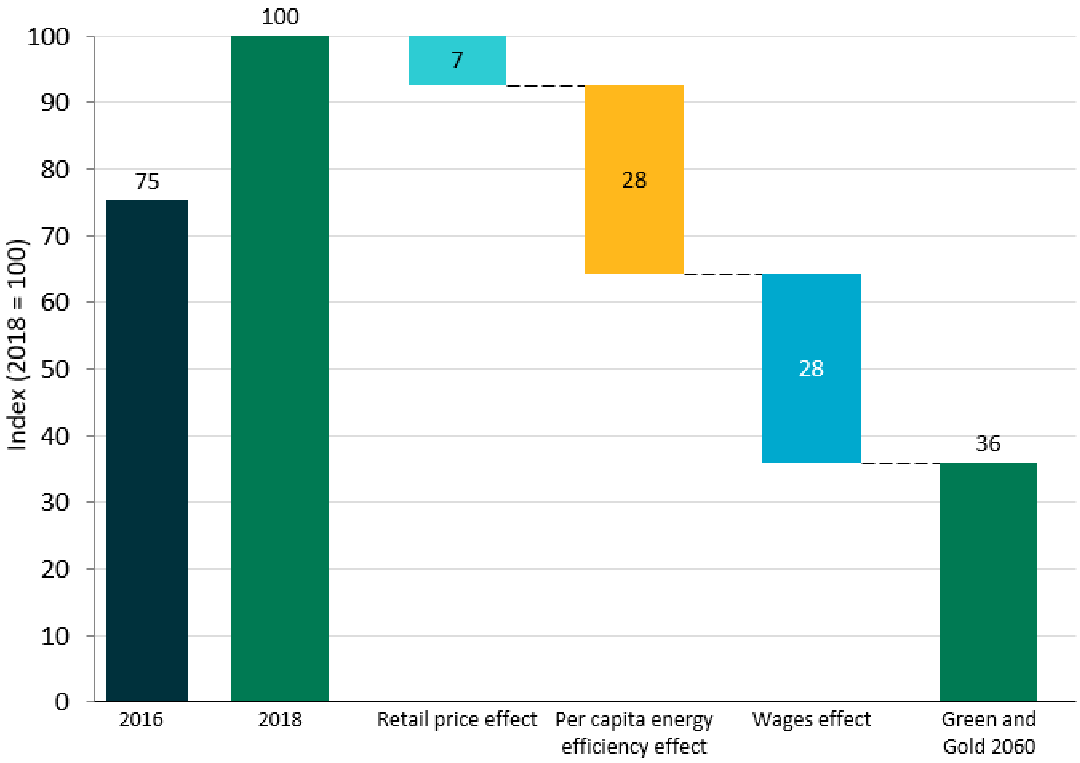

Figure 6.41 Decomposition of changes in *Green and Gold* electricity affordability, index (2018 = 100)

The outlook for energy poverty in Australia is dependent on the distribution, not just averages of future energy prices; access to energy efficiency improvements; and wages as well as pressures from other living expenses and broader income inequality. Hence, the response from government will also be an important influencer of these pressures and subsequent rates of energy poverty across the nation. This will include outcomes around stable policy and investment to manage energy prices and supply, and support for low income and disadvantaged households to access efficiency improvements and navigate energy pressures (ACOSS, 2017; Nance, 2017).[13]

There is a strong technical potential to reduce energy use in buildings to reduce costs, alleviate energy poverty and reduce emissions. Many of these opportunities are already cost effective although their uptake is impeded by a number of barriers discussed previously. As buildings and the equipment are long-lived assets, delays in capturing such opportunities risk locking in high levels of emissions and poor energy performance for decades to come. Additionally, ASBEC (2016) identified several benefits associated with improving energy performance. Some of these include:

- increased asset value and returns to building owners
- reduced maintenance costs
- productivity improvements, at a household, business and national level
- improved physical and mental health, particularly among children and the elderly
- economic growth and job creation
- reductions in peak energy demand, reducing need for higher cost peaking generation and additional transmission infrastructure.

Some customers (residential and commercial) will be able reduce their electricity costs further by installing rooftop solar panels. Other customers may increase their exposure to electricity costs as they adopt EVs. This analysis has not included these considerations since access to rooftop solar and EVs is dependent on several demographic factors such as income, dwelling type, home ownership and education levels (Graham et al., 2018). Of most concern is the impacts of affordability on the most vulnerable customers (low income, renters, low educational attainment) who are expected to be late adopters of these behind the meter technologies.

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[13] This may also include new financing mechanisms to incentivise and lift access to efficiency improvements, revised energy standards and efficiency schemes to guide retail markets and household spending, and new tools to enable and inform consumers on energy-related decision making and consumption.

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7 Agriculture and land use

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7.1 Agricultural productivity

7.1.1 Context

For the majority of Australia's agricultural history, productivity improvements have buffered the industry against declining terms of trade, as well as the impacts of climate and environmental change (Figure 7.1). The main drivers of these productivity improvements have been new genotypes, changes in land management, increased resource-use efficiency, increases in land and labour productivity, and efficiencies achieved by increasing the scale of farm operations (Grundy et al., 2016). This history is explored by Angus (2001) and Moloney (2014), drawing links between historical wheat yields and developments such as new cultivars, fertilisers and farm practices. Agricultural production and land-use also respond to a number of other factors, such as domestic and international price settings and subsidies, climate change and variability, irrigation and infrastructure development, and resource availability (Grundy et al., 2016).

Since the mid-1990s, both globally (Fuglie and Nin-Pratt, 2013) and in Australia, the rate of increase in total factor productivity of agriculture has declined. The climate-adjusted total factor productivity increase declined from 2.15% pa prior to 2000 to 1.06% pa over the following decade for cropping (Hughes et al., 2011) while lower levels of productivity increase, and even some absolute declines, were observed in other agricultural industries (Grundy et al., 2016). This slowdown has been attributed primarily to climatic influences, such as the Millennium drought between 2000 and 2010, and under-investment in research and development, which drives technical innovations (Sheng et al., 2011). The variability of Australian agricultural productivity over recent decades is displayed in Figure 7.2.

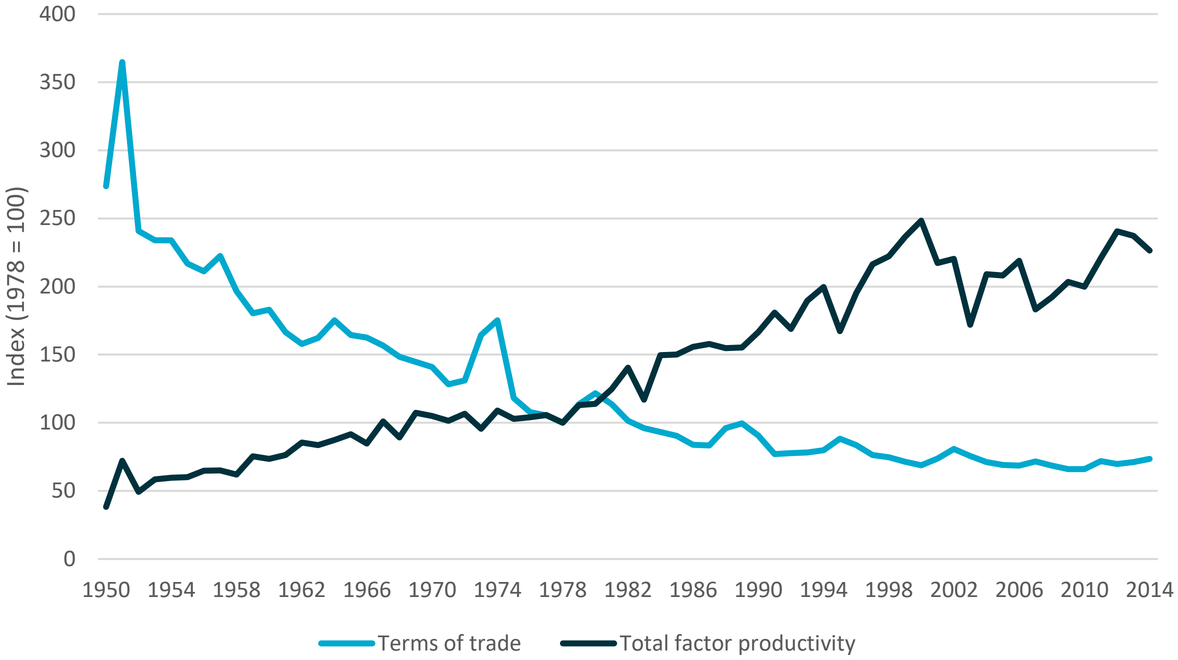

Figure 7.1 Agricultural productivity and terms of trade, 1950-2014, index (source: Xia, Zhao and Valle 2017)

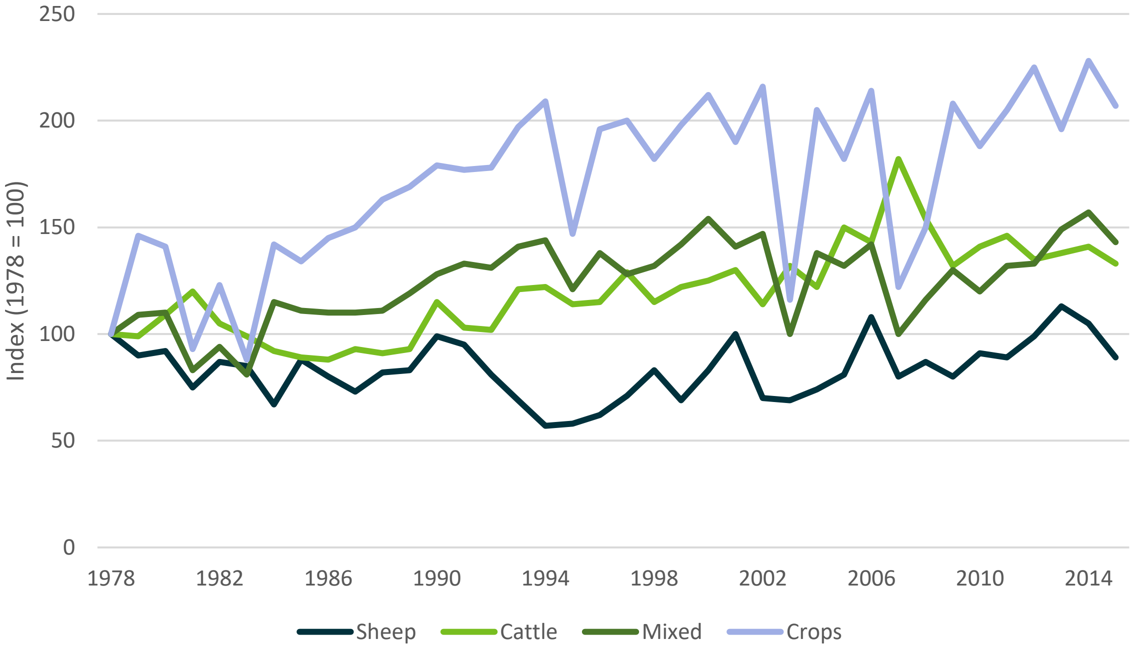

Figure 7.2 Total factor productivity by agricultural commodity, 1978-2015, index (source: ABARES 2017)

Research into yield gaps[1] in Australian grain cropping suggests that stalling yield growth is partly a result of impacts of climate change such as reduced rainfall and increased temperatures (Hochman et al., 2017), modified by the fertilisation effect of increasing CO_2 levels. Farmer

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[1] Refers to the gap between yields currently achieved on farms and those that are theoretically achievable under ideal conditions (by using the best adapted crop varieties and land management practices for a given environment).

Source: van Ittersum et al. (2013)

adaptations and technology driven change have maintained yields against these trends. While this illustrates the challenge of returning to past high levels of agricultural productivity, Hochman and Horan (2018) used the observed response to identify significant opportunities to raise the yield threshold. More generally, while the digital and communication revolution has been delayed in its influence in agriculture (due to complexity, distance and population scarcity), its effective deployment has been identified as a new driver of productivity growth (Leonard et al., 2017), along with the further realisation of potential of new approaches to genetic improvement.

7.1.2 Future outlook

Note that while the Australian National Outlook 2019 report discusses results under two scenarios: *Slow Decline* and *Outlook Vision*, this report goes into further detail by reporting results for the *Outlook Vision* under two different global contexts: *Thriving Australia* under a fractious global context and *Green and Gold* under a more harmonious global context. It should be noted that both scenarios fall under the *Outlook Vision*. Chapter 2 of this report describes these scenarios in further detail.

Given the sensitivity of agriculture and rural land use outcomes to realised productivity, the *Thriving Australia* and *Green and Gold* scenarios include ambitious ‘stretch’ goals for agricultural productivity. Achieving improved rates of agricultural productivity will be essential for the future resilience of agricultural industries as they face challenges from rising costs, pressures from natural resource degradation and a changing climate. While costs rise, the prices of agricultural commodities are largely driven by international supply and demand pressures. In this context, potentially falling prices and rising costs results in a ‘cost-price’ squeeze that will place the industry under increasing pressure to remain economically viable. If however, an ambitious investment in improving agricultural productivity is realised (as envisaged in the ‘stretch’ productivity setting), then, with wider opportunities arising from an increased value in carbon sequestration, a richer range of rural land use options emerge.

While research and development into agricultural productivity improvements have historically helped farmers get more from their land thus reducing the pressure of the cost-price squeeze, there are significant new avenues of agricultural innovation emerging. These include digital disruption (Keogh and Henry, 2016) and harnessing the genetic revolution. With potential innovation leading to labour changes, increased timeliness, efficiency and better market connections, it can be foreseen that climate and cost threats might be moderated and new sources of productivity increases identified and captured. The opportunity is built around hitherto unavailable real time knowledge of agricultural systems and climate outlooks and a set of land use options to take advantage of the knowledge. That will allow productivity increases through two complementary strategies. Firstly, increasing agricultural output closer to the current yield potential, which is achieved by optimising production within the given system constraints. Secondly, agricultural output can be increased by expanding the potential yield envelope. This requires breakthrough development in technologies that allow for increased production for a given level of resource input and availability. For both methods of increasing agricultural productivity, new technologies and farming methods will need to be adopted. This will require increased rates of research, development and deployment of a number of future innovations. Many examples of these are listed by Robertson et al. (2016).

There are constraints to achieving this ambition, however. Climate change and ongoing natural resource degradation pose significant threats to achieving sustained agricultural productivity improvements (Arrouays et al., 2014; Ausubel et al., 2013; Fischer et al., 2014; Food and Agriculture Organisation of the United Nations (FAO), 2011; Metcalfe and Bui, 2017; Sonneveld and Dent, 2009). Potential climate change impacts include (Reisinger et al. 2014) reduced inflow to the Murray Darling river system that supplies a substantial portion of irrigated agriculture, reduced productivity and quality of current wheat and grape cultivars, and uncertain effects on weeds, pests and diseases. Across Australia, erosion, acidification, soil compaction and soil nutrient decline have limited the capacity to sustain productivity increases and need to be addressed. The forthcoming Wentworth Group paper on conserving, repairing and managing Australia's environmental assets is a comprehensive accounting of the scale of the issue and provides suggested solutions (WGCS, forthcoming).

Table 7.1 Climate Change Impacts on Australian agriculture

	IMPACTS	*CONFIDENCE*
Temperature	Further warming with more hot extremes and fewer cold extremes	Very high
Sea Level	Further sea level rise	Very high
Rainfall and water availability	Less winter and spring rainfall in southern Australia, with • increased evaporation, • reduced humidity, • reduced soil moisture and • greater frequency of severe drought	Very high
	More winter rainfall in Tasmania	Medium
	Uncertain rainfall changes in northern Australia	Low
Extreme events	Harsher fire weather in southern and eastern Australia	High
	Greater intensity of extreme rainfall events that lead to flooding	High
	Fewer tropical cyclones, but a greater proportion of intense cyclones	Medium

Source: ACCSP 2016

To illustrate some of the potential impacts of these climate constraints, the LUTO system was used to model both a shortfall in overall productivity (from 3% to 2%) and the effects on achieved productivity of a recurrence of a drought event similar to the 'Millennium drought'. These results are in Section 7.1.3 and in Section 8.3.2.

While the possibility of widespread changes in consumer preferences, such as a shift away from animal products was raised by some Australian National Outlook (ANO) participants, this was not included as a disruption in the ANO modelling. Given the export-oriented nature of Australia's agricultural system, and major global food trends – in particular the burgeoning middle-class and associated meat demand in Asia – the impact on Australian production is to a large extent driven by external and competing trends (Porfirio et al., 2018) that were not resolved in this study.

7.1.3 Modelling agricultural production

While there are gradual, adaptive changes in agricultural systems that improve agricultural productivity in the short term, as discussed above, substantive changes in agricultural productivity have historically been caused by ‘revolutions’. Since unforeseen changes such as these are not convincingly modelled, the ANO 2019 modelling suite does not endogenously model agricultural productivity. Rather, productivity rates across the scenarios were assumed at both trend and above trend (and close to historic highs) rates, and applied in the Land use trade-offs model (LUTO - described in Chapter 16). The ‘average’ impact of climate change on agricultural production was modelled using climate projections from four Global Climate Models (GCMs) (Figure 7.3, see also Chapter 16). Although significant drought events have been simulated, the impact of climate change is currently underestimated in the modelling, owing to unmodelled extreme events which will both increase in likelihood and induce substantially greater impacts under climate change.

The agricultural productivity rates assumed in LUTO range from 1.25% per annum in *Slow Decline*, to an above trend path of 3.00% for *Thriving Australia* and *Green and Gold*. This higher rate of agricultural productivity is intended to represent an ambitious stretch goal in line with an aspiration associated with substantial innovation in productivity, active climate change management (see Rickards and Howden, 2012) and enhanced investment in land use choices, whereas improvement of 1.25% represents a rate of improvement in line with more recent experience and lower than the long term historical average.

These productivity parameters are driven by the scenarios, and assumed in rather than predicted by the modelling in the same sense that successful climate change mitigation is assumed. Although 3.00% is considerably higher than the recent historical average, there are instances of farms and farmers exceeding the average and achieving high levels of productivity, demonstrating these assumptions are possible under certain conditions, although extrapolating actual productivity gains of individual enterprises to the entire industry represents potential that is, at best, demanding. However, with digitisation and genetic mapping now available, clearer productivity pathways are emerging that may further drive higher future productivity improvements. The intention is to illustrate the advantages gained by a successful drive for innovation in agricultural productivity.

Land use change can also impact overall agricultural output and was modelled in ANO 2019 using LUTO (Connor et al., 2015). Land use change is a feature of the *Green and Gold* scenario. A relatively high carbon incentive drives a shift from agricultural production to forestry for carbon sequestration and biodiversity benefits on lands where the relative returns encourage the shift. The impact of this shift on agricultural production is shown in Figure 7.3. Although production as a whole remains above that achieved in the *Slow Decline* scenario, there is a significant shift away from agricultural production as these other land uses become more profitable, particularly after 2040. Australian land use begins to then play a major role in using stored carbon in stabilising the climate.

This effect is most significant in livestock production, with both cattle and sheep production levels decreasing to below *Slow Decline* by 2060, while some crops also decline markedly to levels slightly above those in *Slow Decline*. In *Thriving Australia* there is a comparatively lower carbon price as well as an assumption that agricultural production is favoured over carbon forestry which coupled with high productivity assumptions, results in far lower shift to carbon forestry.

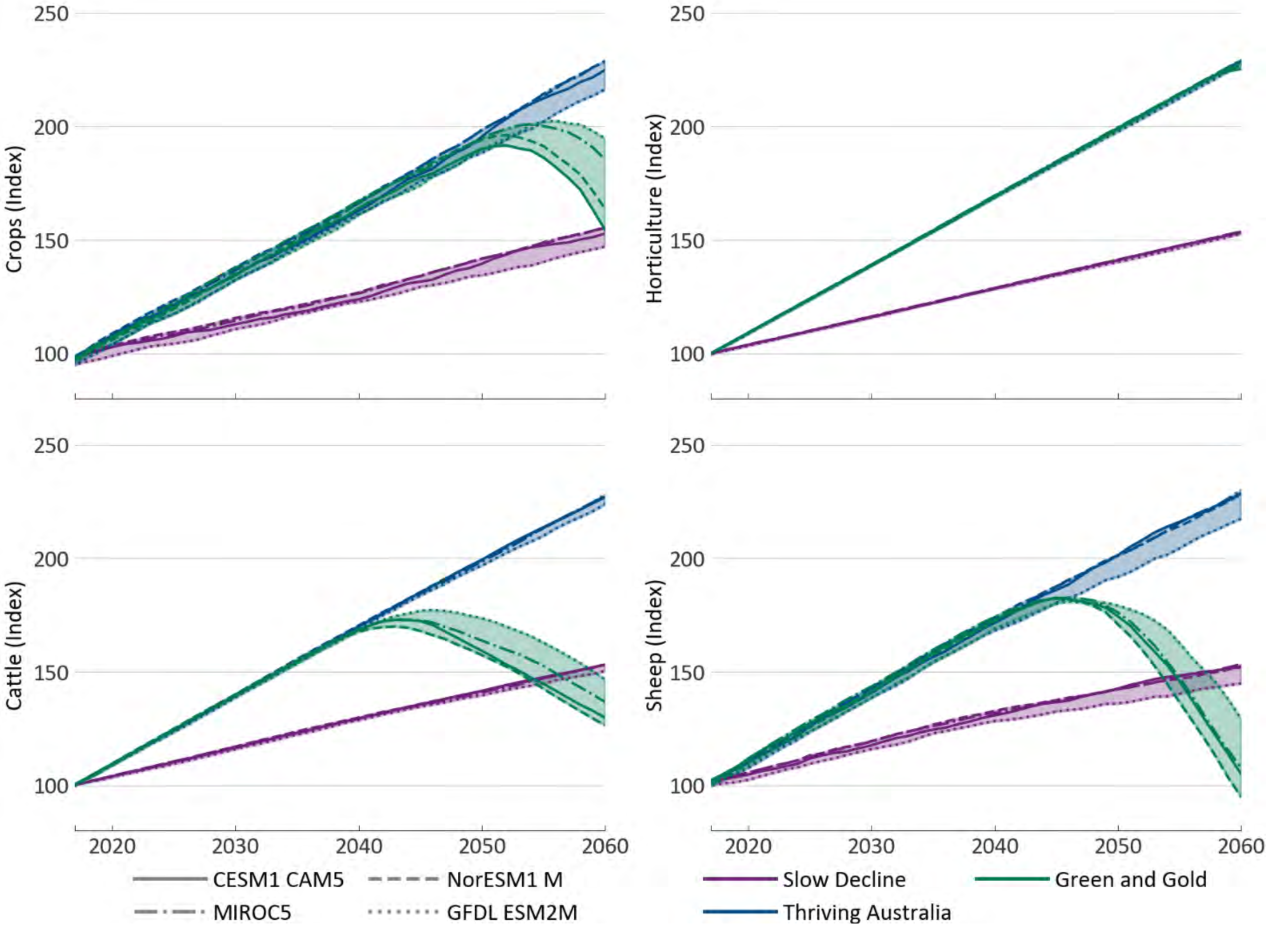

Figure 7.3 Production of agricultural commodities by scenario and the range of climate change simulated by four global climate models

Agricultural production more than doubles in this scenario, whereas production levels in *Green and Gold* experience a substantial decline once the rising carbon price improves the relative profitability of other land uses such as forestry. It is important to note that climate constraints in achieving productivity increases are substantially greater in *Thriving Australia* and therefore such increases are less likely to be achieved.

The LUTO model does not consider land use change outside of the 'intensive' agricultural zone, which accounts for a considerable amount of Australian livestock production. Production in these areas is assumed to continue with limited land use change into carbon farming. The modelling from LUTO is complemented by VURM, which includes the scope for agriculture across the entire continent and also considers the agricultural sector within the context of the entire economy.

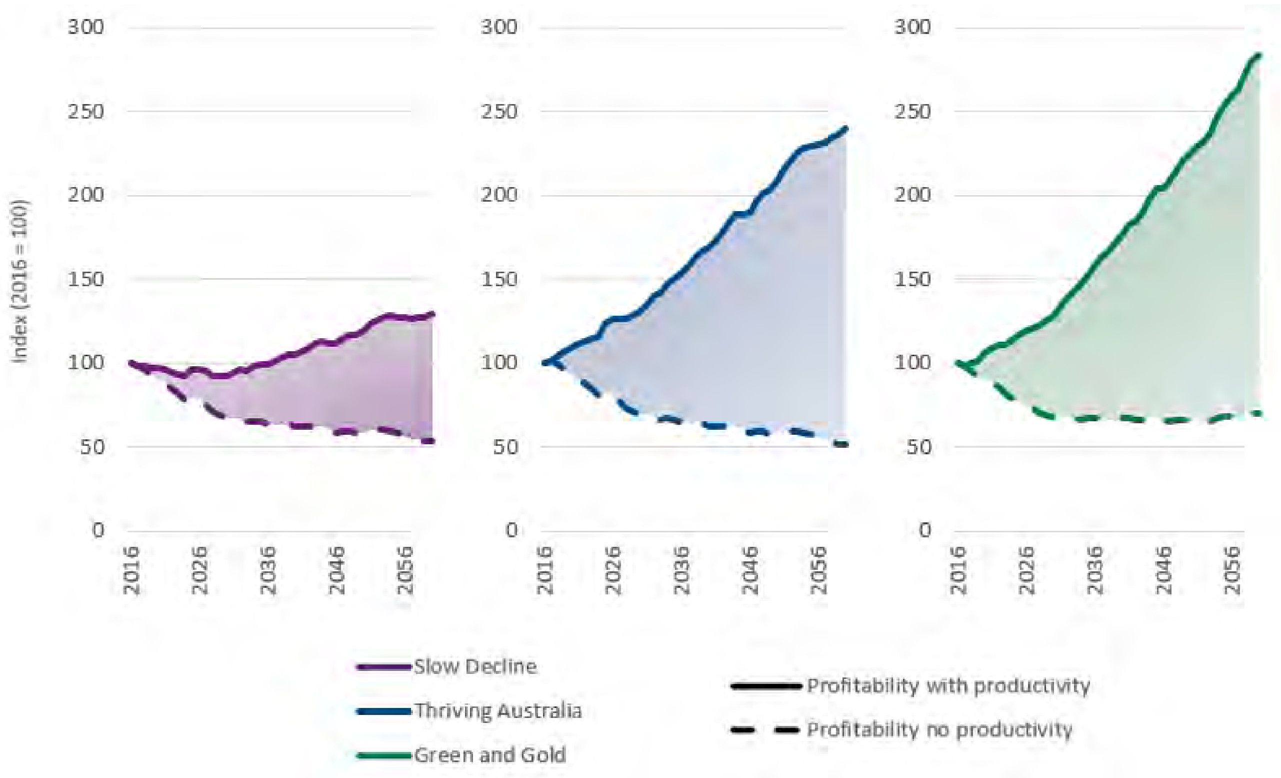

Figure 7.4 Significance of productivity improvements in maintaining agricultural profitability, variation by scenario

The importance of agricultural productivity in mitigating the cost-price squeeze is demonstrated in Figure 7.4 above, which shows rising winter cereal costs in each scenario regardless of assumed productivity increases. Where the rate of these rising costs exceeds revenue increases, this represents a period of declining farm profitability. In order to capture the range of possible outcomes, each scenario was analysed under an assumption of no productivity improvement, which intuitively results in a cost-price squeeze throughout the entire modelled period in all scenarios. Under the productivity assumptions of *Slow Decline* (1.25%), this cost-price squeeze is observed between 2019 and 2050, representing a sustained period of declining (but still positive) farm profitability. The importance of agricultural productivity in overcoming the cost-price squeeze is demonstrated in *Thriving Australia* and *Green and Gold* (assuming productivity is realised), where increasing farm revenues derived from higher productivity rates are able to outpace rising costs, delivering better outcomes for landholders and the agricultural sector. If a productivity increase of 2% is realised, many of the overall benefits of the ambitious scenarios for Australia are lessened (Figure 7.5).

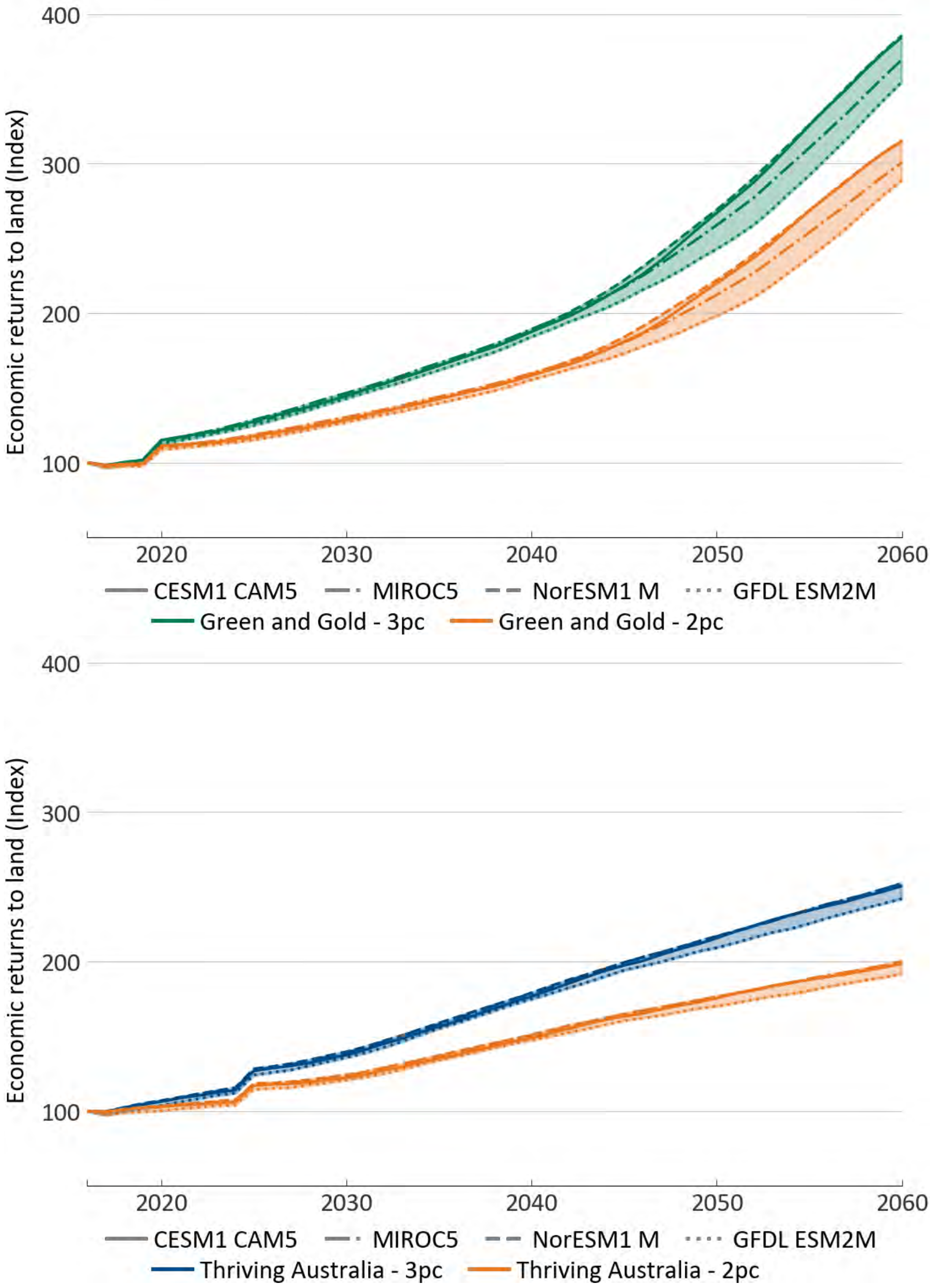

Figure 7.5 The impact of realising a lower level of productivity on economic returns

7.1.4 Implications

The ambition for Australia inherent in the *Thriving Australia* and *Green and Gold* scenarios requires a focus on substantial innovation in agricultural productivity. Achieving sustained productivity growth drives the economic future of agriculture and rural Australia. It requires investment by government, investors, industry bodies, farm businesses and supporting services.

Additionally, farmers and the agricultural technology they wield will need to adapt to higher temperatures, changes in rainfall, and more extreme climatic events. High rates of improvement in agricultural productivity will be more difficult to achieve in scenarios that exhibit higher warming. Even without climate change, productivity increases will depend on limiting or reversing environmental degradation, reducing inefficiencies, and development of new technologies, genotypes, and farm practices (Grundy et al., 2016).

7.2 Carbon sequestration and environmental forests in the landscape

7.2.1 Current context

Carbon sequestration

Carbon sequestration is a strategy to reduce greenhouse gas concentrations in the atmosphere by increasing the rate at which carbon dioxide is removed from the atmosphere via technological or natural processes and stored with permanence in the biosphere or geosphere.

Sequestration methods include storage of carbon in soil, vegetation, oceans, and geological formations (Parliament of Australia, 2010). Carbon sequestration in the biosphere has been shown to be an important part of Australia's potential climate mitigation response, particularly in low emissions trajectories such as those required to reduce emissions to net zero by the middle of the century (ClimateWorks Australia, 2014). Eady et al. (2009) explored a wide range of land based sequestration options and concluded that carbon farming (trees with limited diversity) and biodiverse plantings were both effective and achievable.

Australia currently has market mechanisms in place to facilitate emissions reductions in the land sector, such as the use of Australian Carbon Credit Units (ACCUs), which can be traded to generate a return for landholders. The Emissions Reduction Fund (ERF) was established by the Australian Government in 2014, providing a scheme through which the Australian Government purchases ACCUs generated through eligible projects. The ERF contains three elements; crediting, purchasing, and safeguarding emissions reductions (DoE, 2015), seeking to incentivise businesses and landholders to reduce emissions through adoption of new technologies and practices, including the storage of carbon through revegetation and reforestation. There is also the potential to trades ACCUs on secondary markets (Cook, 2016) to individuals looking to voluntarily offset emissions, and for companies with compliance obligations under the safeguard mechanism.

Environmental forests

Australia has seen the largest documented biodiversity decline of any continent in the past 200 years, due to declining vegetation and habitats in terrestrial ecosystems. More than 50 species of Australian animals have been listed as extinct, while the number of threatened species continues to grow at some of the highest rates in the world (ABS, 2010; Metcalfe and Bui, 2017). In terms of global comparisons, Australia ranked as the second largest contributor to global biodiversity loss between 1996 and 2008 with between 5-10% of species lost, and is among the top seven countries responsible for 60% of total biodiversity loss (Waldron et al., 2017). Due to the complex range of interrelationships between species and ecosystems, the loss of individual species can have significant implications for the functioning of ecosystems as a whole.

There are a number of current and future threats to Australian biodiversity, which will have impacts at different temporal and spatial scales (Metcalfe and Bui, 2017):

- Land-use change such as vegetation clearing and habitat fragmentation
- Invasive diseases, pests and weeds
- Unsustainable use of natural resources
- Pollution
- Changing fire regimes
- Climate change

7.2.2 Future outlook

Carbon sequestration

With high incentives for carbon sequestration, carbon forestry has the potential to become profitable across substantial areas of Australia's intensive agricultural zone presenting economic opportunities to stimulate investment and innovation in business and address a number of other environmental outcomes for Australia. Profitable adoption of carbon forestry would potentially transform the management of Australian landscapes and deliver significant economic and environmental outcomes to Australia. As with any land use change, the conversion of agricultural land to carbon or environmental plantings will also have trade-offs for food production as implications for social and environmental outcomes.

The conversion of land used for agriculture to carbon forestry would be moderated by a range of factors including supply chain limitations, social lags of uptake, and other factors such as potential community resistance to large-scale land use change. Supporting mechanisms such as the provision of relevant infrastructure, research and development for develop carbon-related technologies and operational procedures funded through either public or private investment could enable a large-scale carbon sequestration industry (Mitchell et al., 2012).

Environmental forests

Modelling suggests that Australia’s potential biodiversity loss as a result of climate change and loss of natural ecosystems is comparable in orders of magnitude to the impact from land clearing following colonisation. The future risk to biodiversity will be dependent on the spatial patterns of temperature and rainfall change that accompanies changes in climate (Steffen et al., 2009). Reisinger et al. (2014) identified a number of projected impacts of climate change on Australian biodiversity, including:

- High vulnerability in alpine zones due to loss of snow cover, invasions by exotic species and changed species interactions (very high confidence)
- Substantial risks to ecosystems across the continent, including coastal wetlands, tropical savannahs, inland freshwater and groundwater systems, peat-forming wetlands, and tropical and subtropical rainforests (high confidence)
- Limited in situ adaptive capacity or ability of many species to shift to more climatically suitable areas (high confidence). Potential for complete loss of climatically suitable habitat

for some species within a few decades, increasing risk of local or global extinction (medium confidence)

While biodiverse plantings will achieve less sequestration than forests optimised for carbon capture, recent studies have estimated that actions such as the restoration of native vegetation could sequester more than 90 $MtCO_2e$ annually, while generating significant revenue even under conservative carbon price assumptions (WGCS, forthcoming).

7.2.3 Modelling carbon sequestration and biodiversity in the landscape

Modelling carbon forestry

Carbon sequestration was projected in LUTO for each of the scenarios by modelling the relative profitability of both carbon (monoculture) forestry and environmental (biodiverse, mixed species) plantings relative to other farming land uses. The economic profitability of carbon sequestration in ANO 2019 is determined by the carbon price trajectory of the global contexts (covered in more detail in Section 3.4 of Chapter 3). Landowners are assumed to switch land use practices to carbon or environmental forestry when this becomes more profitable than the incumbent land use, with a time lag of adoption consistent with that observed with previous land use innovations. The extent of land use change to carbon sequestration is therefore driven by land and carbon prices, financial returns from existing land uses, and other economic and social factors.

As with agricultural production, the potential for carbon sequestration in LUTO is only modelled for the intensive agricultural zone. ANO modelling does not consider the potentially significant carbon sequestration that could be achieved in less intensive land such as Northern Australia. Nous Group (2010) found that while Outback Australia has low carbon storage per hectare, the amount of available land means it holds considerable carbon stores estimated at almost 10 billion tonnes. While Nous Group (2010) identified potential for substantial abatement in remote Australia through changed land management practices, further research is required to assess the potential sequestration that is achievable, potentially long-lasting and economically feasible in these areas of Australia.

There are a number of social and institutional factors that would moderate land use change to extensive carbon forestry. Conversion of agricultural land to carbon forestry reduces land management flexibility due to high costs and difficulties in switching away from such land-use (Polglase et al., 2013). Despite potential economic advantages, landholder preferences and opportunity costs may restrict conversion of land to forestry. A carbon sequestration industry also faces potential regulatory uncertainty, absence of a formal carbon compliance scheme, and other challenges managing carbon through the entire product cycle (Mitchell et al., 2012). Limited knowledge and capital availability for landholders and carbon offset companies, along with financier understanding of the carbon industry also serve as barriers to uptake of plantings.

In LUTO, allowance has been made to model these factors through applying a ‘social lag’, delaying the land-use response to represent gradual adoption in the uptake of carbon plantings over a period of 16 years (see Chapter 16 for further detail). The *Slow Decline* and *Thriving Australia* scenarios of ANO 2019 were constructed to favour food production over landscape repair, achieved through a policy uncertainty setting that restricted uptake of carbon plantings to 50% of economic potential. This setting was not applied in *Green and Gold*, with constraints on planting uptake only implemented through the social lag and a requirement for mixed-species plantings in water restricted catchments (discussed in more detail below).

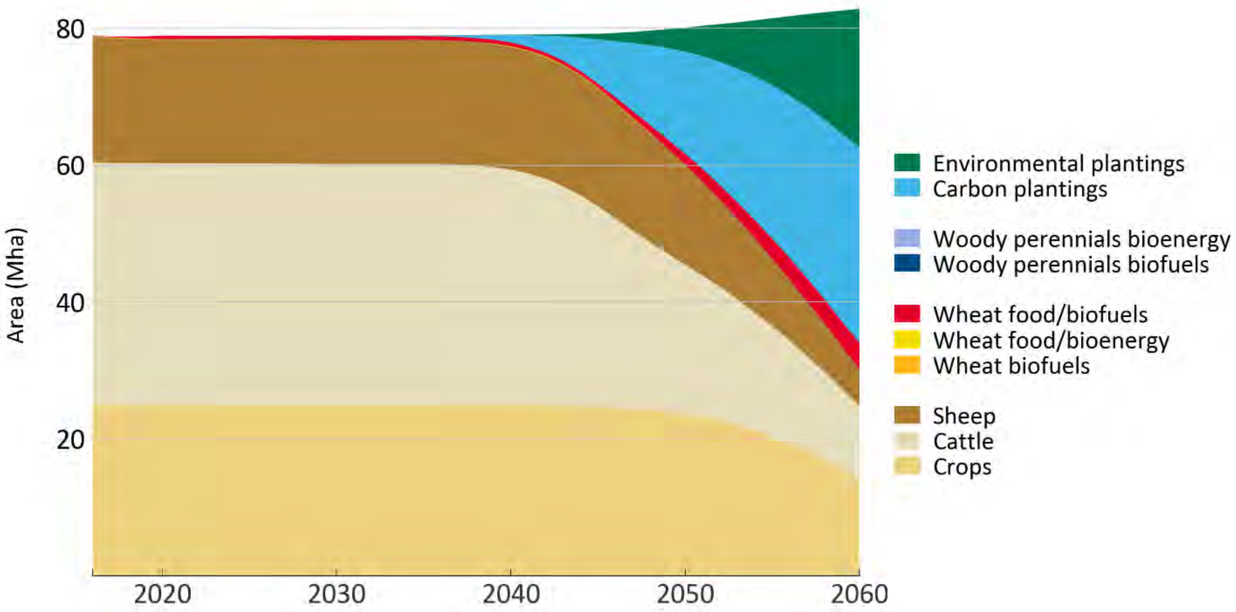

Figure 7.6 Land use change, *Green and Gold* scenario

The modelling results for ANO 2019 found that with lower global action on climate change (and therefore a relatively low carbon price), the mix of land use remains similar to present arrangements, influenced by interactions between prices, productivity trends and the range of market opportunities available. The result of these conditions are represented in modelling of *Slow Decline* and *Thriving Australia* scenarios, where minimal land use change was observed as the carbon price did not reach levels that would induce significant conversion to carbon forestry. Note that agricultural land use change has been a constant in Australia; it is probable that change within and between commodities will occur with market and supply dynamics (outside the modelling framework used here).

Green and Gold represents a scenario with much higher global action on climate change and a higher carbon price paid for carbon forestry. In this scenario, a wider range of land uses become economically attractive, in particular carbon forestry, environmental forestry and the production of biofuels. In *Green and Gold*, there is minimal land use change to carbon forestry early in the modelling period when the incentive for carbon sequestration is lower.

Carbon forestry is evident from around 2029 at a carbon price of \$45/tCO$_2$e, although the activity is limited to early adopters as assumed by a social lag, and by 2041, 1% of the study area is modelled to have adopted carbon forestry with an incentive of \$90/tCO$_2$e. Within these price ranges, other factors play an important role influencing the relative adoption of carbon forestry such as rising livestock prices and plantation establishment costs. By 2047, at a price of \$128/tCO$_2$e, carbon plantings would be economically attractive on over 10% of the study area and increasing significantly thereafter in line with modelled increases in the price on carbon.

The extent of land use change in *Green and Gold* is displayed in Figure 7.6[2] above, showing that a high incentive to reduce greenhouse gasses has a very significant impact on the relative profitability of land uses by 2060, favouring sequestration over agriculture on more marginal lands where lower value agriculture is currently practiced. The impact of a declining agricultural area on food production and returns to landholders is discussed further in sections 7.1, 7.4, and 7.5. In reality, changes to land use at this scale would represent substantial regional and rural disruption and a range of constraints to change would be triggered. From a technical perspective, the requirement for significant infrastructure to support plantings may limit annual conversion and the social response to changing landscapes may have unpredictable consequences on the degree of land use change that is possible from a realistic perspective. The LUTO modelling represents complete adoption (over time) of the most profitable land use. While for various reasons (known and unknown), this level of change is unlikely, nonetheless the modelling suggests a higher level of income across rural land uses and therefore significant sequestration.

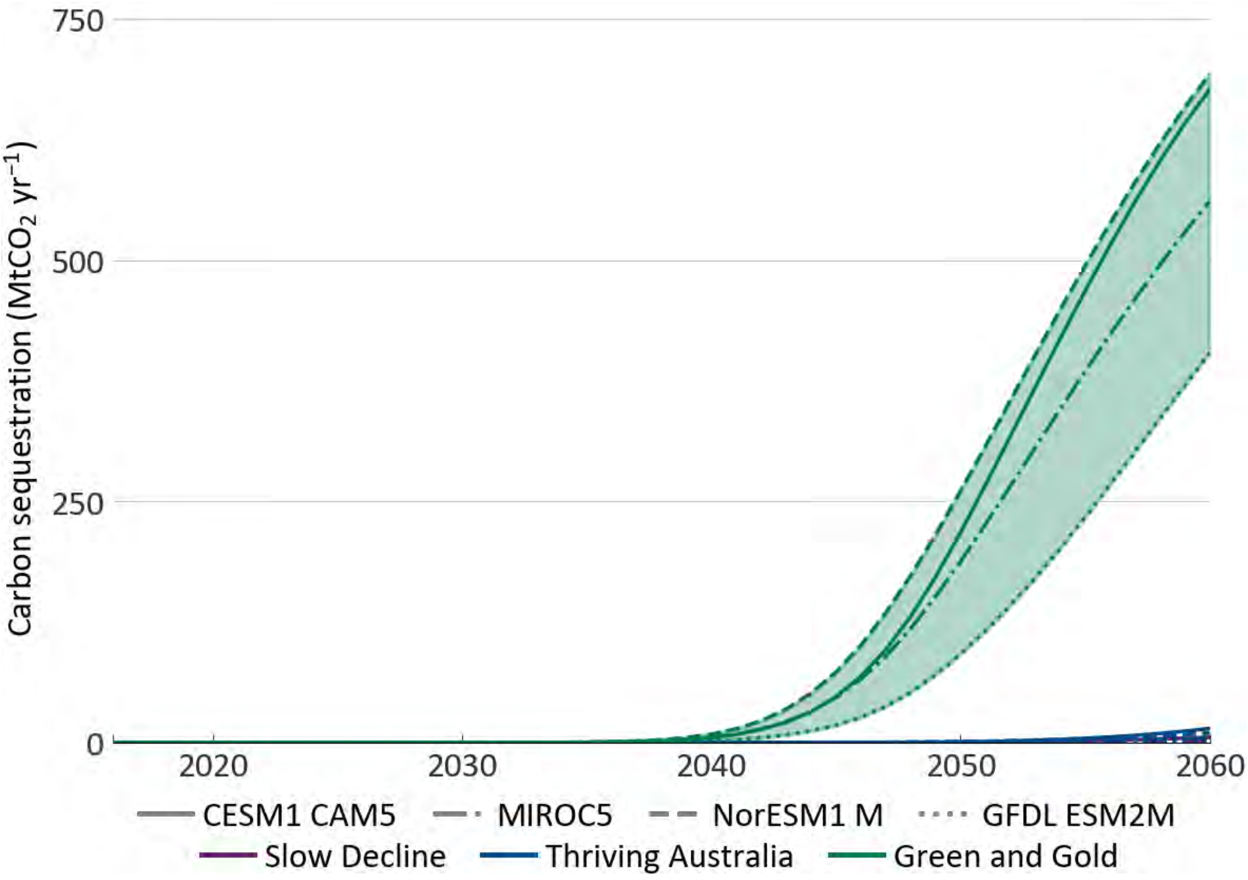

Figure 7.7 Emissions abatement from carbon sequestration, by scenario and GCM range

Results for tree-based carbon sequestration across four different GCMs are presented in Figure 7.7, showing very little sequestration under the low carbon price scenarios. The impact of different GCMs represent the impact of different possible climate futures on rates of carbon sequestration, and are discussed in more detail in the LUTO technical report (Chapter 16). Given the minimal carbon forestry in *Slow Decline* and *Thriving Australia*, the variance across GCMs is best observed in the *Green and Gold* scenario. The GFDL ESM2 climate future is hotter and drier which has

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[2] Figure 7.6 7.6 shows results for the milder 'NorESM1 M' GCM run, which leads to the highest uptake of carbon and environmental plantings of the four GCMs modelled in LUTO. This is intended to represent an upper bound on the amount of tree-based sequestration that could be achieved under the ANO scenario settings. The range of possible outcomes across scenarios and GCMs is presented in Figure 7.7 below.

significant impact on sequestration, with 404 $MtCO_2e$ in 2060 compared to 693 $MtCO_2e$ in the milder NorESM1 M. This occurs due to a decrease in profitability, reducing area planted and through impacts on growth for areas that are profitable. With the MIROC5 climate future, sequestration is 561 $MtCO_2e$ in 2060 and 677 $MtCO_2e$ for CESM1 CAM5. These results demonstrate that under high carbon prices, carbon plantings can provide important abatement even under the more extreme climate impacts. Additional emissions abatement would also be achieved through avoided agricultural emissions and from biofuels displacement of fossil fuels. The increased risk of forest fires has not been modelled.

Modelling environmental forestry

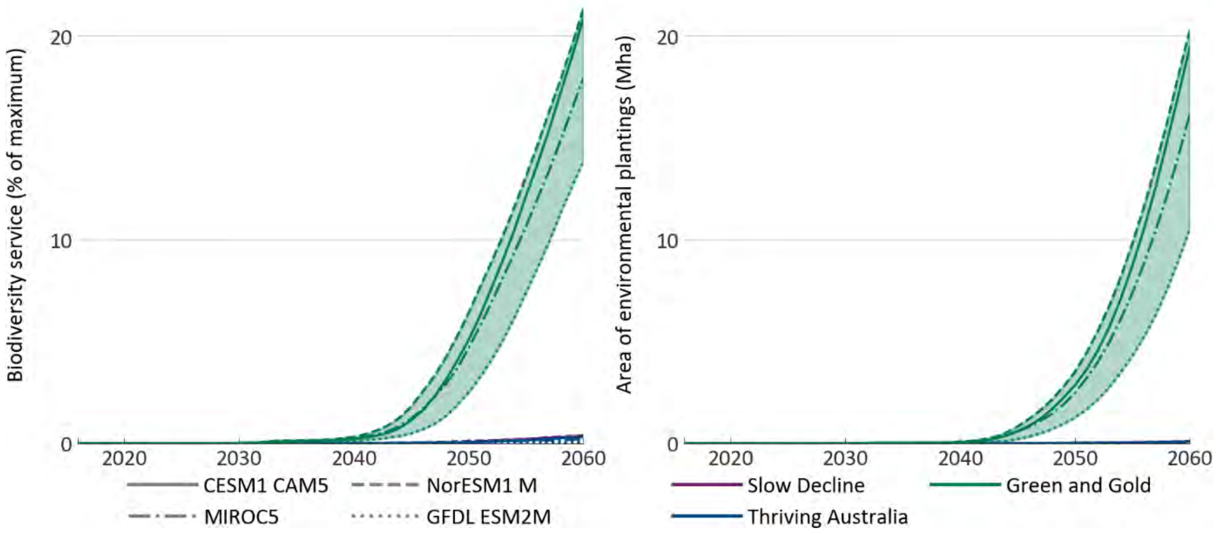

Figure 7.8 Biodiversity services and area of environmental plantings by scenario and GCM range

While biodiversity outcomes are not explicitly modelled in ANO 2019, environmental plantings are assumed to be one way to consider biodiversity outcomes quantitatively, through a combination of a carbon price and biodiversity levy as discussed in Chapter 16. The modelling does not include any land clearing for the expansion of agricultural land, which would pose additional threats for Australian biodiversity. In the ‘four degrees track’ Global Climate Action settings (*Slow Decline* and *Thriving Australia*), with large changes in regional climate and extreme weather and a preference for agriculture over landscape repair (as discussed above), Australian ecosystems would be at a very high risk of significant biodiversity loss by 2060. Although global temperatures do not diverge significantly under different emissions scenarios until after 2030, reducing emissions before 2030 will reduce the climate risks faced by ecosystems later in the century.

Extensive habitat restoration is one means of reducing biodiversity loss in the face of a changing climate, by increasing the area and connectivity of land to support viable populations of species in the future. Within natural ecosystems, the number of species generally increases with area of available habitat, with the benefits of revegetation assumed to be greatest for ecological environments that are or will become rare due to natural or human influences (Prober et al., 2015). The success of habitat restoration will be increasingly challenged by extreme weather events as a result of climate change.

In order to model biodiversity co-benefits from action on carbon sequestration, levies on plantings were allocated to a biodiversity fund (discussed in Section 16.3 of Chapter 16) which was used to target land use change in areas of high biodiversity priority (Ferrier et al., 2007).

As with carbon sequestration and water interceptions (discussed below), the level of biodiversity benefits is negligible under the construction of the ‘four degrees track’ settings. As the carbon price increases in the *Green and Gold* scenario and carbon levy funds an annual sequestration increase, the area of biodiversity-funded mixed species plantings grows, providing increasing biodiversity benefits as well as carbon abatement. We model increases of the biodiversity fund to AUD$ 5 billion by 2050, rising to AUD $26 billion in 2060 under *Green and Gold*. As shown in Figure 7.8, this sees close to 21% of the maximum biodiversity services[3] achieved by 2060 under the NorESM1 M climate future and at most 20.27 Mha, or 24.47% of the 85 Mha LUTO study area converted to mixed-species environmental plantings.

Coupling carbon plantings with co-benefits such as nature conservation can be expected to increase social acceptance and market valuation of extensive plantations (Bekessy and Wintle, 2008; Fensham and Guymer, 2009). Increasing the value proposition of environmental plantings will be an important factor in compensating for the lower carbon sequestration potential of such plantings compared to monoculture carbon forestry.

While environmental plantings were the only biodiversity mechanism explicitly modelled in ANO 2019, a carbon price is only one potential driver of biodiversity improvements. While there are a range of other methods of improving biodiversity outcomes and reducing environmental degradation that are not contingent on global action on climate change, many of these would require large amounts of public investment. The consideration of alternative mechanisms to a carbon price were not considered in the modelling for ANO 2019.

Modelling water requirements of carbon and environmental plantings

Water use is one of many environmental factors relevant to agriculture and land use change, and has been modelled in LUTO in relation to carbon and environmental plantings (Figure 7.11 7.9 and 7.10). Although Australia’s agriculture sector is the largest water consumer in Australia, a mix of policy, effective management, technological developments and consumer preferences can mitigate this impact. Without complementary land use controls and water accounting arrangements, carbon forests could take over high quality agricultural land and affect surrounding environments, with potentially adverse implications for food and fibre production, and regional jobs that depend on such industries (WGCS, 2014). Therefore, any potential impacts on water systems due to carbon and biodiversity plantings in response to high carbon prices would need careful management. As outlined in the National Water Reform report (Productivity Commission, 2017), forest plantations in Australia are currently required to obtain water licences for alternative uses, thereby factoring the need for sustainable water use into decision-making regarding water allocation and extraction.

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[3] Each cell measured in LUTO is weighted in terms of its contribution to biodiversity benefits. Biodiversity benefits can be achieved through increasing representation of plant communities in new and existing vegetation, and through connecting existing habitat (Bryan et al. 2014). The biodiversity services score represents the sum of the biodiversity benefits scores for each scenario as a percentage of the maximum score. A maximum score would represent complete revegetation of the LUTO study area.

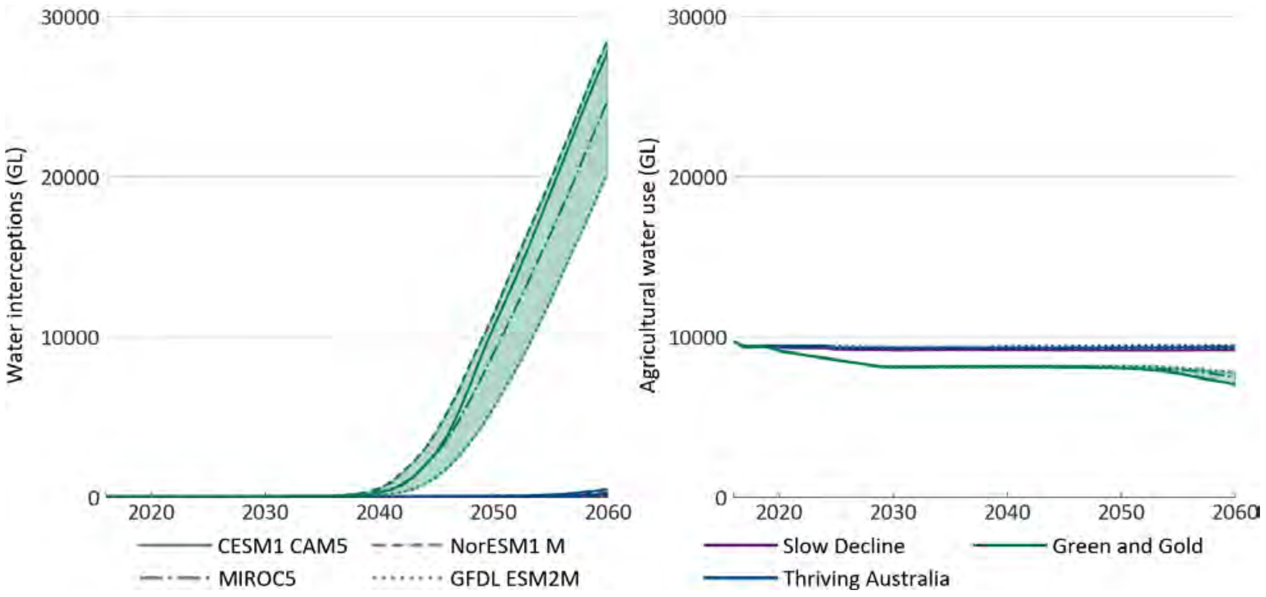

Figure 7.9 Water interception from plantations and irrigated water use, by scenario and GCM range

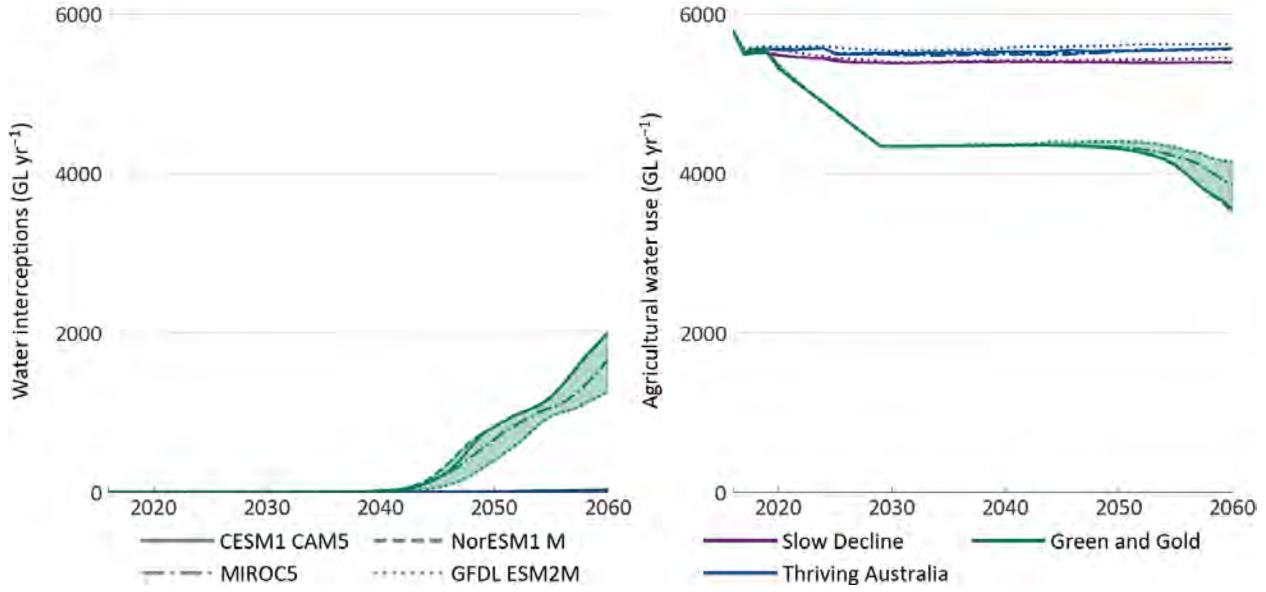

Figure 7.10 Water interceptions from plantations and irrigated water use in water stressed catchments, by scenario and GCM range

Under *Slow Decline* and *Thriving Australia*, the relatively minor adoption of carbon forestry is not likely to significantly impact on water supply, while the higher carbon price in *Green and Gold* increases pressure on water availability, with total water interceptions in the order of three times as high as irrigated water use by 2060. In *Green and Gold* (discussed in LUTO technical report) carbon monoculture forestry is restricted from water stressed catchments. A cap is imposed on these catchments' total water use such that environmental plantings and irrigated agriculture compete for available water. Through productivity measures, irrigated agriculture in these water stressed catchments is assumed to achieve water use efficiencies of 20% over ten years from 2020, with half the water saving returned to environment. The other 10% savings are available for interception by plantations. These scenario assumptions provide a managed response to the impacts of rainfall-runoff interceptions by forestry for water stressed catchments. In addition, where rising groundwater has historically been an issue, tree plantings offer significant mitigation if placed appropriately in the landscape. The importance of effective water management will be amplified due to the likely increased number of water stressed catchments in southern Australia as a result of climate change.

7.2.4 Social and environmental co-benefits of carbon sequestration

While not modelled in ANO 2019, there is the potential for social and environmental co-benefits of carbon sequestration alongside emissions reductions. For example, land management practices such as savanna burning provide numerous benefits for Indigenous communities and ecosystems generally. Initiatives such as the West Arnhem Land Fire Abatement (WALFA) project aim to combine traditional management practices with emissions accounting to reduce emissions within broader objectives of reconnecting Indigenous people to country, sustaining traditions, and building adaptability to changing circumstances (Cook and Meyer, 2009). Through the promotion of conservation stewardship, cultural, environmental and economic benefits may accrue to Indigenous rural communities and result in sustainable land management outcomes more generally (Russell-Smith et al., 2009). Other initiatives include the establishment of Indigenous Protected Areas (IPAs) and ranger groups, delivering land and sea management alongside economic, educational and cultural benefits (Putnis et al., 2007). The successful integration of Indigenous and western knowledge may produce benefits for Indigenous values, biodiversity, tourism and employment (McGregor et al., 2010), pending appropriate institutional and governance frameworks suitable to the cultural requirements of Indigenous communities (Whitehead et al., 2009).

7.3 Bioenergy production

7.3.1 Current context

Bioenergy production in Australia is below the OECD average, accounting for just 1.5% of electricity generation in 2016 (DoEE, 2017) although Australia exports significant agricultural product for bioenergy production elsewhere notably canola for biodiesel production in the European Union (Eady, 2017). Bioenergy has the potential to be used in a range of Australian sectors such as electricity generation, heating in industry and buildings, and biofuels production (Australian Government and Bioenergy Australia, 2010).

In 2015, the Clean Energy Finance Corporation (CEFC) contributed $100 million towards establishing the Australian Bioenergy Fund - an equity fund focusing on bioenergy and energy in the agricultural and forestry sectors (CEFC, 2015). Technologies available for investment under the fund include:

- Energy from agricultural waste
- Biomass to energy projects, for example plantation timber residues
- Conversion of forestry plantation waste into pellets for burning
- Production of biofuels

7.3.2 Future outlook

Similar to the potential represented by other renewable energies (discussed in Section 6.2.2), Australia has an opportunity to establish a sustainable and competitive bioenergy industry for domestic use (ARENA, 2018). Conversion of land to the production of renewable bioenergy offers a range of benefits, contributing to improved energy security, emissions reductions, and regional development through increased and diversification of returns to landholders (Clean Energy Council, 2008).

There are a range of factors that would help the bioenergy market reach this potential in Australia, which would in turn improve the value proposition of converting land to bioenergy production purposes. These include (Australian Government and Bioenergy Australia, 2010):

- Secure demand for bioenergy products
- Cost on carbon emissions
- Greater understanding of environmental and social costs and benefits
- Mapping of current industry technologies and potential feedstock volumes
- Integration of bioenergy production with co-products such as foodstuffs and chemicals

7.3.3 Modelling land use for bioenergy production

The LUTO model explores the supply of crops (grain and/or stubble) and woody perennials (plantings with a modelled 10 year coppiced harvest) for the production of biofuels and bioelectricity. LUTO models the profitability and supply of bioelectricity in relation to the wholesale electricity price and the profitability of biofuel in relation to the oil price. While crop and crop residue do not have significant additional costs associated with harvesting, woody perennials plantings require establishment costs to be recouped. In these scenarios, the forecast for wholesale electricity and oil prices were not sufficiently high enough for woody perennials plantings to be profitable for either bioelectricity or biofuels.

The energy sector model outputs provide an estimate of biofuel use in transport and these estimates were used to constrain the LUTO model's production of biofuels. Given these production constraints, the supply of crop stubble for biofuels appears profitable across large areas of South Australia, Western Australia and Queensland, with capacity being achieved across *Slow Decline*, *Thriving Australia* and for the *Green and Gold* scenarios (Figure 7.11). Note that the use of crop stubble requires balancing this potential with the impacts on soil cover and therefore erosion and in the return of nutrients to the soil (Herr et al. 2012), so that in practice some *in situ* retention of stubble will reduce the availability of supply.

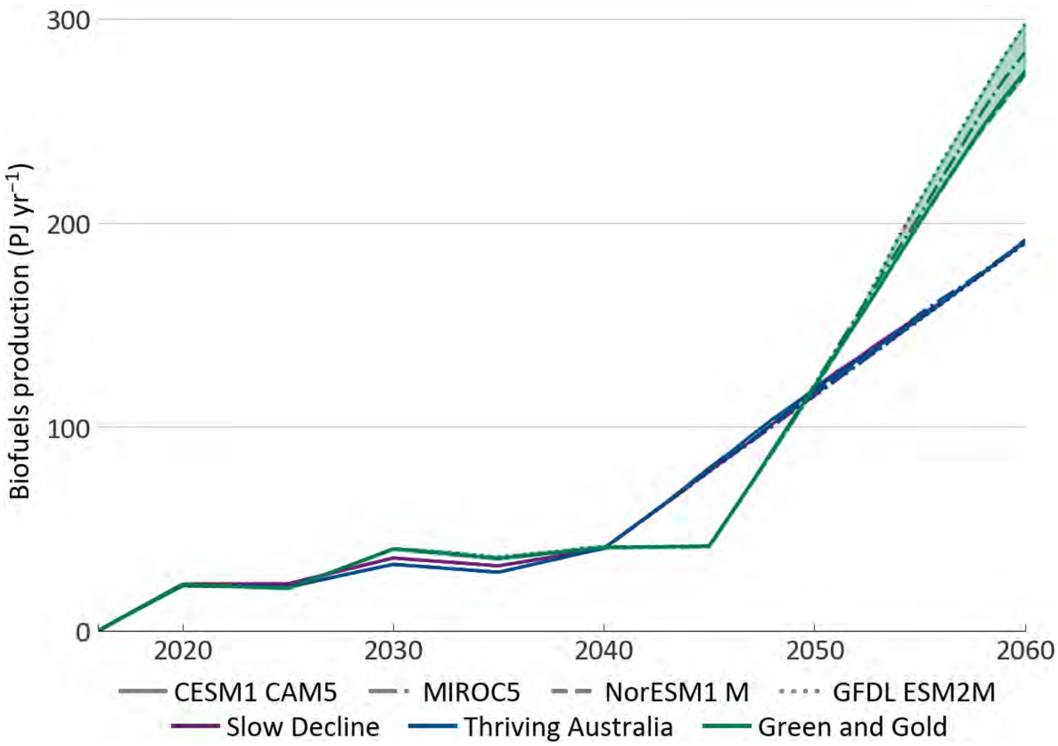

Figure 7.11 Biofuels production, by scenario and regional climate change projections from four global climate models

7.4 Managing land use change

With high incentives for reductions in greenhouse gas emissions and provisions for biodiversity, a wider spectrum of land-uses such as carbon forestry, biofuels, environmental forests as well as agriculture become substantially more profitable than present and therefore broaden the viable options available to landholders. However, there is increasing evidence that land use change would be challenged by the extent to which farmers can maintain productivity in the face of climate change impacts, particularly in the global context of *Slow Decline* and *Thriving Australia* where higher rates of global warming are assumed. Recent research indicates that climate changes are already impacting on realised productivity (Hochman et al., 2017), suggesting the ability to realise productivity gains at the higher end will face complex and substantial challenges. With reduced likelihood of adapting to climate change and sustaining agricultural productivity (both domestically and globally) in a ‘four degrees track’ context (Rickards and Howden, 2012), food production targets will become increasingly harder to meet.

Although other land uses such as carbon sequestration do incur trade-offs, the ANO modelling demonstrates that if step change productivity improvements are achieved there can be a net increase in agricultural production across all scenarios, due to increased output rates on (more capable) land that stays in food and fibre production. This includes *Green and Gold*, which sees a net increase in production across all agricultural commodities on 2015 levels, despite significant conversion of land to other uses, in particular carbon and environmental plantings. Thus under high productivity growth assumptions, strong environmental policy settings do not necessarily come at the expense of economic performance (CSIRO, 2015). An ambitious emphasis on productivity improvement will allow agricultural industries to prosper with and without significant land-use change, and form part of an overall increase in profitability across the entire land sector (Bryan et al., 2016). However, without an emphasis on productivity technologies and strong action to limit global warming to below two degrees, climate change impacts are likely to reduce or reverse these improvements in profitability.

Figure 7.12 Illustrative mosaic of possible land uses

The land use change modelled in ANO would be more likely to occur at a more detailed spatial resolution (within paddocks and between paddocks) than is possible to be represented in the LUTO modelling. Across many farm landscapes, a wider variety of profitable practices can form a more diverse enterprise mix. Practices can be adapted across the landscape in a 'mosaic' of land uses, as options are matched to land types. This mosaic of land uses can contribute to achieving greater productivity, sequestration and biodiversity, particularly towards the end of the modelling period as a more diverse mix of profitable land uses emerge. This arrangement could also allow increased emphasis on landscape restoration, although this has not been a modelled outcome in ANO.

In *Green and Gold* particularly, there is substantial potential for a diverse mix of land uses. Carbon forestry of the magnitude presented by LUTO would not necessarily require wholesale conversion of entire paddocks, farms or landscapes to carbon forestry. Figure 7.12 illustrates a hypothetical example of how these practices could be combines within a landscape, with cropping centred on the most suitable soils and carbon and biodiverse plantings occurring where food production would be more marginal.

The principle of a mosaic of land uses, focussed on maximising productivity, sequestration and biodiversity reinforces the ambitious narrative assumptions in *Green and Gold*. Where agricultural production is focussed on the most productive areas of a landscape, high overall rates of productivity (such as though assumed in *Thriving Australia* and *Green and Gold*) will become more achievable.

7.5 Returns to landholders

The modelling for ANO 2019 suggests that with the change in profitability of different land uses in the scenarios modelled (particularly resulting from incentives for carbon sequestration), a profit driven landowner will have a greater range of land use choices. Under the assumptions of the more ambitious ANO 2019 scenarios, a land-use mix could emerge that achieves a balance between intensive agriculture, biofuel production, and forestry for carbon and biodiversity. While there are many trade-offs between these different land uses, there is also the potential for significant co-benefits, with landholders diversifying their incomes to improve resilience to economic and environmental shocks. The full expression of these changes would be subject to the adequate provision of supporting infrastructure and the social acceptance of the new mix in rural land use, albeit with an overall increase in land use income.

7.5.1 Modelling returns to landholders

Figure 7.13 plots the relative returns to land for *Slow Decline*, *Thriving Australia* and *Green and Gold* scenarios across the different climate futures, with the variation across climate futures indicative of the complex interplay between the impacts of climate on modelled agricultural production and tree growth, among other factors. With increasing agricultural productivity, and despite declining crop prices, returns to land increase by around 60% and 150% by 2060 in *Slow Decline* and *Thriving Australia* respectively. In *Green and Gold*, the higher carbon price assumptions lead to a greater range of profitable land use choices, with returns to landholders increasing by just under 300%, nearly double the increase of *Thriving Australia* over the same timeframe. This translates to economic returns to landholders being between $63 billion and $37 billion higher in *Green and Gold* compared with *Slow Decline* and *Thriving Australia* respectively (in when averaged across GCMs). These findings assume that production rates of varying land uses (agriculture, carbon plantings, bioenergy) are achievable under climate change impacts, which will be particularly challenging in the ‘four degrees track’ Global Climate Action settings.

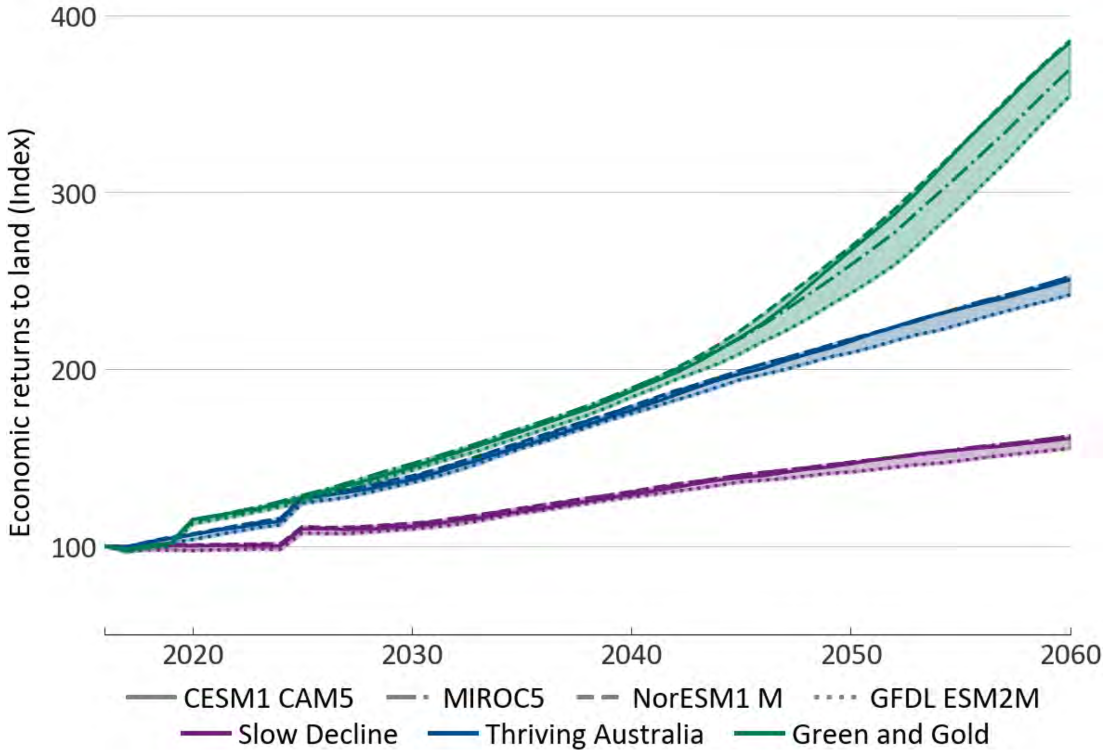

Figure 7.13 Economic returns to landholders by scenario and GCM range, 2016–2060

7.5.2 Implications

These results suggest that additional income from other land use change can more than offset reductions in agricultural production (CSIRO, 2015), partly due to the fact that agricultural production concentrates on more productive land, with less productive land transitioned to other uses. Some studies suggest that co-benefits between market and non-market objectives can lead to greater efficiency in more diverse mixes of land uses compared to a single focus such as purely livestock production (Stoeckl et al., 2015). In this way, land use change has the potential to enhance overall land sector profitability, with benefits for regional and remote development, providing jobs and investment to support thriving communities. The full expression of these changes would be subject to the adequate provision of supporting infrastructure and the social acceptance of the new mix in rural land use, albeit with an overall increase in land use income. These requirements for adaptation will be made more challenging by the impacts of climate change, especially under ‘four degrees track’ Global Climate Action settings.

Along with the economic benefits accruing to landholders, there are other social and environmental implications resulting from different land-use practices, as farmers and members of rural communities derive additional value from rural space, beyond solely consumptive or market purposes (Lockie, 2015). A range of recent studies have identified that the majority of Australians place significant value on the wellbeing of ecosystems (Esparon et al., 2015; Holmes, 2010; Jackson et al., 2011; Larson et al., 2015; Larson et al., 2013; Lockie, 2015). In agriculturally marginal regions, mixed land uses might provide opportunities to diversify sources of value in rural landscapes, such as through tourism based on aesthetic qualities, or special interest activities such as on-farm product sampling and purchase from the production source (Holmes, 2010; Lockie, 2015; Pearce, 2013).

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8 Environment and climate change

Authors: Cameron Butler, Kevin Hennessy, Katherine Wynn

8.1 Environment

Over the last 200 years, Australia has undergone a significant land use transition, much of which has led to environmental degradation, particularly through the permanent removal of native vegetation for conversion to large-scale pasture and crops. Australia's water resources have also been impacted by agricultural, industry and household consumption, as well as development projects altering availability and quality of water. Several river health problems such as salinity, blue-green algae outbreaks and turbidity are attributable to human activities altering river flow and water quality, such as excessive nutrient runoff, irrigation and land clearing (ABS, 2010). However, the *State of the Environment 2016* report (Metcalfe and Bui, 2017) found that improved land management practices in recent decades have substantially improved issues, such as water erosion of soils, through reduced tillage and improved natural cover management. According to this report, the main future challenges facing Australia's natural environment will be population, economic growth and climate change, specifically (Metcalfe and Bui, 2017):

- production of energy, metals, minerals, food, fibre and timber
- increased water consumption
- generation of waste
- threats posed by invasive species
- climate change (both gradual changes and extreme weather events).

This will place continued strain on Australia's environmental assets – soil, water and carbon resources, as well as native vegetation and fauna. Environmental degradation also significantly impacts on-farm productivity and income, through ongoing salinity and soil erosion, acidification and contamination. Environmental protection objectives of the Australian Government are outlined under the 'Caring for Our Country' initiative (Lesslie and Mewett, 2013), while *Blueprint for a healthy environment and productive economy* (Wentworth Group of Concerned Scientists, 2014) highlighted several changes required to improve environmental sustainability in Australia.

8.1.1 Environmental outcomes in the Australian National Outlook (ANO) scenarios

The *Green and Gold* scenario represents, by design, several desired environmental outcomes across a number of dimensions, due to an explicit focus on the co-management of Australia's agricultural potential and environmental sustainability, and active management of the entire landscape. Firstly, land and water degradation is managed to allow for strong improvements in agricultural productivity. Secondly, reforestation of land encourages biodiverse environmental plantings, which can deliver habitat corridors for native species, thus, increasing biodiversity and resilience to environmental pressures. Finally, global action on climate change limits global warming below 2 °C, reducing the impacts on water, ecosystems, biodiversity and other environmental stressors.

In *Thriving Australia*, there is weaker global action on climate change, resulting in global average temperatures increasing 4 °C above pre-industrial levels and representing major risks for the Australian environment. In this scenario, a lower assumed carbon price is not sufficient to drive significant reforestation with either carbon or environmental forestry. A high assumed agricultural productivity improvement rate in *Thriving Australia* is contingent on overcoming the challenges associated with climate change as well as land and water degradation, which will be more challenging than achieving the same rate in *Green and Gold*. Therefore, the ability to achieve positive outcomes for the agriculture sector in this scenario will require substantial investment in improved natural capital for land and water.

In *Slow Decline*, insufficient investment in agricultural productivity, land and water remediation, and emissions reductions results in poor environmental outcomes, which will also result in lower economic outcomes from land use sectors.

Note that while the Australian National Outlook 2019 report discusses results under two scenarios: *Slow Decline* and *Outlook Vision*, this report goes into further detail by reporting results for the *Outlook Vision* under two different global contexts: *Thriving Australia* under a fractious global context and *Green and Gold* under a more harmonious global context. It should be noted that both scenarios fall under the *Outlook Vision*. Chapter 2 of this report describes these scenarios in further detail. While climate change mitigation effort (reducing greenhouse gas emissions) have been incorporated in ANO 2019 results, the costs and benefits of adaptation have limited representation and are generally underestimated due to the complexity of the modelling involved. This is not because these topics aren’t important, but because they were either beyond scope of the project or because they have, in some cases, been addressed thoroughly elsewhere.

8.2 National emissions

8.2.1 Current context

Australia’s domestic emissions were 533 $MtCO_2e$ in 2016, increasing by 2.5% since 2013, after emissions had decreased 14.7% in the period between 2005 and 2013 (DoEE, 2017). Electricity generation, transport and other stationary energy accounted for around 70% of total emissions in 2016 (Figure 8.1).

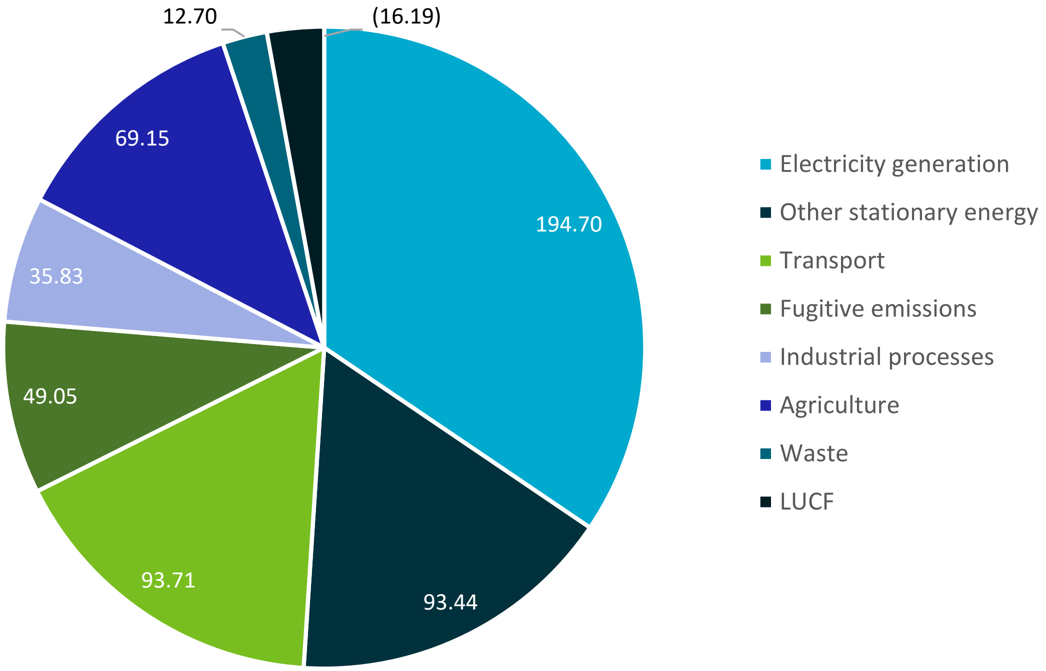

Figure 8.1 Emissions by source, 2016 ($MtCO_2e$)

As a signatory to the 2015 Paris Agreement, Australia has a target of reducing emissions by 26%–28% on 2005 levels by 2030, forming part of the global commitment to limit global warming to less than 2 °C. Delivering on the Paris Agreement goals will require global net emissions of greenhouse gases (GHGs) to approach zero by the end of the century, while limiting warming to 1.5 °C will require net zero by around 2050 (IPCC, 2018). This has been identified as possible in an Australian context in ClimateWorks Australia's *Pathways to deep decarbonisation in 2050* report (ClimateWorks Australia et al., 2014). Under current and proposed policies, Australia's emissions are on track to an 11% decrease by 2030 on 2005 levels (ClimateWorks Australia, 2018), far below the level of decarbonisation required to meet Paris or net zero targets entirely from domestic abatement efforts beyond those implemented to meet the Kyoto targets, requiring the purchase of emissions permits arising from international abatement to make up the shortfall.

8.2.2 Modelling national emissions

Along with international action on climate change (imposed in the ANO modelling via an increasing price on carbon), numerous other factors determine emissions reductions at the national level, such as technology availability and costs. Each of these inputs were modelled within the core scenarios of ANO 2019 (CSIRO and NAB, 2019) with varying assumptions.

Given the ANO approach to emissions modelling is largely based on carbon pricing, there is no hard constraint applied to Australia's domestic emissions. The implication of this approach is that, whatever Australia's notional contribution to global emissions reduction might be under the scenario, the difference will be met between that emission level and the domestic abatement achieved through the purchase of international permits at the assumed prevailing carbon price. In summary, purchasing international abatement is lower cost than pursuing further domestic actions beyond those projected in the modelling. Conversely, if Australia's international share of abatement is exceeded, then this represents a potential opportunity to sell emission permits to other countries.

Slow Decline scenario

Under *Slow Decline* (Figure 8.2), overall net emissions decrease from 533 $MtCO_2e$ in 2016 to 476 $MtCO_2e$ in 2060. This decrease is driven primarily by a 94% decrease in emissions from electricity generation, while transport emissions also decrease 37% by 2060. These reductions are partially offset by emissions from other stationary energy more than doubling over the period, and a 62% increase in fugitive emissions in industry. As discussed in Section 7.2, there are minimal emissions reductions of around 28 $MtCO_2e$ through sequestration in the landscape.

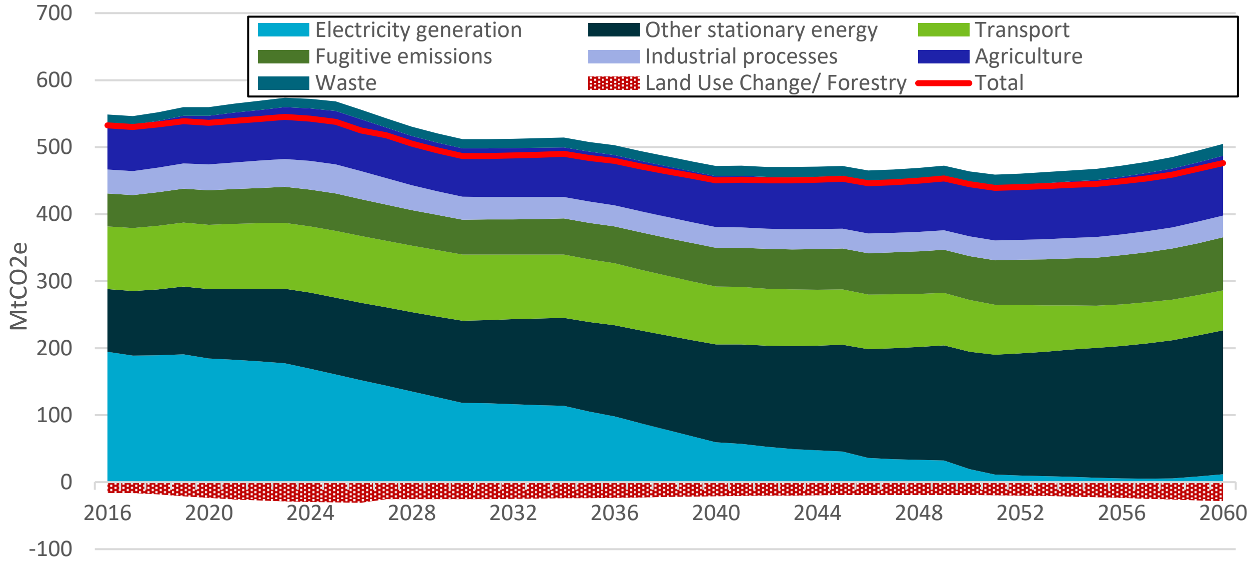

Figure 8.2 National emissions, 2016–2060, *Slow Decline*

Thriving Australia scenario

Thriving Australia (Figure 8.3) results in overall emissions slightly lower than *Slow Decline*, falling 19% to 432 $MtCO_2e$ in 2060. Compared to *Slow Decline*, similar reductions are achieved across transport and electricity generation. However, in order to achieve greater rates of energy productivity, stationary energy emissions are 66 MtCO2e lower than in *Slow Decline*, where energy productivity remains at current trends. There is a small level of abatement from carbon and environmental plantings in *Thriving Australia*, although it is greater than that achieved in *Slow Decline*, contributing to approximately 33 $MtCO_2e$ of emissions reductions achieved through land use change and forestry.

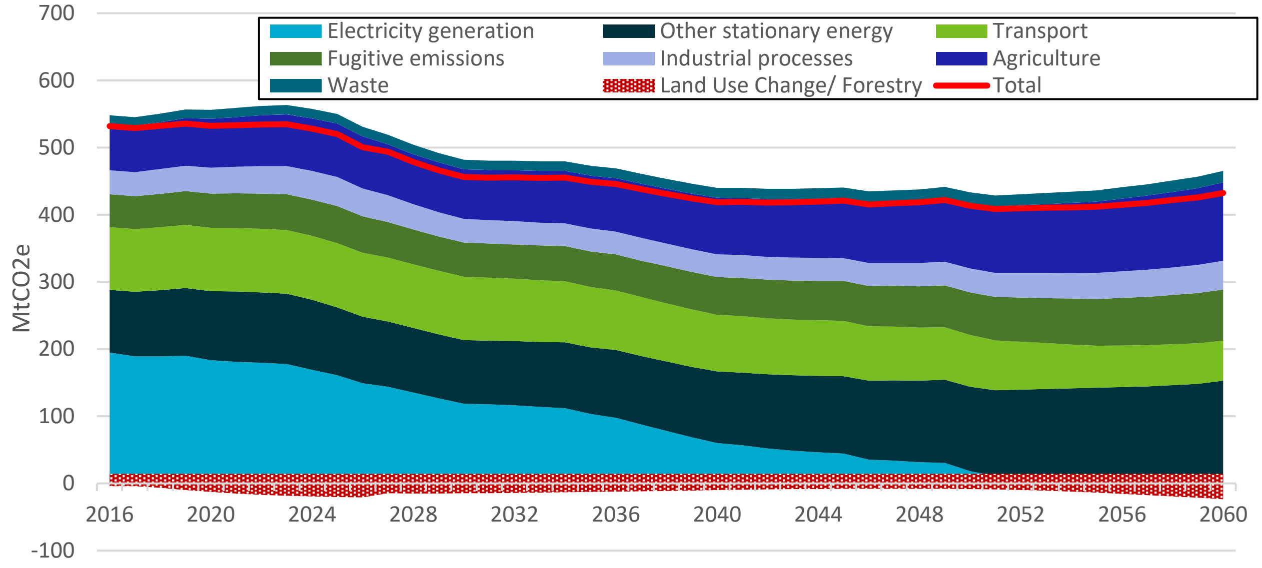

Figure 8.3 National emissions, 2016–2060, *Thriving Australia*

Green and Gold scenario

In the *Green and Gold* scenario (Figure 8.4), emissions (excluding land use change and forestry) fall gradually and consistently to 317 $MtCO_2e$ in 2060. These reductions are achieved across most of the economy, with the exception of agriculture (20% increase) and stationary energy, which increases by 39% due to strong growth in industrial production, partially offset by relatively strong energy productivity. By 2060, the shift to renewables has removed almost all emissions from electricity generation, with further reductions in transport (64%), industrial processes (36%), and fugitives (31%). Most significantly, the high incentives for carbon sequestration provide the opportunity to sequester as much as 700 $MtCO_2e$ of emissions through forest management (discussed in Section 7.2), leading to a net negative emissions position of –399 $MtCO_2e$ in 2060. This trajectory of abatement enables Australia to meet its 2030 Paris target of 26%–28% emissions reductions relative to 2005, reach net-zero emissions by 2050, and potentially export surplus abatement from forestry in the form of carbon credits.

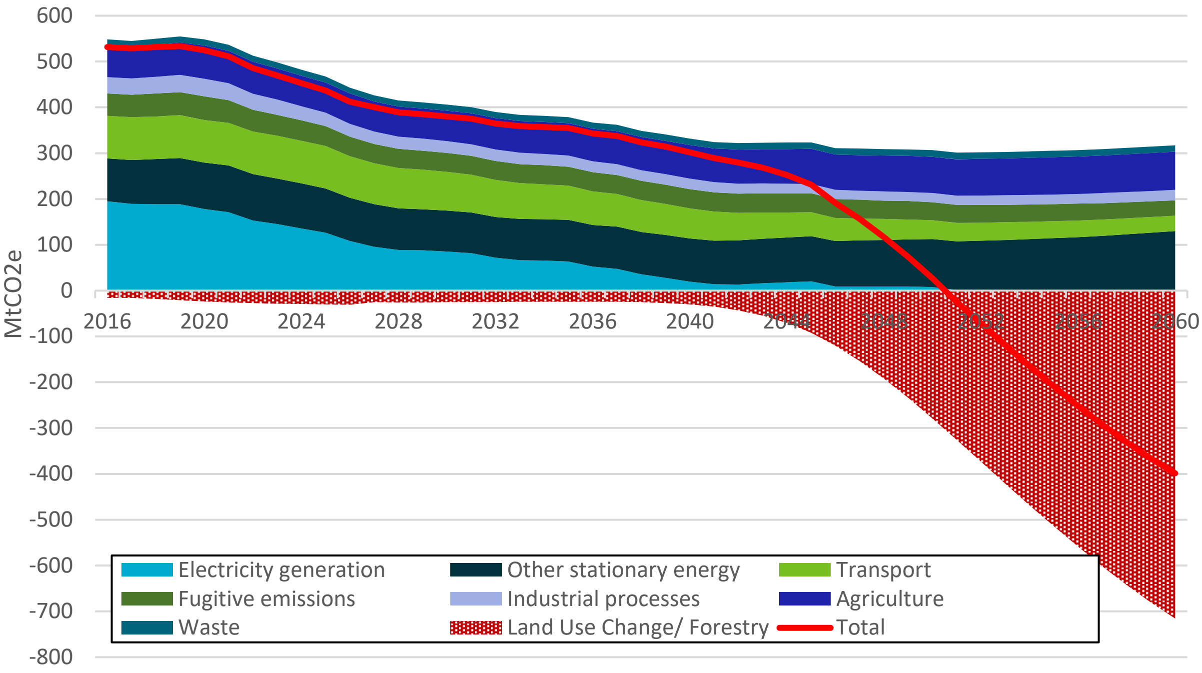

Figure 8.4 National emissions, 2016–2060, *Green and Gold*

Emissions intensity of gross domestic product (GDP)

Figure 8.5 demonstrates the relationship between GHG emissions and economic performance across the scenarios. Due largely to the extensive potential for carbon forestry under the modelling assumptions of *Green and Gold*, GDP per capita undergoes a significant ‘decoupling’ from emissions in this scenario relative to *Thriving Australia* and *Slow Decline*.

To compare the scenarios in more detail, Figure 8.6 shows the emissions intensity of GDP, calculated as the amount of emissions per unit of GDP, and presented as an index to observe changes over time. Even ignoring the potential for vast emissions reductions achieved through carbon forestry, economic performance in *Green and Gold* shows a higher rate of decoupling from emissions than both *Thriving Australia* and *Slow Decline*, through a larger decline in emissions intensity of GDP over the modelling period. This confirms the findings of ANO 2015 (CSIRO, 2015) that stronger action on environmental measures such as emissions reductions need not come at the expense of economic growth.

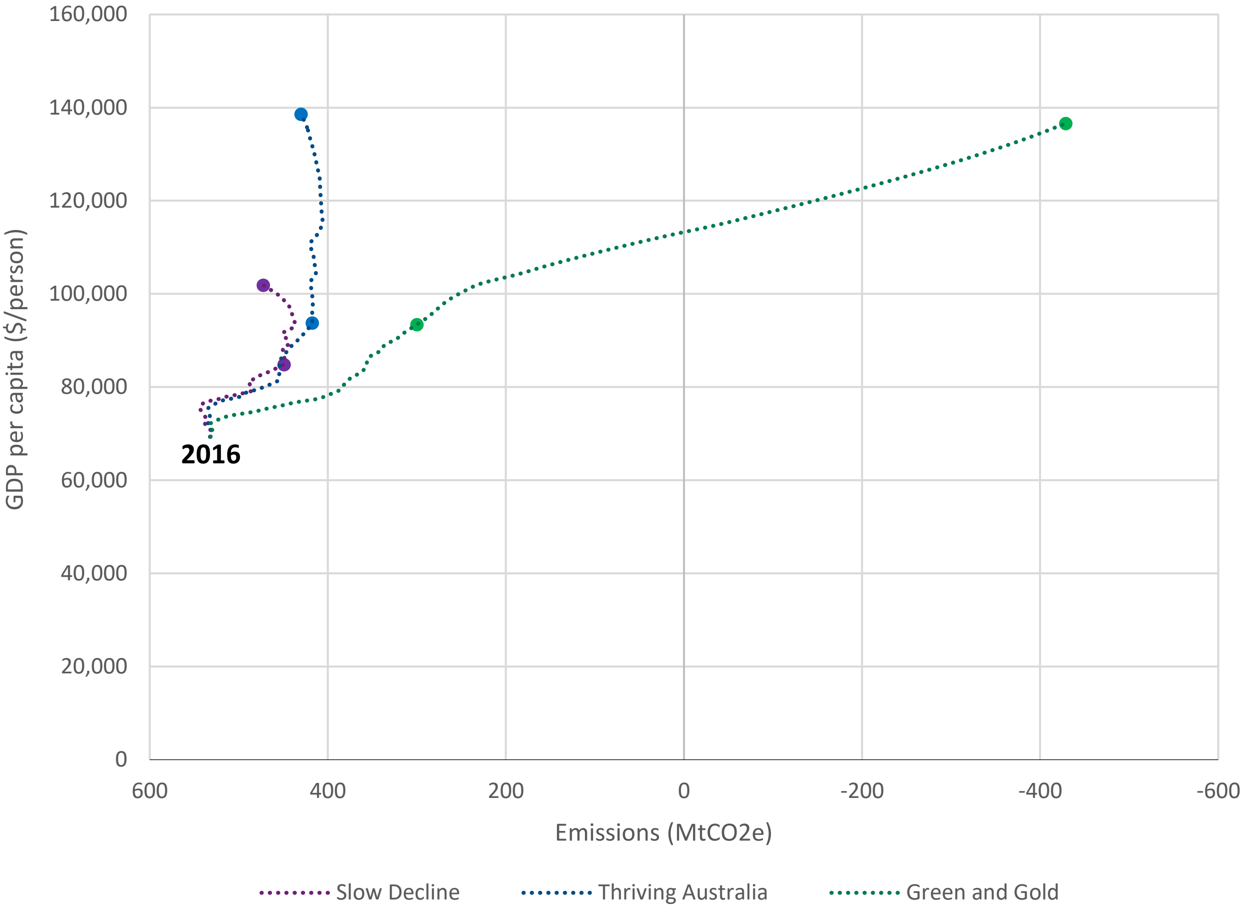

Figure 8.5 GDP per capita and national emissions by scenario

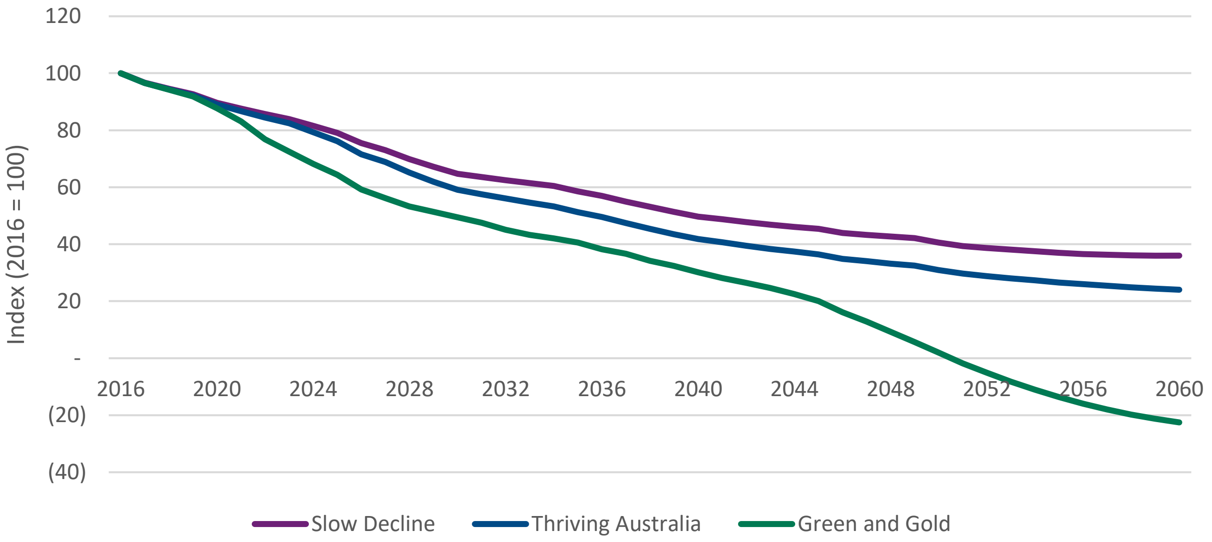

Figure 8.6 Emissions intensity of GDP, 2016-2060, index

Decomposition of emissions reductions in the scenarios

To identify the contribution of different components to overall emissions reductions, the emissions trajectories of each scenario were compared to a 'baseline' calculated by holding emissions intensity constant and applying this to production quantities observed in the scenarios. This is presented at 2030 and 2060 for the *Green and Gold* scenario in Figures Figure 8.7 and Figure 8.8. The decline in emissions relative to this baseline for *Green and Gold* was then attributed to different 'pillars', broadly in line with those identified in *Pathways to deep decarbonisation in 2050* (ClimateWorks Australia et al., 2014). Between 2016 and 2030, almost all of the reductions in emissions are due to energy productivity improvements and the decarbonisation of the electricity generation sector. By 2060, there is a more even share in the emissions reductions by pillar relative to the baseline, with low-carbon electricity, energy productivity and sequestration contributing 24%, 33% and 35% of reductions, respectively. This is due to the annual energy productivity improvements assumed in the modelling (described in Chapter 6, Section 6.1), the complete decarbonisation of electricity generation by 2060, and the extensive sequestration potential of carbon forestry brought about by an increasing carbon price, particularly post-2040.

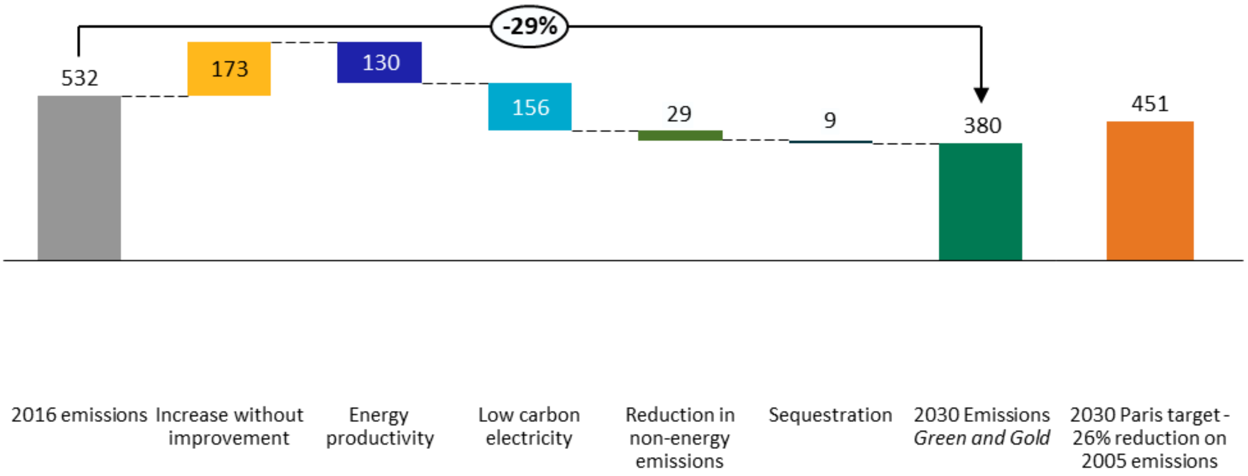

Figure 8.7 Emissions reduction in 2030 relative to 2016, decomposition by pillar, *Green and Gold* ($MtCO_2e$)

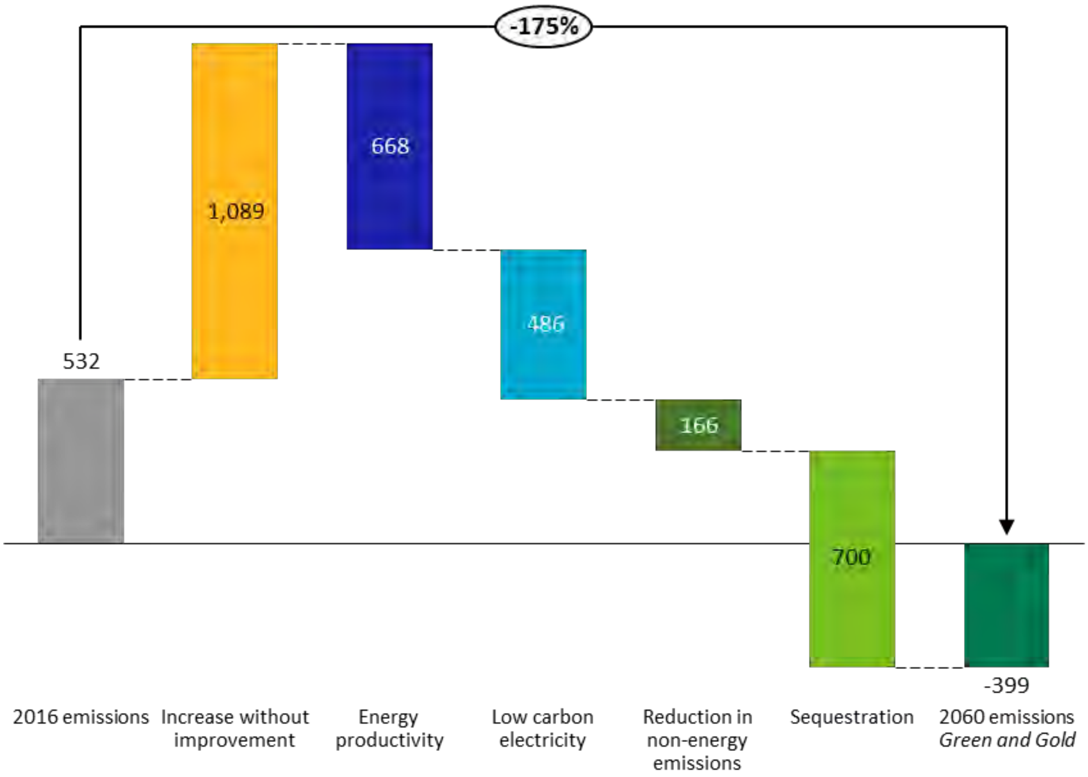

Figure 8.8 Emissions reduction in 2060 relative to 2016, decomposition by pillar, *Green and Gold* ($MtCO_2e$)

8.3 Climate impacts

ANO 2019 explores the effects of climate change qualitatively and quantitatively through mitigation and adaptation using two global contexts (see Chapter 2 and Chapter 3).

Differences in mitigation effort have been incorporated in the national results and are discussed in Chapter 3. However, climate impacts and adaptation were not part of the core modelling suite used in ANO 2019. This is because relevant data were not readily available in an appropriate format for modelling, highlighting the need for an integrated national assessment of the costs and benefits of climate change, with and without adaptation and/or mitigation. Instead, economic impacts of climate change on Australia have been explored through a literature review with modelling limited to exploring the effects of drought in agriculture. Further details on this analysis can be found in the following section.

8.3.1 Analytical framework used to conduct literature review of economic impacts of climate change

Evidence of the economic impact of climate change was sought to inform the ANO 2019 scenario modelling both in terms of the model inputs and outputs. It was also considered timely to develop a summary of the evidence of economic impacts of climate change at the global and Australian scales and at the sectoral level in Australia.

A systematic review was undertaken to find literature and data on the economic impacts of climate change with particular focus on Australia. Empirical evidence was collected and summarised that fit the following pre-specified research questions:

- What is the expected economic impact (e.g. on GDP) in 2060 for **Australia on a trajectory of 2 °C** of global warming compared to a pre-industrial baseline by 2100?
- What is the expected economic impact (e.g. on GDP) in 2060 **globally on a trajectory of 2 °C** of global warming compared to a pre-industrial baseline by 2100?
- What is the expected economic impact (e.g. on GDP) in 2060 for **Australia on a trajectory of 4 °C** of global warming compared to a pre-industrial baseline by 2100?
- What is the expected economic impact (e.g. on GDP) in 2060 **globally on a trajectory of 4 °C** of global warming compared to a pre-industrial baseline by 2100?
- What research has been conducted on **sectoral impacts** of climate change in Australia and globally?
- What are the costs and benefits of **adaptation** (building resilience) and what are the residual impacts?
- What are the costs and benefits of **mitigation** (reducing net GHG emissions) and what are the residual impacts?
- Is there evidence to support the conclusion that **it is more cost effective (cheaper) to mitigate and adapt** some climate change now (resulting in 2 °C of global warming) than deal with the larger adaptation and residual damage from climate change later (resulting in 4 °C of global warming)?

ANO 2019 considers economic impacts in 2060 for global warming scenarios of 2 °C and 4 °C above the pre-industrial baseline (1850 to 1900) in 2100. This corresponds to the upper end of the warming range for RCP 2.6 and RCP 6.0, respectively (Box 1). Scenarios also sought to consider mitigation and adaptation activities and their effect on the economic impact of climate change. In addition, economy-wide impacts and sectoral impacts were sought. Evidence fitting these pre-defined criteria were included in the analysis and used to inform the modelling.

In many cases, the published literature refers to economic impacts for different amounts of global warming (e.g. 1.5 °C, 3 °C), or different baseline periods (e.g. 1986 to 2005), or specific years in the 21st century (e.g. 2050, 2100), or specific GHG emission/concentration scenarios (e.g. SRES A1FI, RCP8.5). Where possible, statistical conversions were made to express the changes in terms of global warming relative to the pre-industrial baseline (see Box 1), otherwise the literature was excluded from the analysis.

Many impact studies might include or exclude costs and/or benefits of mitigation and/or adaptation, and adaptation might be pre- or post-impact. Understanding which combination is used for a scenario, which scenarios have been used in a report and how these variables interact is often very difficult.

Registers of the published literature on economy-wide (GDP) and sectoral economic impacts of climate change have been developed.

Box 1 Climate impacts

According to the Intergovernmental Panel on Climate Change (IPCC, 2013), there is clear evidence for climate change; for example, a surface global warming of 0.85 °C from 1880 to 2012, and a rise in global average sea level of 17 to 21 cm from 1901 to 2010. IPCC (2018) concluded that global warming reached 1 °C in 2017. It is extremely likely that human influence has been the dominant cause of the observed global warming since the mid-20th century. Human influence has also been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise and in changes in some climate extremes.

Scenarios of future emissions and concentrations of GHGs, aerosols and chemically active gases have been developed (van Vuuren et al., 2011). The IPCC selected four representative concentration pathways (RCPs), namely RCP 2.6 (where radiative forcing peaks at 3 W/m^2 before stabilising at 2.6 W/m^2 by 2100), RCP 4.5 and 6.0 (where radiative forcing is stabilised at 4.5 and 6.0 W/m^2 after 2100), and RCP 8.5 (where radiative forcing reaches more than 8.5 W/m^2 by 2100).

Continued net emissions of GHGs in the 21st century will cause further warming and changes in all components of the climate system (IPCC, 2013). Global warming by 2100 relative to the pre-industrial period 1850 to 1900 is likely to be 0.9 to 2.3 °C (RCP 2.6), 1.7 to 3.2 °C (RCP 4.5), 2.2 to 3.9 °C (RCP 6.0), or 3.6 to 5.8 °C (RCP 8.5)[1]. RCP 2.6 and RCP 6.0 have been used for the ANO project because the upper end of the global warming range corresponds with 2 °C and 4 °C above the pre-industrial baseline (1850 to 1900) in 2100. This will be associated with:

- ongoing sea level rise
- more and longer heat waves, and fewer extremely cold events
- more precipitation over high latitudes, the equatorial Pacific and many mid-latitude wet regions, but less precipitation over many mid-latitude and sub-tropical dry regions
- more intense and more frequent extreme rainfall over most of the mid-latitude land masses and over wet tropical regions
- fewer tropical cyclones, but a greater proportion of high-intensity cyclones
- increased fire frequency, intensity and duration.

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[1] These values for temperature impacts at 2100 slightly exceed those indicated by the thin bars of Figure 8.9, which cover a period range 2080-2099. They also slightly exceed the means in the second column of Table 13.5, which also cover a period range of two decades 2081-2100.

TEMPERATURE ANOMALIES FROM 1850-1900 (°C)

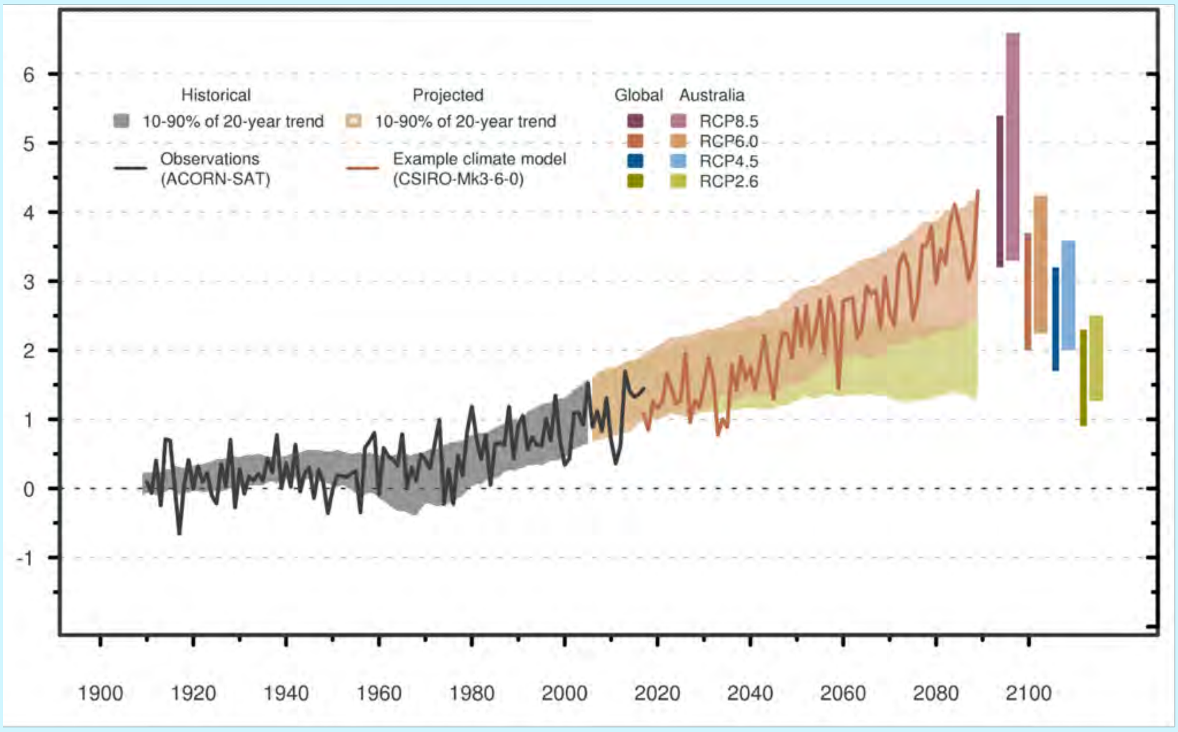

Figure 8.9 Australian temperature record and projections

This figure shows a time series of Australian average annual temperature anomalies for 1910 to 2100 relative to a baseline approximating pre-industrial conditions (the 1850 to 1900 average). It includes observations, the range from the Coupled Model Inter-comparison Project phase 5 (CMIP5) set of global climate models, and an example model. Future projections use the emissions scenarios termed representative concentration pathways (RCPs), and the bars at the side show the average for each RCP in 2080 to 2099 for the globe (thin bars) and Australia (thick bars). For more details on data sources and methods visit: www.climatechangeinaustralia.gov.au.

8.3.2 Global and national impacts

There are multiple lines of scientific evidence that the global climate system is warming and that humans influence the climate system through increases in greenhouse gases (IPCC 2014). It is also clear that unmitigated global warming will cause economic loss both globally and in Australia (Stern 2006, OECD 2015, Diaz and Moore 2015, Garnaut 2008, Kompas, Pham and Che 2018). In this report, the effects of climate change were explored qualitatively and quantitatively through mitigation and adaptation. Differences in mitigation effort (reducing greenhouse gas emissions) have been incorporated in the national results by applying a price on greenhouse gas emissions and through assumptions about technological development driving TFP.

The most reliable estimates aligned to the scenarios indicate that 4°C global warming without adaptation could lead to a global GDP loss of 7.2% and an Australian GDP loss of 1.6% by 2100 (Kompas, Pham and Che 2018, see also Figure 7.10). If mitigation can limit the global warming to 2°C by 2100, the global GDP loss would be reduced to 0.5-1.6% by 2050-60 and 1.8% by 2100, and the Australian GDP loss would be reduced to 0.6% by 2100 (*ibid.*), The GDP loss would be further reduced by adaptation (OECD 2015).

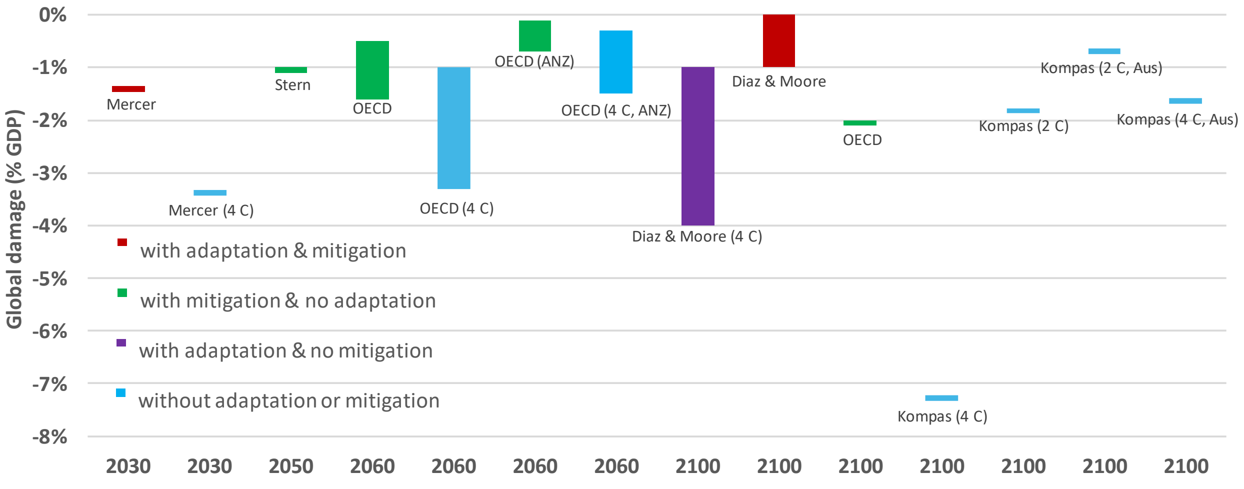

Figure 8.10 Estimated GDP loss (%) due to climate change

This figure shows estimated GDP loss (%) due to global damage caused by climate change for various combinations of adaptation and mitigation by 2030, 2050, 2060 and 2100. All estimates are global except for Australia (Aus) and Australia and New Zealand combined (ANZ). Scenarios *without mitigation* lead to a global warming of 4 °C by 2100 relative to 1850–1900. The scenarios *with mitigation* lead to a global warming of about 2 °C by 2100 relative to 1850–1900. Source: Stern (2006), Mercer (2011), OECD (2015), Diaz and Moore (2017) and Kompas et al. (2018).

Australian sectoral impact

Reisinger et al. (2014) provided a good summary of impacts for various Australian sectors, regions, timeframes and RCPs. The sectors with the most information were infrastructure, building and agriculture. However, this information was dominated by physical impacts (e.g. changes in species abundance, heat-related deaths or crop yield) with limited coverage of economic impacts. More recent literature included physical, economic and social impacts.

Table 8.1 Summary of Australian sectoral impacts

SECTOR	IMPACTS
Infrastructure	• There is an increase in the cost of supplying urban water by 34% with no mitigation (4.6 °C warming in 2100 relative to pre-industrial). This could be reduced to a 4%–5% increase with globally effective mitigation (stabilisation at 450 or 550 ppm CO_2-eq, 2.4 °C warming in 2100 relative to pre-industrial) (Garnaut, 2008). • There is $46–60 billion in asset value of road infrastructure (including freeways, main roads and unsealed roads) and $4.9-6.4 billion in rail and tramway infrastructure in Australia at risk of a sea level rise of 1.1 m by 2100 (2008 replacement value) (DCCEE, 2011). • Deloitte Access Economics (2016) projected the total economic costs of natural disasters to reach $34 billion per year by 2050 in Australia due to an increase in the amount and value of coastal infrastructure, up from around $10 billion per year in 2015. However, this figure does not include future climate change. • Cleugh et al. (2017) reviewed a variety of studies in Australia and around the world (e.g. Deloitte Access Economics, 2013; Mechler, 2016; Wang et al., 2016), and found growing evidence that adaptation costs for infrastructure are typically around 10% of the benefits gained from avoided damages, even when the benefits are discounted over time.
Agriculture	• 16% decline in Australian agricultural production by 2080 with no mitigation (Cline, 2007) • 92% drop in irrigated agricultural production in the Murray-Darling Basin by 2100 with no mitigation (49% by 2050) (4.6 °C warming in 2100 relative to pre-industrial). This could be reduced to a 6%–20% loss with globally effective mitigation (stabilisation at 450 or 550 ppm CO_2-eq, 2.4 °C warming in 2100 relative to pre-industrial) (Garnaut, 2008) • 9%–10% decline in Australian production of wheat, beef, diary and sugar by 2030 and 13%–19% decline by 2050. Declines in the Australian exports of these commodities of 11%–63% by 2030 and 15%–79% by 2050 (no mitigation) (Gunasekera et al., 2007)

SECTOR	IMPACTS
	• In 2100, globally effective mitigation (stabilisation at 450 or 550 ppm CO_2-eq, 2.4 °C warming relative to pre-industrial) could reduce the decline in irrigated agricultural production in the Murray-Darling Basin from 92% to only 6%–20% and reduce the increase in the cost of supplying urban water from 34% to only 4%–5% (Garnaut, 2008).
Dwellings	• There is $51-72 billion in asset value of residential buildings in Australia at risk of a sea level rise of 1.1 m by 2100 (2008 replacement value) (DCCEE, 2011). • By 2030 the accumulated loss of land value from storm surge is likely to be between $823 million and $1086 million (Fletcher et al., 2013; Rambaldi et al., 2013). • Unmitigated climate change is expected to increase wind damage to dwellings, costing Cairns, Townsville, Rockhampton and south-east Queensland up to $3.8, $9.7 and $20.0 billion by 2030, 2050 and 2100, respectively (assuming a 4% discount rate) (Stewart and Wang, 2011). • The present value of expected direct damages to residential housing in the absence of mitigation is substantial but at least half of these direct damages can be avoided through proactive intervention, applying well known measures, and the cost of intervention is one-tenth or less than the damages avoided in present value terms (Stafford Smith, 2014). • For coastal residential buildings, expected damage due to sea level is about $8 billion (NPV) by 2100 (A1B scenario, 3.5 °C warming relative to pre-industrial). The best performing adaptation action/stance combination (Anticipate Protect) designed to reduce vulnerability to storm tides can reduce expected damages to residential housing to around $200 million and provides net benefits of around $4 billion up to 2100 (NPV, $2006, 2.6% discount rate) compared with implementing current standards on the basis of historical climate information. The best performing stance/action combination (Anticipate Protect) produces up to $12.8 billion net benefit under the A1FI scenario (4.6 °C warming relative to pre-industrial; Wang et al., 2016). • Increasing the design wind classifications in the Australian Standard *Wind Loads for Houses AS4055-2012* for all new housing in south-eastern Australia can lead to risk reductions of 50%–80%, at a cost of no more than 1%–2% of house replacement value (Stewart, 2013).
Energy	• The total heating/cooling energy requirement of 5-star houses is projected to vary significantly by 2100. For a 2 °C global warming (550 ppm scenario), the change in energy demand is –27% in Hobart, –21% in Melbourne, +61% in Darwin, +67% in Alice Springs and +112% in Sydney. For a 4 °C global warming (A1FI scenario), the changes are –48%, –14%, +135%, +213% and +350% respectively (Wang et al., 2010).
Business	• $58–81 billion in asset value of commercial buildings (used for wholesale, retail, office and transport activities) in Australia at risk of a sea level rise of 1.1 m by 2100 (2008 replacement value) (DCCEE, 2011). • $4.2–6.7 billion in asset value of light industrial buildings (used for warehousing, manufacturing, and assembly activities and services) in Australia at risk of a sea level rise of 1.1 m by 2100 (2008 replacement value) (DCCEE, 2011). • $2.5 billion in adaptation costs to 2015, to meet increasing demand for air conditioning and increase resilience to climate-related hazards (Parsons Brinkerhoff, 2009). • If coral bleaching persists, tourism areas adjacent to the Great Barrier Reef could see the number of visitors being reduced from 2.8 million (2015 figures) to around 1.7 million per year. This is the equivalent of more than $1 billion in tourism expenditure, threatening around 10,000 tourism jobs in regional Queensland (Swann et al., 2016).

Extreme weather events in agriculture

Where climate change has been modelled, the focus has been limited to specific impacts, such as the different rainfall and temperature trajectories considered in LUTO. For agriculture, changes in average temperature and rainfall may have less impact than the effects of extreme weather events such as droughts, which are expected to become more frequent under climate change.

In order illustrate the potential impacts of extreme events occurring more frequently, a future drought scenario was modelled in LUTO (detailed in Chapter 16). Quantifying the impact of a potential future extreme event is difficult, as the intensity, frequency and duration of such events cannot be predicted decades in advance with high confidence. However, by simulating such an event, ANO 2019 is able to provide some guidance on the magnitude of potential impacts of climatic events that are expected to increase in frequency and severity under climate change.

To simulate the impacts of an extreme drought event, similar rainfall and temperature levels to those experienced in the Millennium Drought were modelled in LUTO at an arbitrary future date. The model then predicted what the results of this drought would be on winter cereals, which make up a large proportion of Australia's agricultural production and are vulnerable to events such as drought. Significant drought events reduce both the yield and productivity improvements that can be achieved during the event, impacting profitability both at the time of drought and in subsequent years. The modelling shows more pronounced profitability impacts in scenarios that relied on high productivity gains, due to these combined effects of reduced yield and lost productivity gains. Importantly, both Thriving Australia and Green and Gold scenarios see higher rates of profitability than Slow Decline, even under a drought simulation, demonstrating the importance of long-term productivity improvements in buffering against extreme weather events.This analysis is not intended to be predictive of the scale of events that may occur during the time period modelled – in reality, extreme events may well be larger or smaller due to inherent climate variability.

As shown in Figure 8.11, the model represents this drought through declined production and reduced rates of productivity improvement as was experienced during the Millennium Drought from 1997 to 2009. This demonstrates the potential for drought to have a substantial impact on both the short-term and long-term profitability of production, which would place acute pressure on farmers in the short term and potential chronic pressure in the long term.

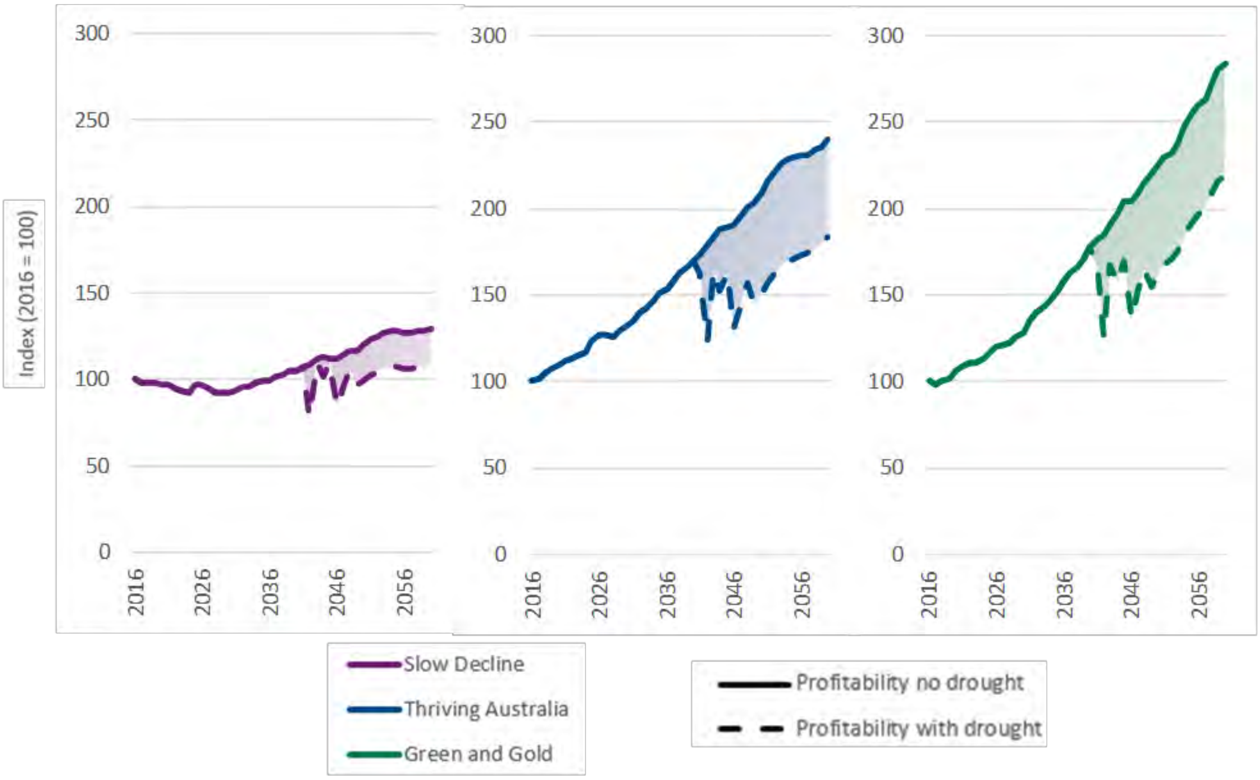

Figure 8.11 Impact of imposed drought event on profitability of winter cereals by scenario

Caveats

The economic impact estimates in the published literature that were used in this project, like the physical impacts, are likely to be conservative and under-predict the damage from climate change. Several studies have concluded that the primary reports on climate change (such as by the IPCC, Garnaut, etc.) under-estimate the projected changes in extreme weather events and the associated impacts (Brysse et al., 2013; Rahmstorf et al., 2007; Pielke, 2008; NRC, 2009; Allison et al., 2009).

There is growing recognition of the limitations of integrated assessment models (IAMs) used to estimate the economic impacts of climate change, with/without adaptation and/or mitigation, especially for global warming beyond 2 °C (Stoerk et al., 2018). These models largely ignore the potential for 'tipping points' beyond which impacts accelerate, so economic damages are probably under estimated.

The IPCC acknowledges the likelihood of impacts being under-estimated:

> *"It is very likely that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. It is virtually certain that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries and populations. In some locations and amongst some groups of people with high exposure, high sensitivity and/or low adaptive capacity, net costs will be significantly larger than the global average." (IPCC 2007)*

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9 Model integration

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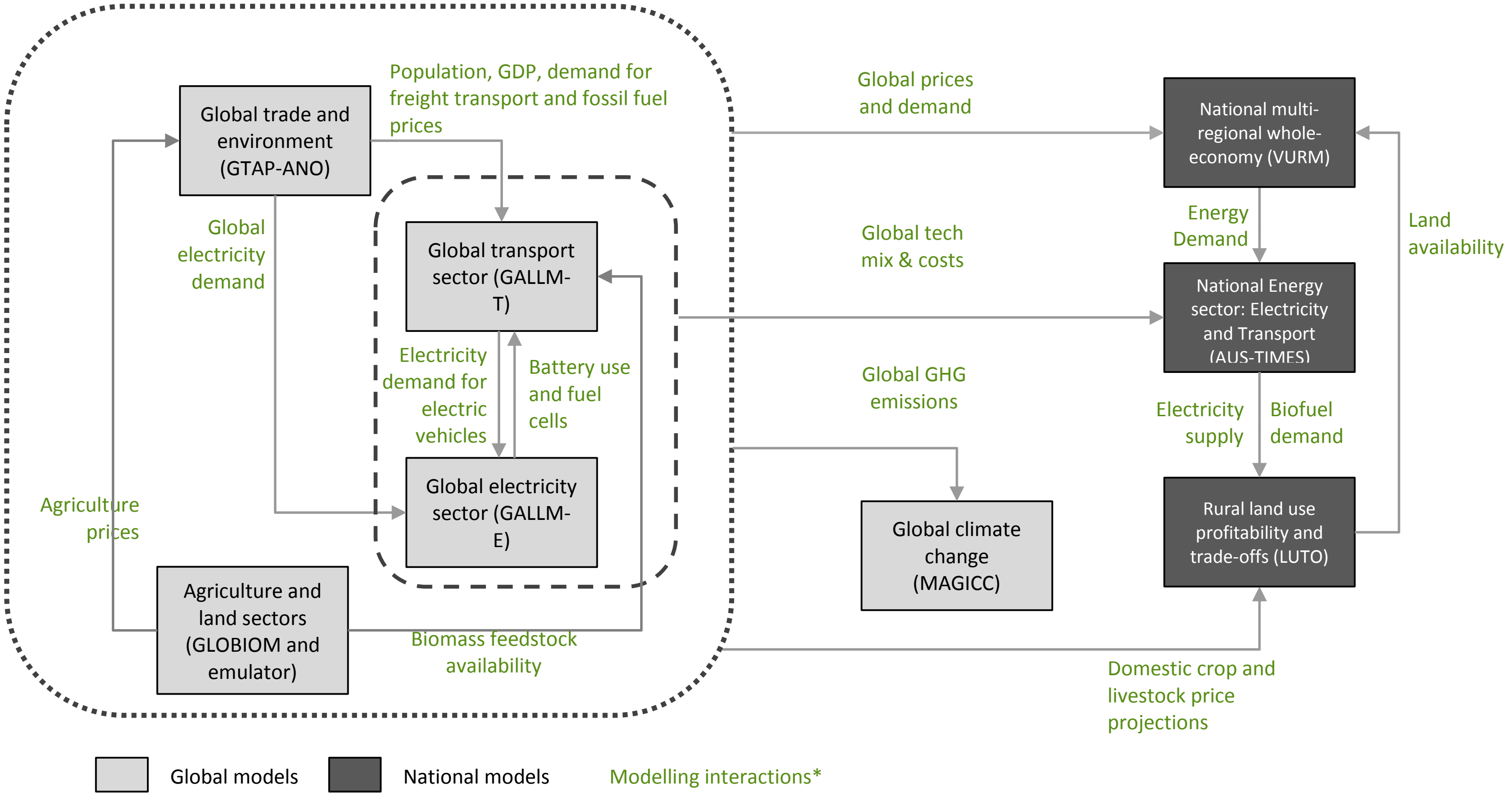
9.1 Introduction

The conclusions of the Australian National Outlook (ANO) 2019 are supported by analysis using quantitative models that are not only credible tools for exploring their specific domains in their own right, but are also integrated. That is, the most important assumptions of these models are aligned to be mutually consistent. This is achieved by ensuring that modelling assumptions are consistent with defined contextual scenarios (see Chapter 2) and that results derived from the analysis by the most reliable model(s) are imposed as assumptions on others.

The quantitative modelling analysis underpinning ANO 2019 has been undertaken by some five core global models representing economic, electricity, transport, land-use and climate international context variables, and four core national-scale models representing economic, electricity, transport, and land-use national variables. Collectively we refer to this ANO 2019 model suite as GNOME.3 – a Global and National Optimisation Model for the Environment, Energy and Economics.

This chapter outlines why these quantitative models in particular were selected for inclusion in GNOME.3, and how they were coordinated to work in a mutually consistent manner. In brief, significant modelling assumptions derived from either articulated self-consistent scenarios that characterised conditions independent of those represented by each model in the ANO 2019 suite, or from modelled results calculated by another model in the suite. Where one or more quantitative models provides (alternative) representations of the same feature any differences among reported results are reconciled before subsequent use, based on understanding the strengths and weaknesses of each model.

In principle, the causation structure of the underlying reality that the quantitative models represent is not unidirectional, however for pragmatic reasons we impose an approximate causation structure on the relationship among our quantitative models that is predominantly unidirectional, and verify with post-model analysis that the resulting inconsistencies are sufficiently immaterial to the conclusions we ultimately draw.



Simplified representation of core models. Excludes scenario/workstream inputs.

Figure 9.1 GNOME.3 Modelling suite overview

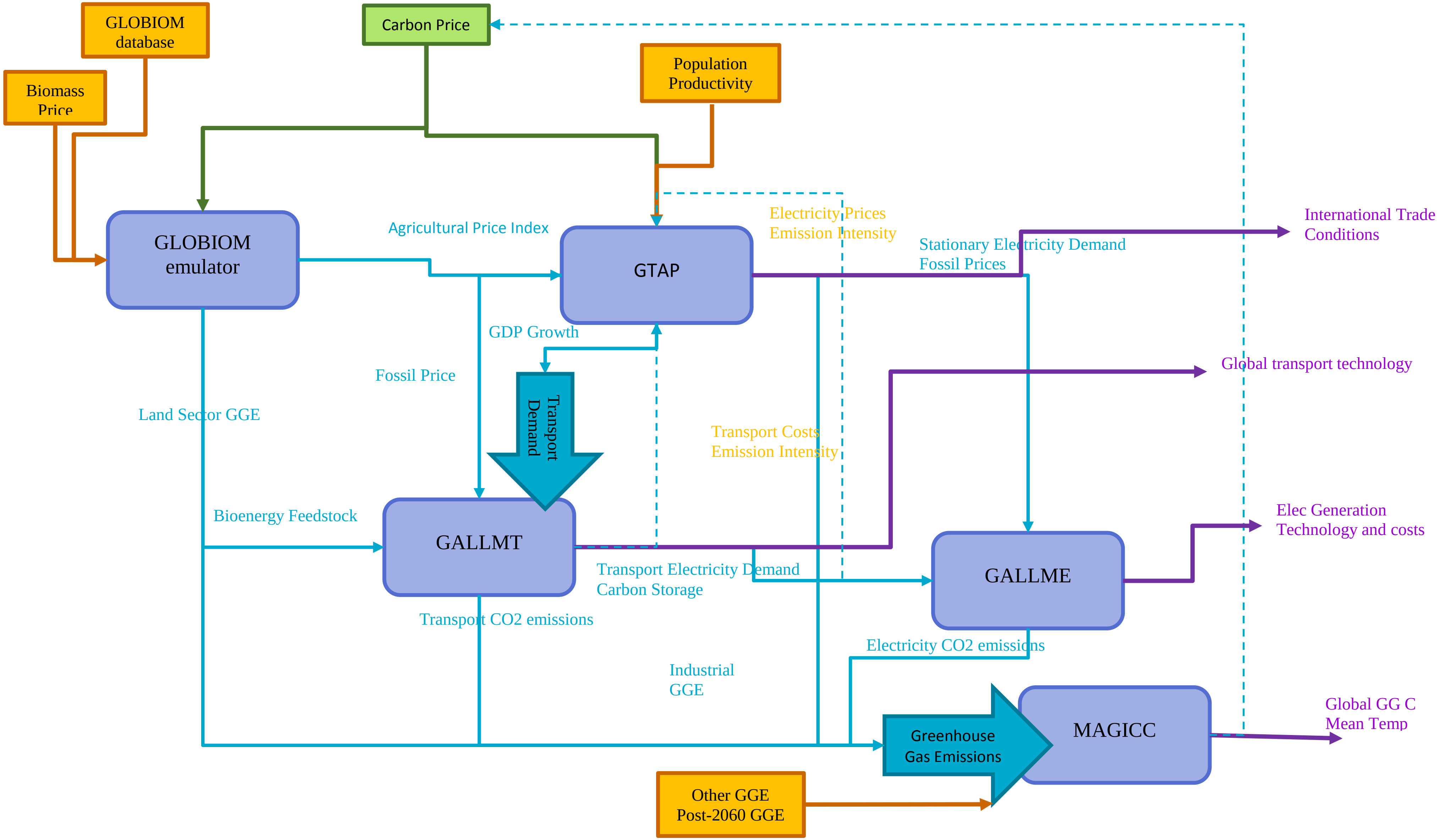


Figure 9.2 GNOME.3 Global modelling suite interactions

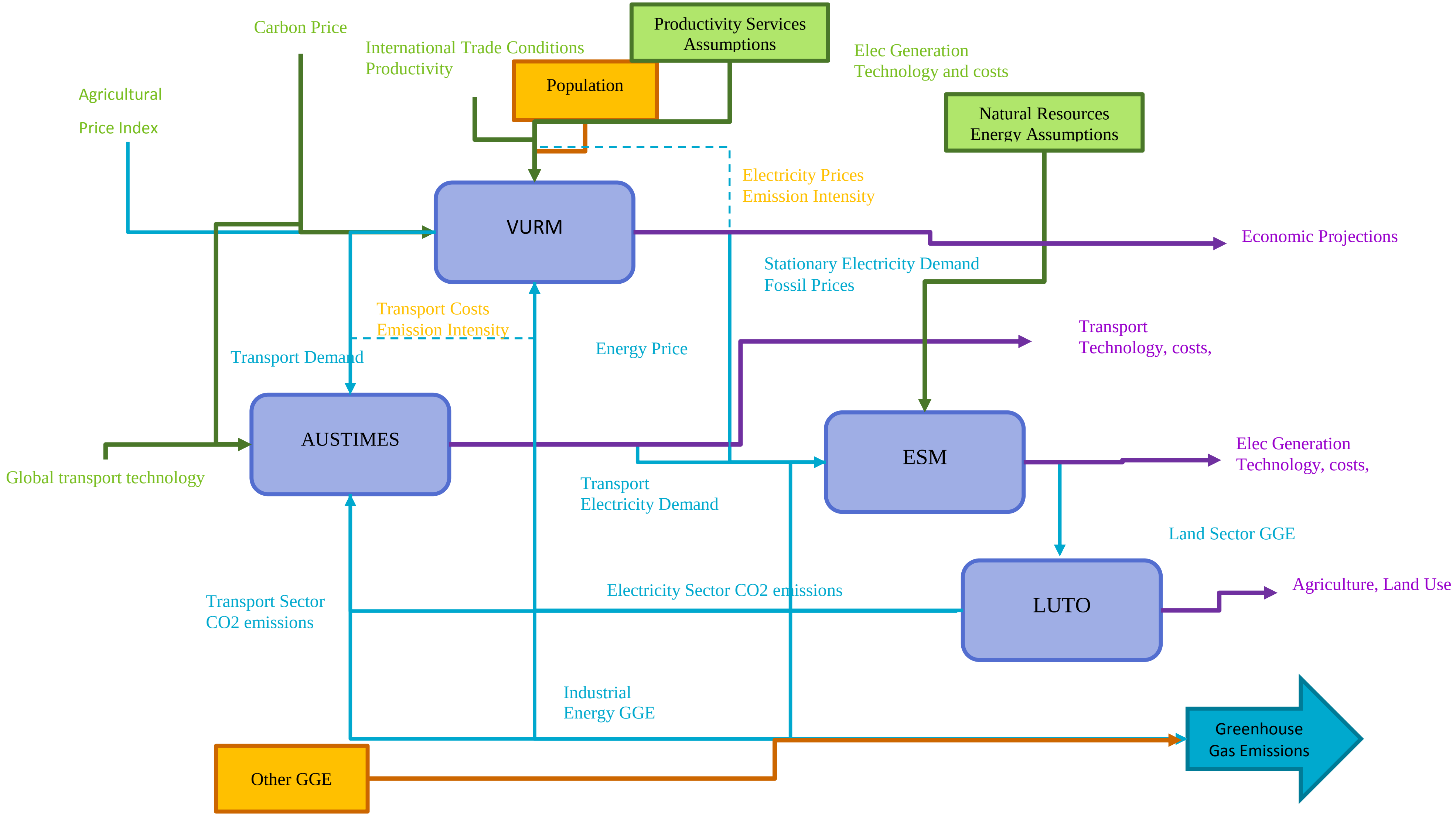


Figure 9.3 GNOME.3 National modelling suite interactions

9.2 Model Interlinkage and Scenario Settings Structure

The GNOME.3 modelling suite evolved from the modelling suite used in ANO 2015 (CSIRO, 2015) and was organised for ANO 2019 into two distinct groups: a global modelling suite representing international context and a national modelling suite representing outcomes for Australia at a higher spatial resolution (See Figure 9.1). We allowed results from the global modelling suite to set various international contextual assumptions for the national modelling, but did not implement any feedback whereby results from the national modelling analysis were used to inform global quantitative analysis assumptions. The reason for this is that Australia is a globally open economy (see Chapter 3), whose economic and geopolitical circumstances are reasonably strongly affected by the global environment. However, across most industries it is a relatively small actor at the global scale. It is therefore reasonable to assume that any difference in the results of modelling different national scenarios at the national Australian scale are not required to be provided to the global modelling settings. Rather, the global projections influence the national projections, but not vice versa.

9.2.1 Final workflow

9.2.1.1 Global model suite

The description following of model workflow and interlinkages for the global modelling distinguishes model assumptions that are model specific from those that are common to more than one model, those that are independent of specific scenario and those that are scenario specific, those that are exogenous to all models versus those that are a results of some models but applied exogenously to others.

The final implementation of the global modelling workflow was the following (See Figure 9.1 and Figure 9.2). The scenario settings inform the land use model emulator, the GLOBIOM emulator, which informs the global economic model, GTAP-ANO. This provides transport demand projections for the transport sector model GALLMT, which is also informed by the biofuel feedstock availability advised by the global land use model. The transport model provides projections of demand for electricity for electric vehicles, which is added to other electricity demand from the economic model to be provided to the global electricity generation cost model, GALLME. Greenhouse gas emissions projections from each of the four emission generating global models are combined as input to the simplified global climate model, MAGICC to produce projected global climate impacts, confirming the reasonableness of the choice of global carbon price trajectory to achieve close to the climate impact targets. Results from the outputs of the global models provide the international context settings for the national models.

For the national modelling workflow, the global modelling results and scenario settings inform first the national economic model, VURM. The economic results, together with national scenario assumptions, provides transport demand to the transport model AUS-TIMES which projects demand for electricity for vehicles which is again added to electricity demand projections from the economic model to provide electricity demand for ESM, using electricity and transport cost projections from the global modelling. For the national land-use model, LUTO, various cost indices are obtained from the global model results, the national economics projections and the national energy sector projections, as well as demand for biofuel feedstock. Land-use projections from the land-use model are imposed on the national economics model to limit the modelled substitutability of land for alternative agricultural purposes. The following provides more details.

First, global scenario assumptions determined the selection of carbon price and SSP settings in which to base global the land-use model GLOBIOM emulator. The SSP setting determines the global biomass price trajectory. The GLOBIOM emulator results of particular interest for other models include international agricultural price trajectories, the availability of biomass for bioenergy feedstock, and greenhouse emissions from global land use.

The global economic model GTAP-ANO, accepts scenario assumptions about the selection of global carbon prices, and SSP settings on which to base global population and economic productivity growth assumptions. Scenario independent assumptions about fossil fuel prices in absence of a carbon price are also provided as in input. Trade barriers assumptions are part of the scenario settings. Price indices for the agricultural subsectors are provided from the GLOBIOM emulator. The results from the global economic model of relevance to downstream models includes the endogenous fossil fuel prices in the presence of a global carbon price scheme, GDP per capita, which informs demand for transport services, the demand for electricity as part of the energy mix, and greenhouse gas emissions from economic sectors not represented by the other global models.

Transport services demand projections are inferred from GDP per capita results from the global energy model, and biofuel feedstock availability is informed by the global land-use model. Together with scenario assumptions about a global emissions price penalty and fossil fuel price projections from the global economic model, these settings determine the results from the global transport model, GALLMT, including the demand for electricity for electric vehicles and biofuels and prospects for battery technology cost improvements. This, in addition to other demand for electricity from the global economic model provides demand requirements for the global electricity generation cost model GALLME, and combined with biofuel feedstock availability from the land use model determines the remaining feedstock available for bioelectricity. Results of both the transport and electricity global models include direct carbon dioxide emissions from these two global sectors as well as technology mix projections and demand for fuels.

Emissions projections for the main greenhouse gases are derived from each of the preceding global models – the GLOBIOM emulator for the land use sector, the transport and electricity detailed sectoral global models for these two sectors, and the global economic model for the remaining sectors. Emissions of remaining gas species are assumed by global scenario. The emissions projections from the four other global models are accumulated and provided to the simplified global climate model, MAGICC. This model is then able to project the consequential impacts on radiative forcing and temperature.

Potentially significant global feedbacks that were neglected include:

- the effect of technology mix from the electricity sector and emissions and costs of electricity on the global economic model
- the effect of costs of transport technology and mix of fuel demand, and emissions on the global economic model

- the effect of the cost of electricity on the transport sector
- the effect of demand for bioenergy feedstocks on global bioenergy prices.

We also neglected to explicitly include an additional modelled feedback loop to ensure that carbon price projections resulted in an targeted global greenhouse gas atmospheric concentration.

Where the same or similar features (modelled phenomena) are represented by more than one model the general principle is that they are checked for general consistency, as evaluated by expert modeller judgement, and if there is a significant difference, they are investigated further or results reconciled by iterative feedback until sufficient convergence is realised. At present the workflows are insufficiently automated to permit routine consistency checks among models, which is therefore undertaken manually.

9.2.1.2 National model suite

In the national scenarios, the first model to be executed is the national economic model (See Figure 9.1 and Figure 9.3), which uses scenario assumptions about productivity, population, carbon price, and takes global scenario modelling results for international economic conditions from the global economic model, including international fossil fuel prices (see Chapter 14). The results of the economic model VURM, are of interest, not only in their own right but also because they form inputs provided to other national models, including the native demand for freight transport and air travel.

This information is provided to the national transport model Aus-TIMES, which is also informed by transport technology global costs from GALLMT. Private transport demand projections are provided as part of the national scenario settings for the Urban Density and Regional Development Issues under the Cities and Infrastructure workstream (see Chapter 2 and Chapter 5). These private transport demands are based on observed regression relationships of transport demand against factors such as petrol prices, urban densities, and average travel to work distances. AUS-TIMES produces, analogously to the global models, a demand for electricity as well as a demand for biofuels (see Chapter 15).

The demand for electricity as a transport fuel is added to the demand for stationary electricity as projected by the national economic model, which does not have a sophisticated model of the prospects for electric vehicles. This electricity demand is provided as a setting for the national electricity generation sectoral model, ESM (see Chapter 15), which has a detailed technological representation of generation technology, the costs of which are determined by global developments and projected by the global model GALLME. Electricity generation technology mix, emissions, demand for fuel and electricity prices are produced by ESM.

The input assumptions for the national Land-Use model, LUTO, include the global projections of fossil fuel prices and agricultural international markets. There is a global carbon emissions price, which is applied to agricultural production and reflected in international prices available to national producers. LUTO’s spatially explicit land use model also informed by electricity price projections and national demand for biofuel feedstock. It is also informed by a labour cost index that describes how wages in rural regions impacts on the costs of agricultural production.

The land use projections calculated by LUTO are imposed on the national economic model (VURM), constraining the extent to which substitutability of land is modelled in VURM. Although this suggests a circular workflow dependence and a need for iteration, in practice the land-use constraints imposed by the national land-use model on the national economic model have only a minor impact on the electricity and transport demands provided to the national energy models and the rural wage index. It follows that the only a single iteration is required, and the primary purpose of imposing land use projection constraints on the national economic model is to improve the accuracy of its economic projections in high land-use sectors (agriculture and forestry).

Scenario assumptions regarding global climate scenario and agricultural impacts in LUTO are not directly linked to the (simplified) global climate model, as the particular relationship between the state of the global climate and localised impacts on Australian agriculture are insufficiently well understood to warrant the imposition of a particular detailed global emissions trajectory from the global modelling suite on a ANO 2019 climate simulation. Instead, potential impacts of global climate change on local agricultural are provided consistently with the global qualitative scenario description of global action on climate change. (See Chapter 16).

Some feedbacks neglected in the national modelling workflow include the impact of Australian economic factors on international markets (e.g. coal), agricultural production in LUTO (a partial equilibrium model) on local market prices, energy technology mix, emissions and costs on the national economic model results, and LUTO biofuel feedstock costs and prices on demand for biofuels. Most of these assumptions are strongly valid, as the feedback strengths have been verified as relatively weak. A more automated process to check the extent of consistency in identified model redundancies and/or to implement feedback iteration, would enhance the confidence in the consistency within the model suite.

For reporting purposes, there is a preference for presenting results from the single individual model that is regarded as the most credible for the reporting output in question. For example, given the technological detail and representation of capital stock, fuel demand projections for the electricity sector are more credibly provided by ESM than the national economic model. The spatial detail of LUTO makes its land-use projections more reliable than the national economic model. However, the general equilibrium perspective provided by the national economic model allows the impacts of an emissions price to differentially affect the growth of various economic sectors and provides the reason that this model is preferred for (initial) projections of electricity demand (excluding demand from electric vehicles). This is generally preferred to constructing blended results from more than one model, although composite results are sometimes constructed.

9.2.2 Model Interlinkage Design Process

The process of selecting model interlinkages is neither arbitrary nor simplistically routinisable, but a process of testing *a priori* expectations. Hypothesised sensitivities or insensitivities can be confirmed or disconfirmed by scenario exploration, and checking model consistency, though strictly speaking this is only valid for the particularities of the scenario settings that are tested. The threshold for evaluating whether a difference is materially significant is often qualitative and somewhat subjective in practice.

For both ANO 2015 and ANO 2019, the preferred mechanism for ensuring model consistency are (in general order or preference)

- Significant inputs representing the same feature in different models use identical data sets (e.g. the global CO_2 emissions price for all models except MAGICC) (or data sets consistent with same assumptions – GLOBIOM emulator and GTAP-ANO using economic scenario settings based on SSP2 and SS1)
- Endogenous results of one model that represents the same feature in another model is:
    - used as a direct input to (electricity demand from GTAP-ANO to GALLME)
    - transformed by intermediate processing before being used as an input to (N_2O emissions from the global transport sector used in MAGICC assumed proportional to CO_2 emissions from GALLMT)
    - used to calibrate

    the other model, preferably unidirectionally, and iteratively only when inconsistency is material
- Endogenous results of several models that represent a common feature are combined (aggregated, blended, preferentially selected) before use by another model (CO_2 emissions from GALLMT replace those from the transport sector of GTAP-ANO for use in MAGICC)
- Endogenous results are compared to ensure relative consistency (that is, differences within accuracy bounds of each model – fuel use from ESM confirmed sufficiently similar to VURM fuel use in the electricity to reflect the impact of emissions price.)

The more well-specified the particular performance indicator variables from the model suite are, the more efficiently a set of appropriate model interlinkages can be identified. Without specific requirements for particular indicator variables to be reported to a particular degree of confidence, the modelling process can stray by pursuit of fidelity of representation of superficial features, such as year to year volatility, rather than results that are more material, such as persistent longer term trends. This can be costly in both model development time and personnel resource requirements, or model execution time and computational processing requirements.

9.2.3 Scenario Parametrisation Process

The Scenario Issue parametrisation process was primarily one for model experts. Starting with an initial interpretation of the various scenario issues, particular parameters in each model were identified that were both indicative of that issue, and to which the model experts believed the model results are reasonably sensitive. Parameter values were identified (that is, the scenario issue stances were ‘translated’) from data sets consistent with the issue stance qualitative description. Guidance for interpretation was provided by Workstream leads.

The process of identifying relevant model parameter and selecting particular datasets as translations was required to take place over many months of weekly meetings. Model experts and workstream leads identified key drivers, and agreed to the process for specifying key inputs where there were significant interactions among model domains and/or workstreams. In many cases, model owners learned that some results were insensitive to input data assumptions that they had previously thought to be significant, either in general or for the ANO 2019 scenarios. This sometimes occurred when looking to other domain experts for guidance on relevant input datasets. Other aspects of inter-model consistency were also discussed and dealt with by discussion among the modelling team, such as selection of appropriate baseline oil and gas prices, or currency conversion data sources. Discussion was necessary to select settings not initially identified as scenario issues for one or more models but are not scenario independent, such as energy efficiency uptake assumptions in the national economic and energy models.

Particularly where there were several alternative candidate translation datasets, but anyway as part of routine confirmation, many of the proposed issue parametrisations and translations were presented to members during workshops July and November 2017. For details of scenario issue final parameterisations and translations, see Chapter 2.

9.3 References

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10 GTAP-ANO

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Model at a glance

Model summary	GTAP-ANO (Global Trade and Analysis Project model for the Australian National Outlook) is a multi-region global economic model. It is calibrated by a 13-region (4 of which are individual countries), 27-sector aggregation of the GTAP v9 database. GTAP-ANO builds upon the standard GTAP framework, which is documented in Hertel (1997).
Key ANO scenario drivers	• growth in population and labour force (source: CEPII) • growth in baseline global domestic product (source: CEPII) • carbon prices/policies, projection of CO_2 prices, applied to both CO_2 and non-CO_2 emissions (source: IPCC and CSIRO) • baseline fossil fuel prices (source: EIA, IEA and CSIRO).
Key inputs and assumptions	• international trade environment: low vs. high trade barriers (source: GTAP database and CSIRO) • economically motivated technical change shifting towards capital (representing renewables) away from energy, and towards electricity away from fuels • agriculture commodities prices (source: GLOBIOMand emulator).

10.1 Introduction

CSIRO undertook modelling of the global aspects of the Australian National Outlook 2019 (ANO 2019) using, in part, their version of the GTAP model especially adapted for energy and environmental modelling.[1] The CSIRO version is labelled GTAP-ANO. While the origins of GTAP-ANO lie firmly in the GTAP framework, many of the enhancements were developed initially for other GTAP-related models, namely GTAP-E (GTAP-Energy and Environment) and the Global Trade and Environment Model (GTEM). The equations and database of GTAP-E lie at the heart of GTAP-ANO. Starting with GTAP-E, equations and data are then added to the existing GTAP-E structure to handle such features as dynamics, non-CO_2 greenhouse gases, and improvements in energy efficiency driven by a greenhouse gas price. GTAP-E is described in Burniaux and Truong (2002) and McDougall and Golub (2007). GTEM is described in Pant (2007).

The GTAP-ANO modelling for the ANO 2019 incorporates global assumptions based on selected global scenario assumptions (see Chapter 3), information from the International Energy Agency (IEA) and projections from other models, notably GLOBIOM (see Chapter 12). The projections from GTAP-ANO are reported and analysed in their own right, and are used to inform simulations of the national economic model, the Victoria University Regional Model (VURM) (Chapter 14). VURM's role is to supply projections of the effects of global greenhouse action and other developments

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[1] GTAP stands for the Global Trade Analyis Project. GTAP is a global network of researchers and policy makers conducting quantitative analysis of international policy issues. It is coordinated by the Center for Global Trade Analysis in Purdue University's Department of Agricultural Economics. The standard GTAP model is a multi-region, multi-sector, computable general equilibrium model, with perfect competition and constant returns to scale. It is documented in Hertel (1997).

(particularly focused on labour market and urban developments) on the Australian economy at the level of detail required by policy makers.

The rest of this chapter is organised as follows. A brief general description of GTAP-ANO is given in Section 10.2. In many aspects, GTAP-ANO is the same as GTAP-E. The main differences relate to the handling of dynamics (GTAP-E is comparative static and GTAP-ANO is dynamic) and non-combustion (non-CO_2) greenhouse emissions (ignored in GTAP-E). These exceptions are discussed in more detail in Section 10.3. Section 10.4 contains a brief discussion of the simulation design for the ANO 2019 scenarios.

10.2 GTAP-ANO model description

The GTAP family of models and VURM are based on a common theoretical framework – the ORANI model of the Australian economy.[2] Each model in the GTAP family can be likened to a series of ORANI models, one for each national region, linked by a matrix of bilateral international trade flows. Similarly, VURM can be likened to a series of ORANI models, one for each Australian state and territory, linked by a matrix of inter-state trade flows. However, unlike the static ORANI model, VURM and GTAP-ANO are recursively dynamic models, developed to address long-term global policy issues, such as climate-change mitigation costs.

This section describes the main features of GTAP-ANO and how GTAP-ANO differs from other models in the GTAP family. There are two sub-sections: structure of demand and a summary of environmental-specific enhancements.

10.2.1 Structure of demand

GTAP-ANO models demand and supply by region, and the inter-regional linkages arising from the flows of tradable goods and services and of capital. In doing so, it ensures that each region's total exports equal the total imports of these goods by other regions.

There are four sources of demand for goods and services produced locally and internationally: industry demands for current production, demands for inputs to capital creation, household demand and government demand.

Industry demand for current production

Industry demands in each region in GTAP-ANO are derived from solutions to a cost-minimisation problem involving a multi-level production function. As is common to all GTAP models, in GTAP-ANO regional substitution is allowed between different national regions. The standard GTAP input structure for a representative industry is shown in Figure 10.1.

GTAP-ANO's structure of industry demand differs from that specified in GTAP by making explicit allowance for substitution possibilities between capital and energy and among different forms of energy. Such substitution is relative-price induced.

A maintained assumption in both models is that producers are price takers in both input and output markets. GTAP recognises two broad categories of inputs: intermediate inputs and primary

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[2] See Dixon et al. (1977) for a description of ORANI.

factors. Industries in each region are assumed to select the mix of inputs that minimises the costs of production for their level of output. They are constrained in their choice of inputs by a production technology comprising several branches, each with a number of levels (or nests).

At the first level, the primary-factor bundle (value added) and bundles of intermediate inputs (including energy units) are used in fixed proportions to produce output. In input/output modelling there is no relative-price substitution; all inputs are used in fixed proportions.

The value-added and intermediate-input bundles are formed at the second level. The primary-factor bundle is a constant-elasticity-of-substitution (CES) combination of labour, fixed capital and agricultural land. Each intermediate-input bundle is a CES combination of a domestically produced good and an internationally imported composite.

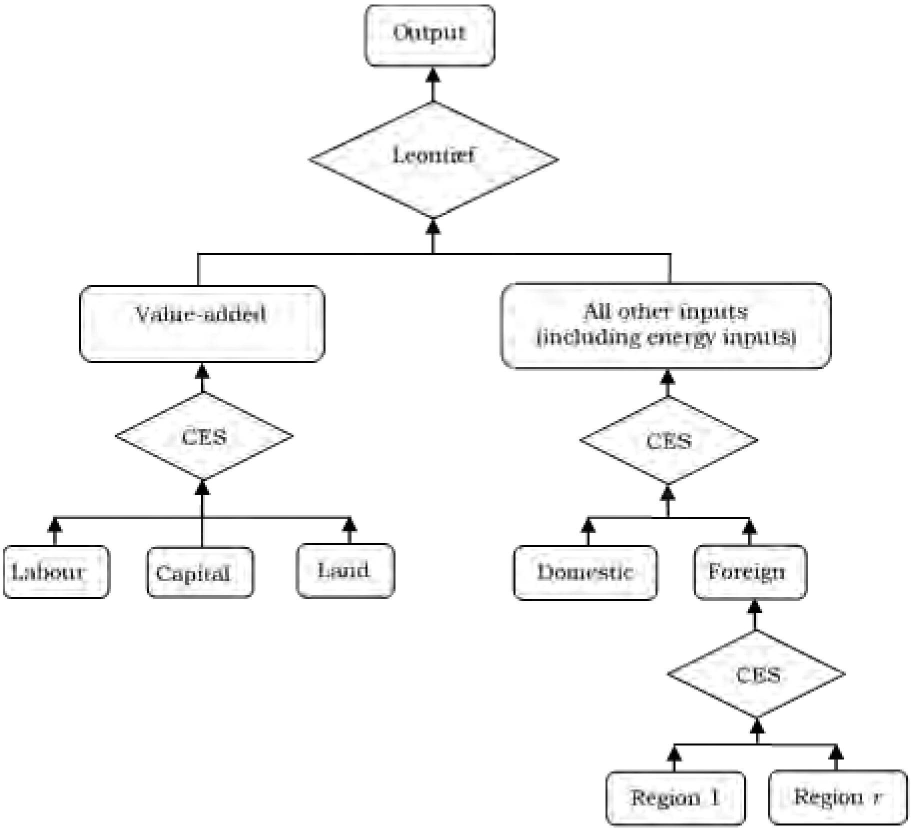

Figure 10.1 Input structure for current production in standard GTAP

'Leontief' refers to the input/output modelling pioneer Wassily Leontief.
CES = constant-elasticity-of-substitution

At the third level, the import-composite is formed as a CES combination of goods from each foreign region. The regional structure of imports is not user-specific – it is determined at the whole-of-economy level.

In GTAP-ANO, following the treatment in GTAP-E, energy is taken out of the intermediate-input bundle and is incorporated into the value-added nesting. This is done in two steps. First, energy commodities (primary fossil fuels, refined petroleum and electricity) are separated into electricity and non-electricity. Some CES is allowed within the non-electricity group and between electricity and non-electricity.

Second, the energy bundle is combined with capital to produce a capital-energy composite. This is combined with other primary factors in a value-added-energy (VAE) bundle. The GTAP-ANO input structure is shown in Figure 10.2 and Figure 10.3.

Calibration of the substitution elasticities is subject to considerable debate. This is partly due to data limitations that impede the necessary econometric analysis, but it also reflects the reality that many of the estimated elasticities have been derived for only one or two countries (the United States and parts of the EU), which may not be applicable to other regions. The substitution elasticity values used for the ANO modelling are available on request and are mainly based on the GTAP-E data (discussed in detail in Section 3 of Burniaux and Truong (2002)).

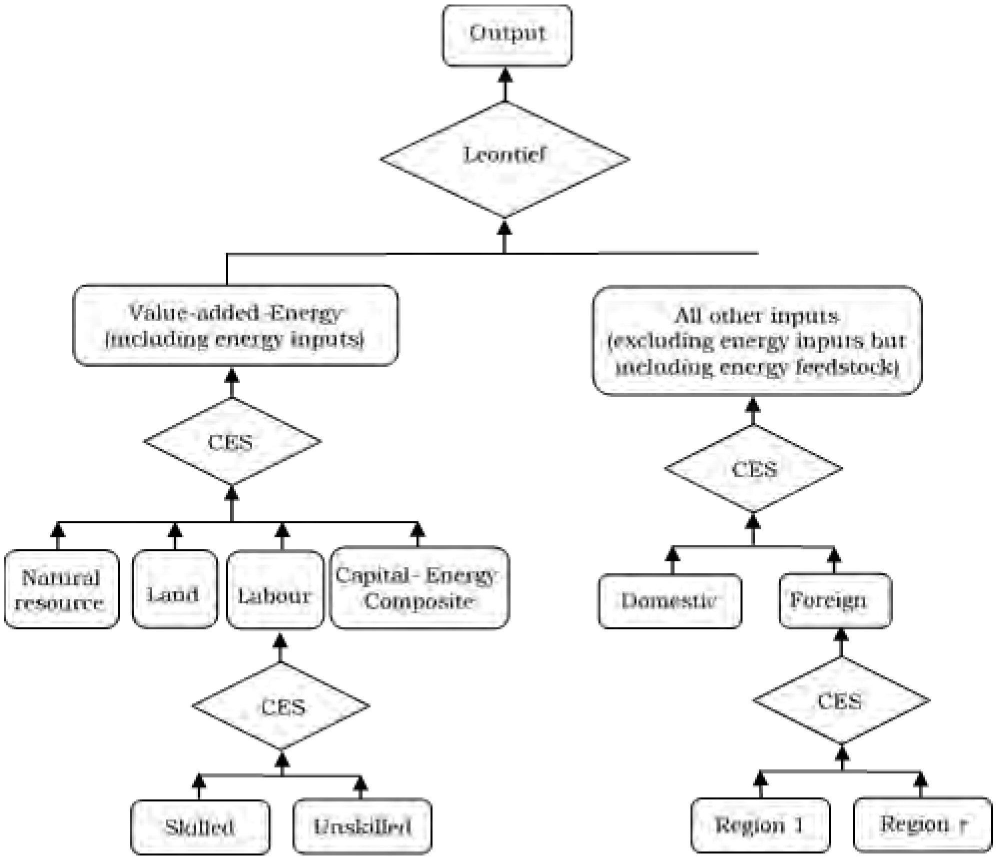

Figure 10.2 Input structure for industry production used in GTAP-E (Part 1)

CES = constant-elasticity-of-substitution

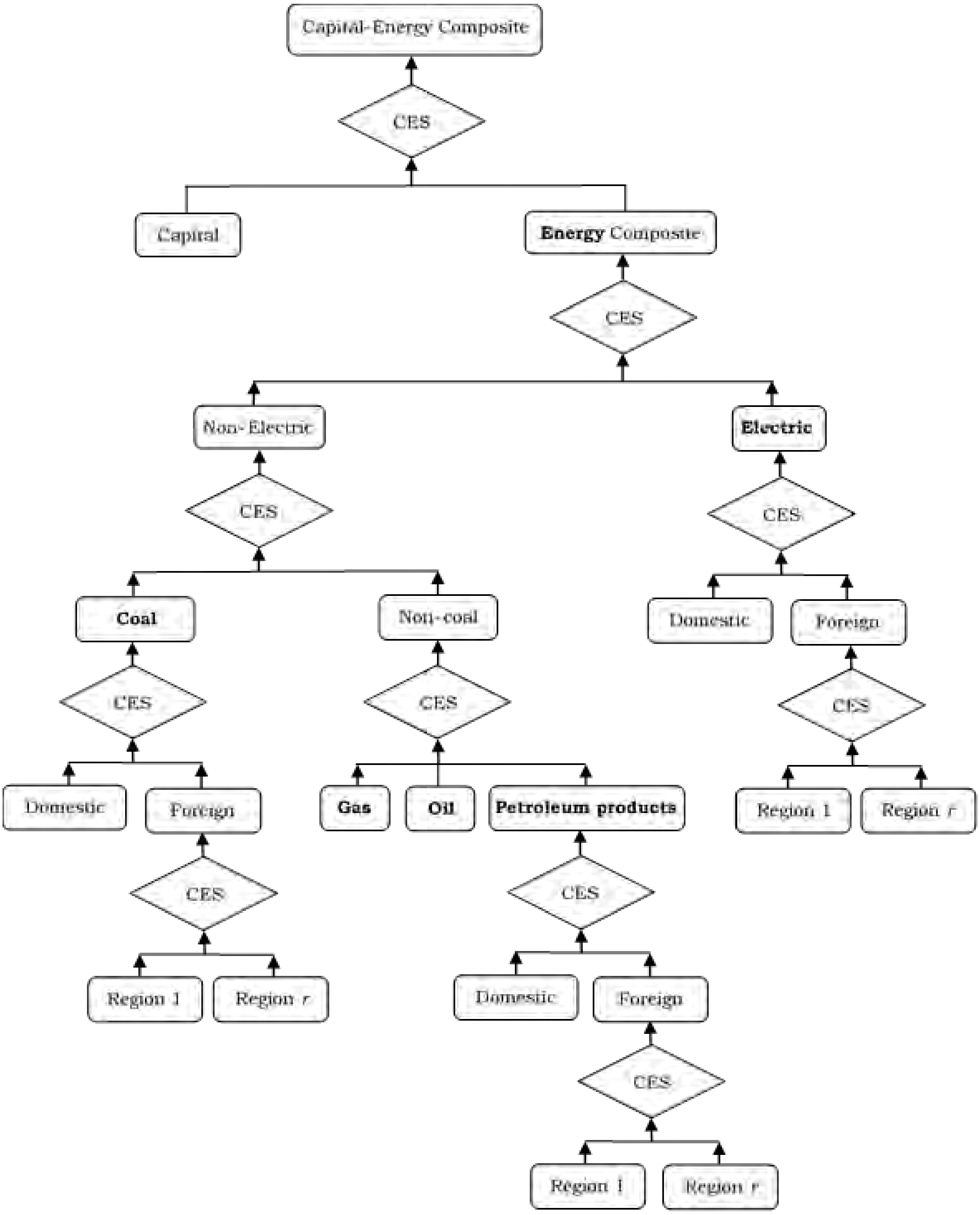

Figure 10.3 Capital-energy composite structure (Part 2)

CES = constant-elasticity-of-substitution

Demand for inputs to capital creation

The second major form of demand is for inputs to capital creation (investment). The cost-minimising capital creator in each region in GTAP-ANO combines inputs to assemble units of capital, subject to a nested production technology similar to that facing each sector for current production. Thus, Figure 10.2 and Figure 10.3 apply to demands by the single investing producer, as well as demand for inputs to current production. As for inputs to current production, the regional structure of imports is not user-specific. In other words, for inputs to capital creations the regional structure of imports is determined at the whole-of-economy level.

Investment in each region is financed from a global pool of savings. In standard comparative-static GTAP, there are two alternative ways of allocating this pool to investment in each region. The first makes investment in each region a fixed proportion of the overall size of the pool – if the pool increases by 10%, investment in each region increases by 10%. The second relates investment allocation to relative rates of return. Regions that experience increases in their rate of return relative to the global average will receive increased shares of the investment pool, whereas regions experiencing reductions in their rate of return relative to the global average will receive reduced shares.

In GTAP-ANO, a third way is adopted and is explained more fully in Section 10.3.1. It is similar to the second approach adopted for comparative-static modelling, but allows for a dynamic relationship between capital growth (investment) and expected rate of return. To ensure that savings matches investment at the global level, saving by region is endogenously adjusted in an equiproportional manner to ensure that the global condition holds.

Household demand

In the GTAP family of models, household (private) consumption is distinguished from government (public) consumption for each region. It is assumed that the household sector demands goods and services to maximise utility from a given level of income. The utility maximising decision is based on given prices and a utility function with a constant-difference-of-elasticities (CDE) functional form. Once the consumption of good, *c*, is determined, then the household decides on how much domestically produced *c* to use and how much imported good *c* to use. The sourcing allocation of imports is determined in line with the general allocation decision made for all users.

In GTAP-ANO, again following the approach of GTAP-E, the utility function inputs is divided into energy and non-energy products. The CDE function is then specified across an energy composite and each of the separated non-energy products, allowing some relative-price substitution. Within the energy composite, CES possibilities exist among the energy types. The GTAP-ANO structure of household demand is shown in Figure 10.4.

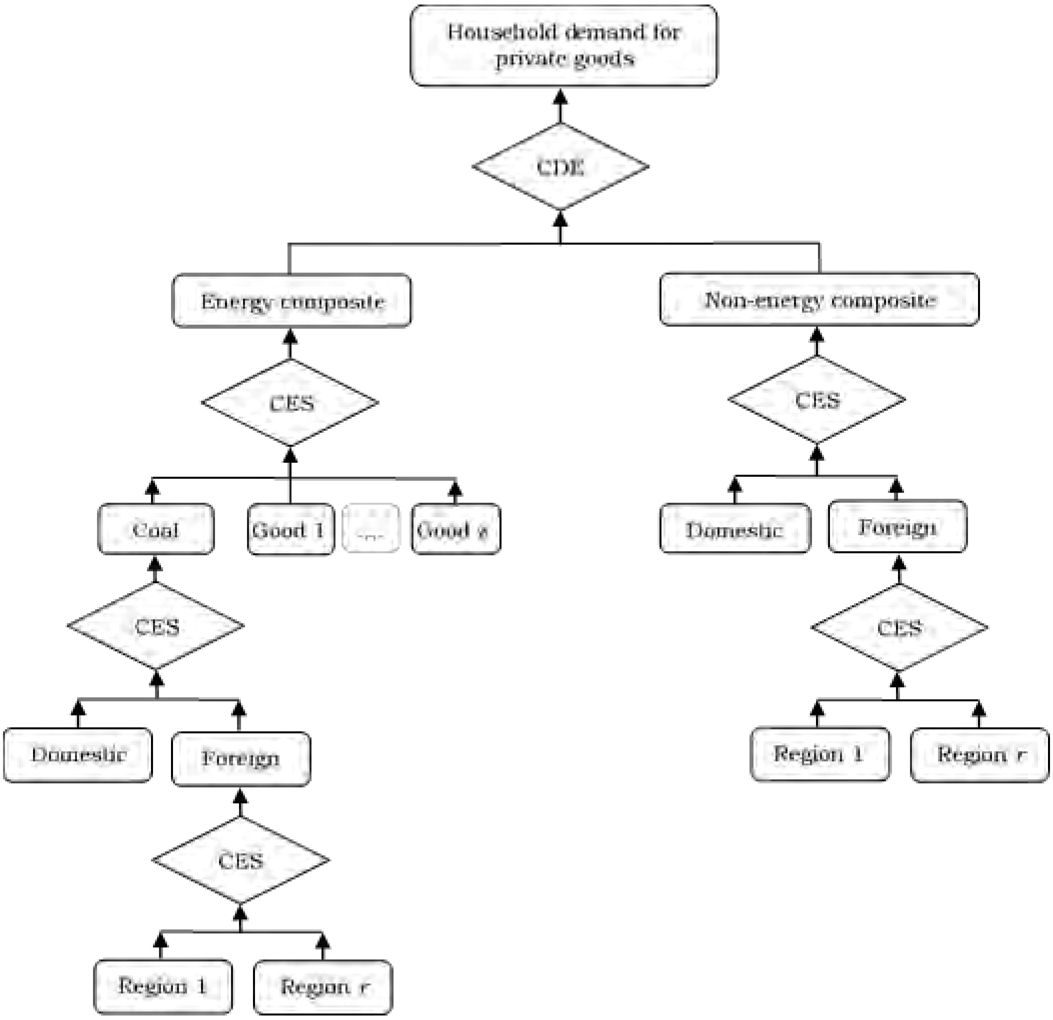

Figure 10.4 Structure of household demand in GTAP-ANO

CDE = constant-difference-of-elasticities, CES = constant-elasticity-of-substitution

Government demand

In the GTAP family of models, government consumption expenditures are assumed to be based on Cobb-Douglas allocation[3] (Cobb and Douglas, 1928) across all commodities. In GTAP-ANO, following GTAP-E, energy commodities are separated from the non-energy commodities with a nested CES structure shown in Figure 10.5.

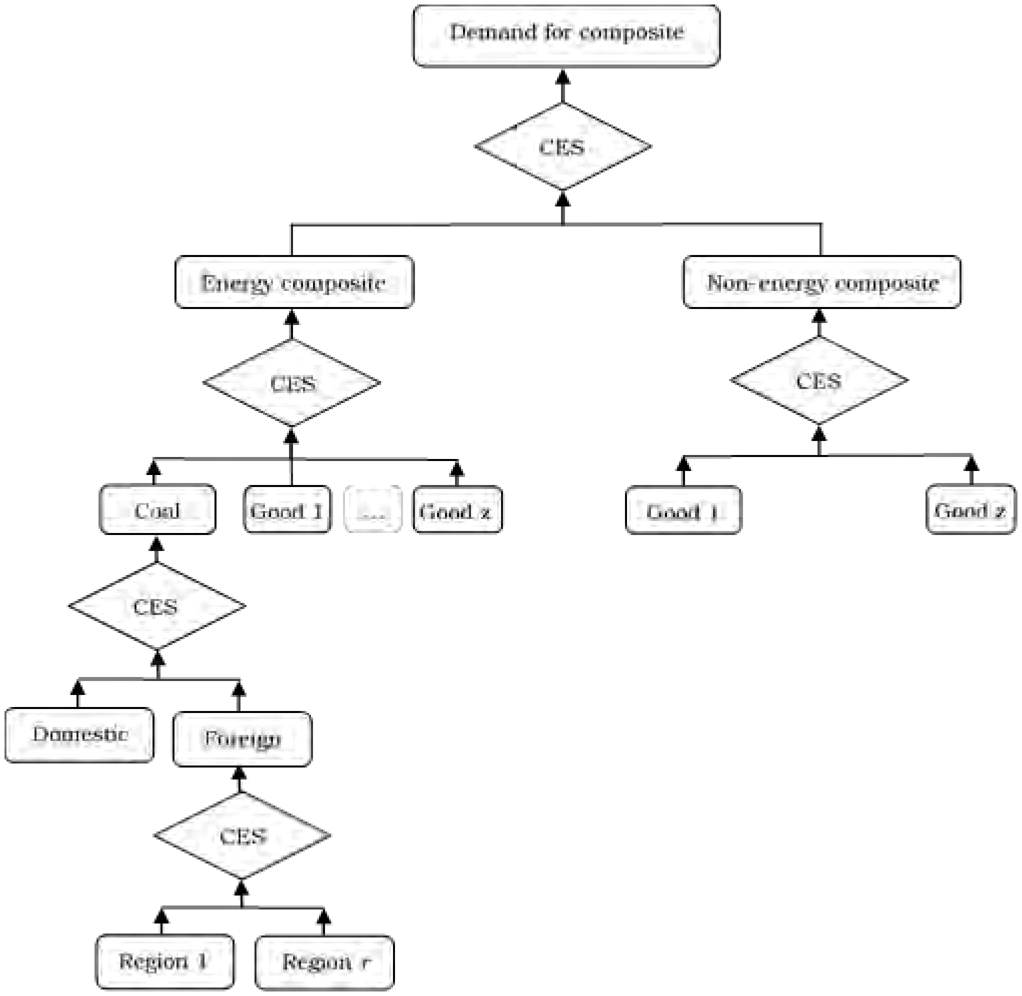

Figure 10.5 Structure of government demand in GTAP-E

CES = constant-elasticity-of-substitution

10.2.2 Summary of environmental enhancements in GTAP-ANO

Many of the environmental enhancements in GTAP-ANO have been taken directly from GTAP-E or GTEM. They include:

- GTAP-ANO provides greenhouse gas emissions projections based on a global emissions database that includes all major sources of greenhouse gases, except land-use change. This database is built primarily from data compiled for the GTAP-E model. That model, however, ignores most non-CO_2 emissions associated with agriculture, fugitives, industrial processes and waste. Data

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[3] 'Cobb-Douglas allocation' refers to an allocation that preserves the value share of commodities in government budget. Fixed value shares are a feature of the Cobb-Douglas production function (see Cobb and Douglas, 1928).

for these non-combustion emissions come from work for the GTAP database documented in Irfanoglu and van der Mensburrge (2015).

- As in both VURM and GTAP-E, it is assumed in GTAP-ANO that combustion emissions of CO_2 are proportional to the quantity of fuel combusted, while non-CO_2 emissions are proportional to the level of production in the associated industry.
- Emission response functions are defined for non-CO_2 emissions. These specify abatement as increasing functions of the rate of carbon tax and reflect the assumption that the marginal cost of abatement increases with the level of abatement. This feature is documented in Section 10.3.2.
- GTAP-ANO has the facility to use the 'technology-bundle' approach to model electricity generation, transport and steel manufacture as specified for the GTEM model. Under this approach, multiple technologies are specified for the production of the relevant output. The shares of the technologies in aggregate output depend on their relative profitability but there is no input substitution within technologies.
- For emerging electricity generation technologies, such as solar and geothermal, learning-by-doing mechanisms are added. These reduce, over time, the modelled requirements for primary-factor inputs per unit of output.
- In some mining industries, factor productivity is assumed to decline with increases in the cumulative level of resource extraction, reflecting increasing extraction costs as the resource base diminishes.

10.3 Dynamics and abatement of non-combustion emissions

10.3.1 Dynamics – investment and capital accumulation

GTAP-ANO extends the basic comparative-static GTAP-E model to include equations that are essential for year-to-year simulations (i.e. dynamic simulations that trace the paths for variables over successive years).

The key dynamic equations relate investment to capital, and relate investment to expected rate of return. In GTAP-ANO, capital and investment are region, but not industry, specific. Hence, the dynamic relationships are specified at the regional level. The specification of these equations draws heavily on the investment and capital theories developed for the single-country MONASH model of Australia (Dixon and Rimmer, 2002, Section 16). In MONASH, investment and capital are industry specific. The industry-specific equations are translated for use in GTAP-ANO by replacing the industry sectoral index with a regional index. Thus, the theory for industry, i, in a single-country context becomes the theory for region, q, in a multi-country framework.

Capital accumulation

In year-to-year dynamic analysis, a solution to the model is interpreted as a vector of changes in the values of variables between two adjacent years. Thus, there is a fixed relationship between capital and investment. Specifically, capital available for production in the current forecast year (year t) is given by initial conditions, with the rate of return in year t adjusting to accommodate the given stock of capital and its utilisation of projected price levels. This means that investment undertaken in year t does not affect productive capital in year t. Typically, we assume that it becomes operational at the start of year $t + 1$.

Bringing these ideas together into an algebraic form yields a capital accumulation relationship with the following form:

$$K_q(t+1) = (1 - DEP_q) \times K_q(t) + Y_q(t) \tag{1}$$

where:

- $K_q(t)$ is the quantity of capital available in region q at the start of year t
- $Y_q(t)$ is the quantity of new capital created in region q during year t
- DEP_q is the rate of depreciation for region q.

Given a starting value for capital in $t = 0$, and with a mechanism for explaining investment, equation (1) traces out the time paths of industries' capital stocks.

Relationship between investment and rate of return

Investment in year t is explained *via* a mechanism of the form:

$$\frac{K_q(t+1)}{K_q(t)} = F_q\left[\frac{EROR_q(t)}{RROR_q(t)}\right] \tag{2}$$

where:

- $EROR_q(t)$ is the expected rate of return in year t
- $RROR_q(t)$ is the required rate of return on investment in year t
- F_q is an increasing function of the ratio of expected to required rate of return.

The function F[ ] is specified in a way that allows investors to supply increased funds to region *q* in response to increases in the expected rate of return for *q*. Static expecations are assumed for the. Thus, the expected rate of return in year t equals the actual rate of return in year t. However, global investors are modelled as being cautious. In any year, the capital supply functions in GTAP-ANO limit the growth in region *q*'s capital stock so that disturbances in *q*'s rate of return are eliminated only gradually.

The actual specification of equation (2) starts with the assumption that the expectation held in period t by owners of capital in region *q* can be separated into two parts. One part is called the expected equilibrium rate of return. This is the expected rate of return required to sustain indefinitely the current rate of capital growth in region *q*. The second part is a measure of the disequilibrium in *q*'s current expected rate of return. In other words, for region *q*:

$$EROR_q = EEQROR_q + DISEQROR_q \tag{3}$$

where $EROR_q$, $EEQROR_q$ and $DISEQROR_q$ are the levels in year t of the expected rate of return, the expected equilibrium rate of the return and the disequilibrium in the expected rate of return, respectively.

The theory of investment in year-to-year simulations then relates the expected equilibrium rate of return for region *q* (EEQROR_q) to the current rate of growth in the capital stock in region *q* ($\mathrm{K\_GR}_q$). The DISEQROR can either be held constant, or be allowed to progressively become smaller through a simulation.

The relationship between capital growth and the expected equilibrium rate of return has an inverse logistic form (see Figure 10.6):

$$
\begin{aligned}
&\mathrm{EEQROR}_q = \mathrm{RORN}_q + \mathrm{F\_EEQROR}_q + \\
&\frac{1}{\mathrm{CAP\_SLOPE}_q} \times \\
&\qquad \left\{ \begin{array}{l} \left[\ln\left(\mathrm{K\_GR}_q - \mathrm{K\_GR\_MIN}_q\right) - \ln\left(\mathrm{K\_GR\_MAX}_q - \mathrm{K\_GR}_q\right) \right] - \\ \left[\ln\left(\mathrm{TREND\_K}_q - \mathrm{K\_GR\_MIN}_q\right) - \ln\left(\mathrm{K\_GR\_MAX}_q - \mathrm{TREND\_K}_q\right) \right] \end{array} \right\}
\end{aligned}
\tag{4}
$$

where:

- RORN is a coefficient representing the region's 'historical/long-run' rate of return
- F_EEQROR allows for vertical shifts in the capital supply curves
- CAP_SLOPE is a coefficient which is correlated with the inverse of the slope of the capital supply curve
- K_GR_MIN is a coefficient, which sets the minimum possible rate of growth of capital
- K_GR_MAX is a coefficient, set to the maximum possible rate of growth of capital
- TREND_K is a coefficient, set to the region's 'historical/long-run' rate of capital growth.

Equation 4 says the following. Suppose that F_EEQROR and DISEQROR are initially zero. Then, for a region to attract sufficient investment in year t to achieve a capital growth rate of TREND_K it must have an expected rate of return equal to its long-term average (RORN). For the region to attract sufficient investment in year t for its growth in capital stock to exceed its long-term average (TREND_K), its expected rate of return must be greater than RORN. Conversely, if the expected rate of return on the region's capital falls below RORN, then global investors will restrict their supply of capital to the region to a level below that required to sustain capital growth at the rate of TREND_K.

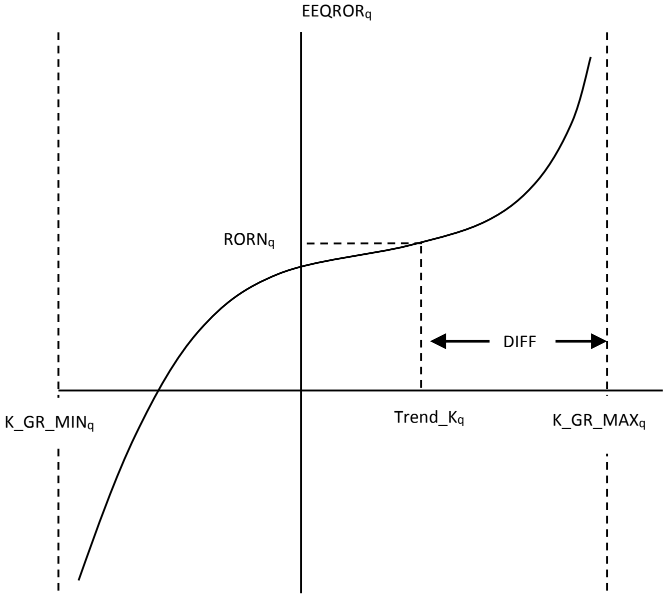

Figure 10.6 The inverse logistic function relating capital growth to the equilibrium rate of return in GTAP-E

10.3.2 Abatement of non-combustion greenhouse emissions

Non-combustion (or activity) emissions include, *inter alia*, agricultural-related emissions (from animals or from disturbing soil) and emissions from land-clearing or forestry, fugitive sources (e.g. gas flaring), industrial processes (e.g. cement manufacture) and municipal rubbish dumps. In the absence of a carbon price, in GTAP-ANO it is assumed that non-combustion emissions are proportional to industry output or industry use of capital, so that non-combustion emissions intensity (emissions per unit of output/capital) cannot change.

The theory of abatement of non-combustion emissions implemented in GTAP-ANO specifies abatement as an increasing function of the emissions price with lagged adjustment. The theory and data for the underlying coefficients generate mainly from the (global) GTEM and (single-country) VURM models. It is explained fully in Adams and Parmenter (2013).

In particular, it is assumed that as the price of non-combustion emissions in \$/CO_2-eq rises, so emissions intensity falls (abatement increases) through the introduction of less emission intensive technologies. To ensure that the emissions intensities of industries do not respond too vigorously to changes in emissions price, especially at the start of a simulation when the price of non-combustion emissions might rise from a zero level, a lagged adjustment mechanism is put in place. This mechanism allows the modelled emissions intensity response to adjust slowly towards required (or targeted) emissions intensity that adjusts immediately to an emissions price change as a static function of that price.

In particular, it is assumed that for industry *i* in region *q*, the targeted emissions intensity, $\lambda^*_{i,q}$, is a function of the level of carbon tax according to:

$$\lambda^*_{i,q} = MAX_{i,q}\left\{MIN_{i,q},\ F_{i,q}\times e^{-a_{i,q}\times(1+T)^{b_{i,q}}}\right\} \tag{5}$$

where:

- *MAX{}* is the maximisation function
- $MIN_{i,q}$ is the minimum possible level of emissions intensity
- $F_{i,q}$ is an exogenous variable necessary for calibration (units measured in the units of the left-hand side variable)
- *T* is the real level of the carbon tax (US$ per tonne of CO_2-eq in 2011 prices)
- $a_{i,q}$ is a positive coefficient
- $b_{i,q}$ is a positive coefficient that further modifies the rate of adjustment of the targeted emissions intensity relative to the tax rate.

Equation (5) defines $\lambda^*_{i,q}$ above $MIN_{i,q}$ as a non-linear monotonic decreasing function of *T*. Typical values of *a* and *b* are around 0.03 and 0.7. With these settings, the value of $\lambda^*_{i,q}$ when the real price of CO_2-eq is, for example, \$50 per tonne is $0.6247\times F_{i,q}$. This compares to a value, when the price of emissions in \$/CO_2-eq is zero, of $0.9704\times F_{i,q}$. Thus, with a \$50 price, targeted emissions intensity is reduced by 35.6% (= 100×(0.6247/0.9704-1)).

Figure 10.7 graphs values for $\lambda^*_{i,q}$ for a hypothetical industry (*i*,*q*), with $F_{i,q}$ = 1.0, $a_{i,q}$ = 0.03, $b_{i,q}$ = 0.7 and $MIN_{i,q}$ = 0.3, for various values of the carbon price (*T*).

The lagged adjustment mechanism is:

$$\lambda_{i,q} = -\lambda_{i,q}\_L + ADJUST \times (\lambda^*_{i,q} - \lambda_{i,q}\_L) \tag{6}$$

where:

- $\lambda_{i,q}$ is the actual level of emissions intensity
- $\lambda_{i,q}\_L$ is the actual level of emissions intensity lagged one year
- *ADJUST* is a speed-of-adjustment parameter with a typical value of 0.3.

Changes in emissions intensity brought about by equations (5) and (6) are not costless. The cost is due to changing technology to achieve the reduction in emissions intensity. It is therefore a once-off cost, but the savings extend across many years. In year t it is assumed the cost increase associated with a reduction in emissions intensity equals the value of the associated emissions-tax savings in year t.[4]

Table 10.1 shows, for a hypothetical emitting industry in a typical year, the costs and benefits associated with increasing values for the real carbon price (T) consistently with equations (5) and (6). Values assumed for the parameters in to derive columns (2) from column (1) are: *F* = 1.0, *a* = 0.03, b = 0.7, *MIN* = 0.3, and *ADJUST* = 1 (thus $\lambda = \lambda^*$). The carbon price rises from \$0 per tonne to \$100 per tonne. As the price rises, so λ falls from an initial level of 0.97 to 0.47 Mt/q (still above *MIN)*. It is assumed that production remains constant, leaving emissions (Mt) to fall in line with λ .

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[4] Here, the proposed treatment differs from the treatment in GTEM where it is assumed that the change in technology necessary to achieve the reduction in emission intensity is costless. In this implementation, the increase in cost is imposed as a contemporaneous all-input technological deterioration in production of the abating industry.

The column labelled ‘Abatement’ (5) shows the total reduction in emissions from the initial level of 0.97 Mt. For example, at a carbon price of $100, emissions have fallen from 0.97 Mt to 0.47 Mt, implying abatement of 0.50 Mt.

The column labelled ‘Cost’ (6) is the accumulated cost of abatement. It is assumed that at any point the increment in ‘Cost’ is the carbon price times the incremental abatement. For example, when the carbon price goes from $50 per tonne to $60 per tonne the incremental abatement is 0.03 Mt (= 0.38 Mt – 0.35 Mt), implying an addition to annual production cost of $2.3 million (= $10.9 m – $8.6 m). As the carbon price rises the cumulative annual cost of abatement measures falls short of the total tax saving. For example, at a price of $60, accumulated saving is $23.0 million (= $60 × 0.38 Mt), and the surplus of accumulated saving over accumulated cost is $12.1 million (= $23.0 m – $10.9 m).

Table 10.1 Annual accumulated costs and savings from non-combustion emission abatement

(1) CARBON PRICE ($ PER TONNE)	(2) (Mt/q)	(3) PRODUCTION (q)	(4) EMISSIONS (Mt)	(5) ABATEMENT (Mt)	(6) COST ($m)	(7) SAVING ($m)	(8) SURPLUS ($m)
0	0.97	1	0.97	0	0.0	0.0	0.0
10	0.85	1	0.85	0.12	1.2	1.2	0.0
20	0.78	1	0.78	0.19	2.7	3.9	1.2
30	0.72	1	0.72	0.25	4.5	7.6	3.1
40	0.67	1	0.67	0.30	6.4	12.1	5.7
50	0.62	1	0.62	0.35	8.6	17.3	8.7
60	0.59	1	0.59	0.38	10.9	23.0	12.1
70	0.55	1	0.55	0.42	13.3	29.2	16.0
80	0.52	1	0.52	0.45	15.7	35.9	20.2
90	0.49	1	0.49	0.48	18.3	42.9	24.6
100	0.47	1	0.47	0.50	20.8	50.2	29.4

Note to table:
Column (1) is assumed.
Column (2) is calculated using equations (5) and (6) with the parameter values given in the text.
Column (3) is assumed.
Column (4) is Column (2) times Column (3).
Column (5) is the change in emissions relative to emissions with a zero price from column (4).
Column (6) is accumulated incremental cost {for price p, = *Cost(*p-10) + p×(*Abatement(*p) – *Abatement(*p-10)}.
Column (7) is Column (1) times Column (5).
Column (8) is Column (7) less Column (6).

Finally, it is shown how the concept of emissions intensity as a function of carbon price (equation (6)), along with the assumption for costs, is related to the better known concept of marginal abatement cost[5]. As above, it is assumed that output (the activity variable for this example) is fixed at 1, and initial emissions (with no abatement) is equal to 0.97. Therefore,

$$Abatement = 0.97 - Emissions \tag{7}$$

Note that both *Emissions* and *Abatement* vary between 0 and 0.97, and that, with unit output, *Emissions* is also emissions intensity.

Figure 10.8 shows a typical marginal abatement cost curve for an emitting industry: abatement is costly and the marginal cost rises with each additional unit of abatement. If a price T^* is paid for a unit of abatement, then the emitter will choose *Abatement* = A, where the marginal cost M = T^*. At this point, the emitter is indifferent to small variations in A, but reaps a surplus (profit) by undertaking the abatement, since initial abatement is cheaper than the current level. The producer surplus is indicated by the shaded area in the diagram.

Figure 10.8 implies a relationship between T and abatement, or between T and emissions intensity (λ), since according to equation (7), λ = *Emissions* = 0.97 – *Abatement*. Figure 10.9 is Figure 10.8 with the horizontal axis of Figure 10.8 reversed to take account of equation (8), and the axes have been exchanged and re-labelled. Based on the assumptions above, the relationship in Figure 10.9 is very similar to the relationship in Figure 10.7. Indeed, if drawn carefully the two would be identical. Note that the shaded portion showing producer surplus for T = T^* represents the concept of surplus whose value is calculated in the numerical example above.

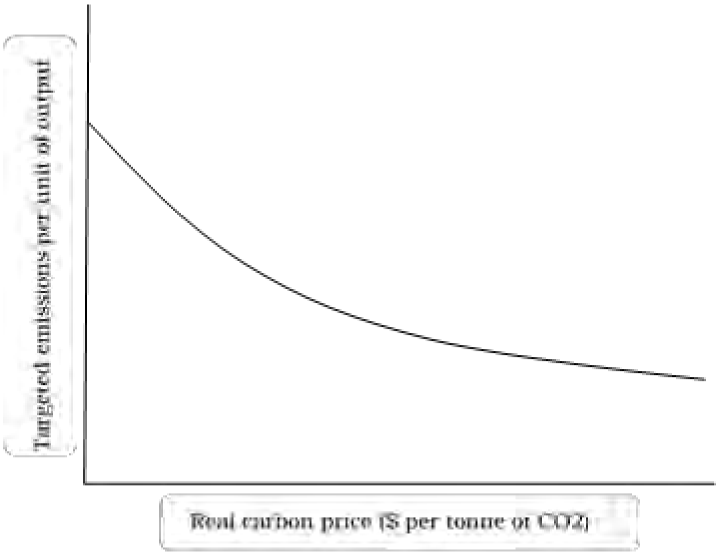

Figure 10.7 Values for λ^* as a function of the real carbon price

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[5] Marginal abatement cost (MAC) curves are used to illustrate the economic and technological feasibility of climate change mitigation. A MAC curve is a graph that indicates the marginal cost (the cost of the last unit) of emission abatement for varying amounts of emission reduction.

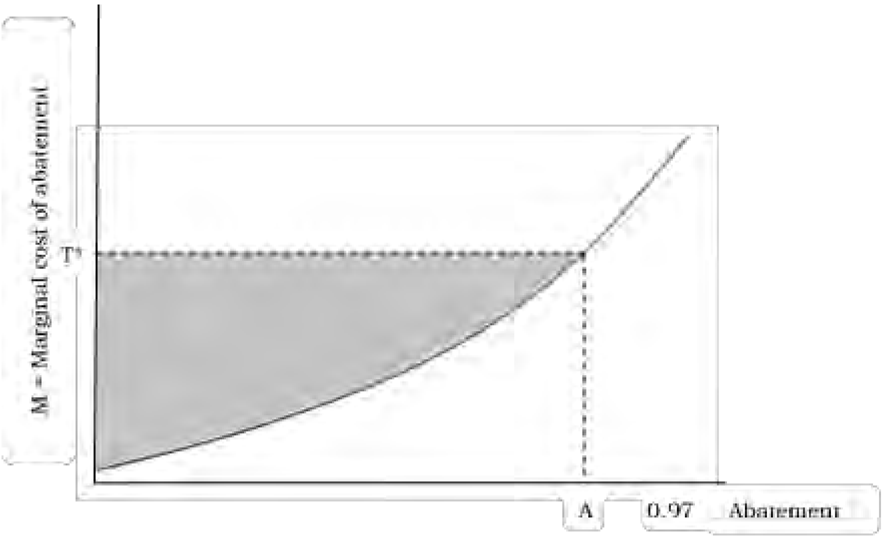

Figure 10.8 Marginal abatement cost curve for a hypothetical emitting industry

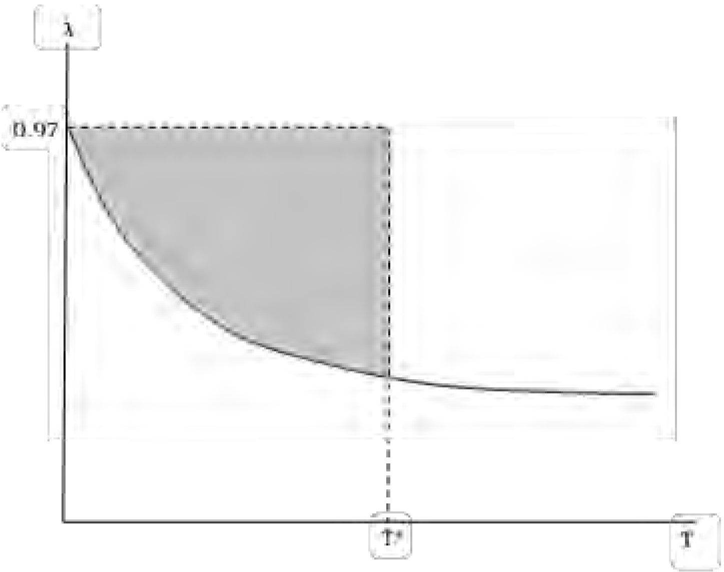

Figure 10.9 Marginal abatement cost curve for a hypothetical emitting industry

10.4 GTAP-ANO Inputs

10.4.1 Overview

GTAP-ANO's simulations for ANO 2019 incorporate information from specialist forecasting agencies and modelling groups, especially from within CSIRO. GTAP-ANO (and later VURM) traces out the implications of the specialists' forecasts at a fine level of industrial and regional detail.

Information imposed on GTAP-ANO includes the following:

1. Projections for population, labour supply and real GDP by region, taken from the Centre d'Etudes Prospectives et d'Informations (CEPII) 'EconMap' database. Specifically, the series corresponding to the relevant no-policy baselines of the Shared Socioeconomic Pathways

(SSPs) are used to carry out a corresponding baseline simulation using GTAP-ANO.[6] Baseline simulations serve to determine values of various productivity parameters that are consistent with the SSPs. Having determined and fixed those values, policy simulations can then be run that involve carbon pricing.[7] The results of these latter simulations are used in the ANO 2019 scenarios.

2. Projections for the baseline world prices of oil, gas and coal are derived from a combination of projections from the (United States) Energy Information Administration (EIA) and the (European) International Energy Agency. Specifically, base case oil price projections were based on the reference case oil price series (Brent spot price) from *Annual Energy Outlook 2017* (EIA, 2017), and extrapolated beyond 2040. For global gas and coal price projections, relative prices of gas and coal prices to oil prices from selected scenarios in *World Energy Outlook 2017* (IEA, 2017) were applied to the extrapolated oil prices series from IEA (2017). For further details, see Chapter 3.
3. These base case fossil fuel price projections were used to calibrate the reference case of the computable general equilibrium (CGE) simulation, before carbon price policies are applied. Final fossil fuel price projections are then calculated endogenously by GTAP-ANO before being applied by the remaining models in the global modelling suite.
4. The regional price of greenhouse gas (GHG) emissions in the near term is based on IEA (2016), World Bank and Ecofys (2014, 2015) and World Bank, Ecofys, and Vivid Economics (2016), and other sources (see Chapter 3 for more information). In the long term they are consistent with the *Nation First* and *Working Together* global scenarios as described in Chapter 3). For *Nation First*, carbon prices are represented as converging across regions from 2025 to \$40/t-CO_2-eq in 2040 before continuing to increase at a constant 1.0% per year growth rate. In the *Working Together* global scenario the international community is assumed to agree to apply a uniform carbon price of \$20/t from much earlier, in 2020, increasing at 5.0%, again a constant growth rate, thereafter. The initial regionally uniform price and growth rates are based on data presented in Clarke et al. (2014, Chapter 6, p. 450).
5. Athough the price of GHG emissions is set exogenously to the ANO 2019 global modelling suite, including GTAP-ANO, the resulting global suite projections were checked for qualitative consistency with the descriptions of the selected ANO 2019 global scenarios (see Chapter 3 and Chapter 13).
6. Agriculture price indexes projected by the GLOBIOM emulator (see Chapter 12 for more information) are imposed on GTAP-ANO ensuring that the greater detail and more thorough parameter calibration of the GLOBIOM model informs the commonly represented sectors in GTAP-ANO. GLOBIOM has much greater sectoral detail than the two-sector (crops and livestock) representation of agriculture in GTAP-ANO, as well as somewhat greater regional detail (32 regions rather than the 13 used for ANO 2019), so some aggregation is required.

To accommodate this information in GTAP-ANO, numerous naturally endogenous (model-determined) variables are made exogenous (user-determined). To allow the naturally endogenous variables to be exogenous, an equal number of naturally exogenous variables are made

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[6] The modelling approach and detailed methodology used to construct the SSPs are described in Foure et al. (2014).

[7] Physical impacts of climate change on the economy are ignored in both the baseline and the policy simulations.

endogenous. For example, to accommodate the exogenous setting of real GDP by region, an all-factor saving technological progress, naturally exogenous in GTAP-ANO but endogenous in the ANO 2019 simulation, imparts an equiproportional change in productivity across each region necessary to achieve the targeted growth rates of real GDP.

10.4.2 Linking export variables

One of the principal uses of the GTAP-ANO projections is as input to the single-country VURM model. The variables transferred from GTAP-E to VURM include the international GHG price, foreign currency import prices and export demand. The GHG price and import prices can easily be taken in to VURM *via* a simple one-way link.[8]. However, in order to infer export prices (using VURM supply schedules), GTAP-ANO must provide VURM with changes in the positions of the (downward-sloping) export-demand schedules of each commodity, not merely changes in quantities or foreign currency prices.

Figure 10.10 and Figure 10.11 illustrate the method by which year-to-year changes in export prices and quantities projected by GTAP-ANO (Figure 10.10) are translated into movements in export-demand schedules in VURM (Figure 10.11). In Figure 10.10, the initial export price-quantity point is A – at the intersection of the initial demand and supply schedules. In a particular scenario demand moves from D to D’ and supply from S to S’, with the price-quantity point changing from A to B. The quantity exported changes by *q*, and export price by *p*. Note that the changes in demand and supply schedules are not directly observed – only the changes by *p* and *q*.

Figure 10.11 shows how the price and quantity information from GTAP-ANO (Figure 10.10) is used to deduce the shift in the export-demand schedule required for the VURM simulation.

The elasticity of the demand curve in VURM is shown for illustrative purposes as being the same as in GTAP-ANO. This is not necessary for the top-down procedure to work, but it does help avoid unduly large differences between the two models in *ex post* outcomes for export quantities and prices. Import substitution elasticities from GTAP-ANO were adjusted to ensure consistency between its implied export-demand elasticities and the explicit elasticities in VURM.

The values for *p* and *q* from the GTAP-ANO simulation are used to shift the (inferred) export-demand schedule in VURM in two directions. The schedule shifts horizontally by *q* and vertically by *p*. If in VURM the supply schedule had the same shape as in GTAP-ANO, and if it were to also shift in the same way as in GTAP-ANO, then in VURM the *ex post* projected outcomes for export price and volume would be the same as in GTAP-ANO. Typically, though, this is not the case: for several commodities, VURM’s (single-country) supply response is quite different from the (global) supply response in GTAP-ANO. Thus, even though the shifts in export demand from GTAP-ANO are imposed on VURM to be the same, the resulting changes in export price and quantity modelled by VURM are quite different.

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[8] The only complication is that GTAP-ANO has a more aggregated commodity classification than does VURM, so the GTAP-ANO information must first be mapped to VURM commodities.

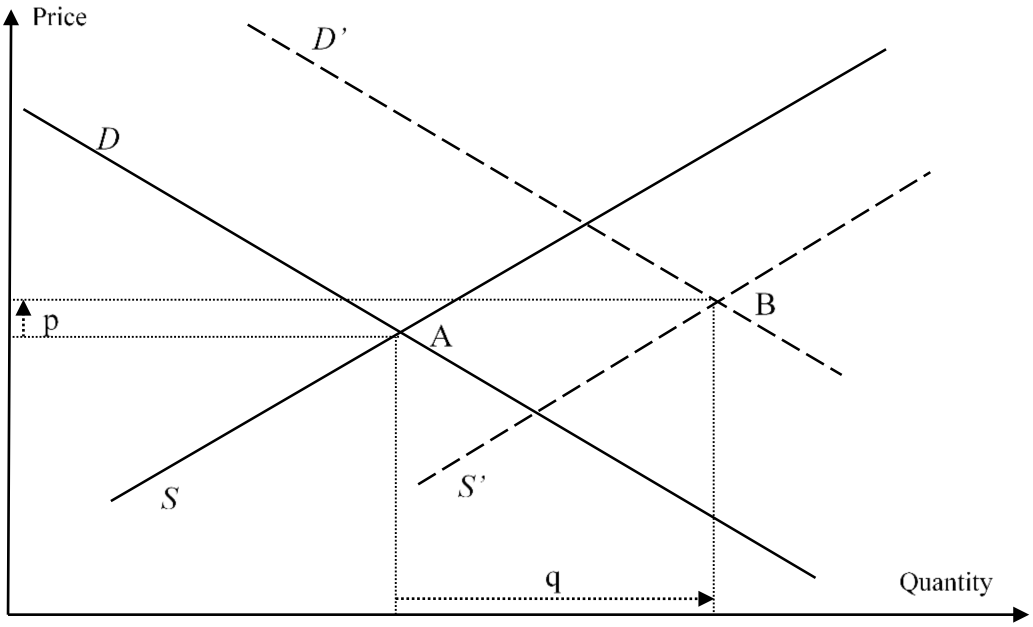

Figure 10.10 Export change in GTAP-ANO

A to B = price-quantity point; D, D' = demand; S, S' = supply; p = export price; q = quantity exported

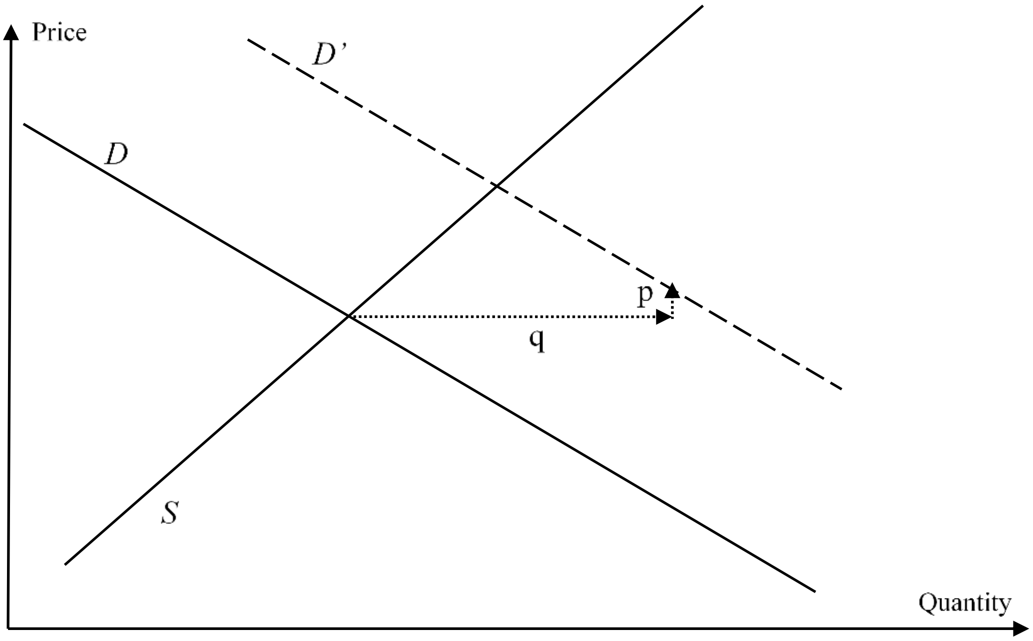

Figure 10.11 Shift in export demand in VURM

D, D' = demand; S, S' = supply; p = export price; q = quantity exported

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11 GALLME and GALLMT

Author: Jenny Hayward

Model at a glance

	GALLME	GALLMT
Model summary	GALLME, GALLMT (Global and Local Learning Models of Electricity and Transport) are 13-region global electricity and transport models. They project changes in technology costs and the generation, fuel and vehicle technology mix, using endogenous learning curve relationships, producing unique technological development paths for alternative scenarios of global political, technological and economic drivers. Developed by CSIRO. For more details see Hayward and Graham (2017).	
Key ANO scenario drivers	• Projection of CO_2 prices (source: IPCC and CSIRO) • Global electricity demand (from GTAP-ANO) • Electricity demand for electric vehicles (from GALLMT) • Fossil fuel prices (from GTAP-ANO) • Biomass prices (from GLOBIOM emulator) • Uptake of batteries for electric vehicles (from GALLMT)	• Projection of CO_2 prices (source: IPCC and CSIRO) • Projected population by region and time for conversion into passenger demand (from GTAP-ANO) • Projected GDP by region and time (from GTAP-ANO) • Demand for freight transport (from GTAP-ANO) • Fossil fuel (particularly oil) and biomass prices (from GTAP-ANO) • Price of biomass feedstocks (from GLOBIOM emulator) • Electricity price (from GALLME)
Key inputs and assumptions	• Renewable energy and other energy emissions policies • Resource limits or constraints on use of coal, oil, gas, biomass. • Resource constraints by region for wind, solar, geothermal, biomass, hydro, wave, ocean current/tidal (PJ/year) • Fuel costs for black coal, brown coal, gas, uranium and biomass • Power plant technology operating and maintenance costs • Capacity factors and historical installed capacities	• Transport policies • Airline efficiencies (from GEA 2012) • Fuel conversion efficiencies (EIA, 2017a) • Cost of vehicle drive trains • Existing and historical road vehicle stock by type and region Road vehicle lifetimes/scrapping rates • Historical travel per mode and number of passengers per mode • International and regional shipping and rail freight • Price of fossil fuels (from EIA) • Prices of fuel (Petrol, diesel, LPG, bunker, gas, jet) by region and time

11.1 Introduction

The Global and Local Learning Models for electricity (GALLME) and transport (GALLMT) will be described briefly here. They are described in more detail in several existing publications (Hayward & Graham, Electricity generation technology cost projections 2017-2050, 2017) (Hayward and Graham, 2013; Hayward et al., 2017).

GALLME was developed in 2011 to provide a transparent and robust method for projecting the future cost of electricity generation technologies. These cost projections have been used in every major national cost projections exercise since 2011 for forward strategic planning to understand how these different technologies might develop into the future (CSIRO, 2011; BREE, 2012; BREE, 2013; CO2CRC, 2015; AEMO, 2018). GALLMT was developed in 2014 to perform the same function but for alternative fuel and transport drive train technologies. While GALLME models electricity generation and GALLMT transport, both models have been built on the same foundation of incorporating endogenous technology learning to project future costs.

11.2 Method

11.2.1 Endogenous technology learning

Technology cost reductions due to 'learning-by-doing' were first observed in the 1930s for aeroplane construction (Wright, 1936) and have since been observed and measured for a wide range of technologies and processes (McDonald & Schrattenholzer, 2001). Cost reductions due to this phenomenon are normally shown via the equation:

$$IC = IC_0 \times \left(\frac{CC}{CC_0}\right)^{-b}, \text{ or equivalently } \log(IC) = \log(IC_0) - b(\log(CC) - \log(CC_0))$$

where IC is the unit investment cost at CC cumulative capacity and IC_0 is the cost of the first unit at CC_0 cumulative capacity. The learning index b satisfies $0 < b < 1$ and it determines the learning rate which is calculated as:

$$LR = 100 \times (1 - 2^{-b})$$

(typically quoted as a percentage ranging from 0 to 50%) and the progress ratio is given by $PR = 100 - LR$. All three quantities express a measure of the decline in unit cost with learning or experience. This relationship says that for each doubling in cumulative capacity of a technology, its investment cost will fall by the learning rate (Hayward and Graham, 2013). Learning rates can be measured by examining the change in unit cost with cumulative capacity of a technology over time. Typically emerging technologies have a higher learning rate (20–15%), which reduces once the technology has at least a 5% market share and is considered to be at the intermediate stage (to ~10%). Once a technology is considered mature, the learning rate tends to be 0–5%.

Technologies are made up of components and different components can be at different levels of maturity and thus have different learning rates. Different parts of a technology can be developed and sold in different markets (global vs. regional/local) which can impact on the cost reductions as each region will have a different level of demand for a technology and this will affect its uptake.

11.2.2 The modelling framework

In order to project the future cost of a technology using experience curves, the future level of cumulative capacity/uptake needs to be known. However, this is dependent on the costs. The GALLMs solve this problem by simultaneously projecting both the cost and uptake of the technologies. The optimisation problem includes constraints such as government policies, demand for electricity or transport, capacity of existing technologies, exogenous costs such as for fossil fuels and limits on resources (e.g. rooftops for solar photovoltaics). The models have been divided into 13 regions and each region has unique assumptions and data for the above listed constraints. The regions have been based on OECD regions (with some variation to look more closely at some countries of interest) and are: Africa, Australia, China, Eastern Europe, Western Europe, Former Soviet Union, India, Japan, Latin America, Middle East, North America, OECD-Pacific, Rest of Asia and Pacific.

The objective function of the model is to minimise the total system costs while meeting demand and all constraints. The model is solved as a mixed integer linear program. The experience curves are segmented into step functions and the location on the experience curves (i.e. cost vs. cumulative capacity) is determined at each time step. See (Hayward & Graham, 2013) and (Hayward et al., 2017) for more information. GALLME runs from the year 2006 to 2100 however results are only reported from the present day to 2060 to fit with other models in ANO 2019.

11.3 Model description

11.3.1 GALLME

Technologies and learning rates

GALLME projects the future cost and installed capacity of 27 different electricity generation and energy storage technologies. Where appropriate, these have been split into their components and there are 42 different components. Components have been shared between technologies; for example there are two CCS components – CCS technology and CCS construction – which are shared among all CCS plant technologies. The technologies are listed in Table 11.1 showing the relationship between generation technologies and their components and the assumed learning rates.

Table 11.1 Technologies and components modelled in GALLME

GENERATION TECHNOLOGY	COMPONENT	SOURCE OF LEARNING	LEARNING RATES (%)
Brown coal, pf[1]	-	-	-
Black coal, pf	-	-	-
Brown coal, IGCC[2]	-	Global	2
Black coal, IGCC	-	Global	2
Brown coal with CCS[3]	CCS technology[4]	Global	20 then 10 then 5
	CCS installation	Local	20 then 10 then 5
	Brown coal CCS BOP[5]	-	
Black coal with CCS	CCS technology	Global	20 then 10 then 5
	CCS installation	Local	20 then 10 then 5
	Black coal CCS BOP	-	
Gas with CCS	CCS technology	Global	20 then 10 then 5

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[1] Pf = pulverised fuel

[2] IGCC = integrated gasification combined cycle

[3] CCS = carbon capture and storage

[4] CCS technology and CCS installation components are shared among all CCS plant technologies

[5] BOP = balance of plant

GENERATION TECHNOLOGY	COMPONENT	SOURCE OF LEARNING	LEARNING RATES (%)
	CCS installation	Local	20 then 10 then 5
	Gas with CCS BOP	-	
Gas combined cycle	-	Global	2
Gas open cycle	-	-	-
Nuclear	-	Global	3
Biomass	-	Global	5
Wind	Turbines	Global	4.3
	Installation	Local	19.8 (11.3 AUS)
Photovoltaics (PV)	PV modules	Global	20 then 10
	PV BOP	Local	17.5
	PV inverter	-	-
	Li-ion battery[6]	Global	20
Concentrating solar thermal	-	Global	14.8 to 7
Enhanced geothermal systems (EGS)	EGS technology	Global	20
	EGS drilling	Local	20
	Geothermal BOP[7]	Global	8
Conventional geothermal	Conv geothermal drilling	-	-
	Geothermal BOP	Global	8
Wave	-	Global	9
Tidal/ocean current	-	Global	9
Fuel cells		Global	20
CHP		-	-
Thermal oil generation		-	-
Utility scale Li-ion battery	Li-ion battery	Global	20
	Installation BOP[8]	Global	7.5
Utility scale flow battery	Flow battery	Global	15
	Installation BOP	Global	7.5

Technologies without a learning rate are considered to be mature and instead of a learning rate they receive an annual cost reduction of 0.05% to take into account incremental reductions in the cost of materials.

Photovoltaics is listed as one technology with components in Table 11.1 however there are three separate PV plant technologies in GALLME:

- Rooftop PV has all of the components listed except for Li-ion batteries.

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[6] Only included in PV systems with a battery. This component is also shared with utility scale Li-ion battery plant.

[7] Geothermal BOP is shared among both geothermal plant types

[8] Installation BOP component is shared among both utility scale battery plant technologies.

- Large scale PV has all of the components listed except for Li-ion batteries and a discount of 25% is given to the local cost components to take into account economies of scale in building a large scale vs. rooftop PV plant.
- PV with storage has all of the components including batteries.

Inverters are not given a learning rate instead they are given a constant cost reduction, which is based on historical data.

Li-ion batteries are a component that is used in both PV with storage and utility scale Li-ion battery energy storage. Geothermal BOP includes the power generation and is a component shared among both types of geothermal plant in Table 11.1. Installation BOP is a component of utility scale battery storage that is shared between both types of utility scale battery storage.

Shared technology components mean that when that one of the technologies that uses that component is installed, the costs decrease not just for that technology but for all technologies that use that component.

Government policies

GALLME contains government policies which act as incentives for technologies to reduce costs or limits their uptake. The key assumption about government policy which has an impact on results is a carbon price. The carbon price trajectories used in ANO 2019 modelling are shown in Section 3.4.2.3 of this report.

Other government policies consistent with either the *Working Together* or *Nation First* scenario were included. These policies include generation targets for various renewable technologies, feed in tariffs, installation targets for various technologies, and bans on some technologies e.g. nuclear is banned in Australia.

Resource constraints

Constraints around the availability of suitable sites for renewable energy farms, available rooftop space for rooftop PV and sites for storage of CO_2 generated from using CCS have been included in GALLME as a constraint on the amount of electricity that can be generated from these technologies (Chandler et al., 2014; Government of India, 2016; Edmonds et al., 2013). See Hayward and Graham (2017) for more information.

Exogenous data assumptions

GALLME obtains the change in demand for electricity from GTAP.ME3 and additional demand for electricity for electric vehicles from GALLMT. GALLME starts in the year 2006 and the 2006 electricity demand was sourced from IEA (2008a). The reasons for GALLME starting in 2006 are historical – it was so the results could be used in the Energy Sector Model (ESM), which started in 2006. However, rather than move the start date forward it has been useful to include historical data in GALLME so we can keep track of the progress of technologies. Fossil fuel and biomass prices are exogenous inputs to the scenarios and are obtained from the GLOBIOM emulator (biomass prices) and from projections by the Energy Information Administration of the US Department of Energy (EIA, 2017b). Power plant technology operating and maintenance (O&M) costs, plant efficiencies and fossil fuel emission factors were obtained from IEA (2016; 2015), capacity factors from IRENA (2015), IEA (2015), CO2CRC (2015) and historical (from year 2006 to

2017) installed capacities from IEA (n.d., 2008b, 2016), Gas Turbine World (2009, 2010, 2011, 2012, 2013), UN (2015a, 2015b), US Energy Information Administration (2017a, 2017b), GWEC (n.d.), World Nuclear Association (2017), Schmidt et al. (2017) and Cavanagh et al. (2015).

11.3.2 GALLMT

Transport models tend to be more complicated than electricity models as there is more than one product to meet demand i.e. in GALLME end-user demand is met by electricity whereas in GALLMT different fuels can be used to meet demand at the point of delivery of transport services. There are also different types of demand as there are different modes of transport and each has different fuel requirements and costs.

GALLMT receives demand for travel by different vehicle types and modes. Within each road-based mode, the model can select the lowest cost engine and fuel type that will power that mode of transport (within constraints). Non-road modes of transport do not have details about the engine type, just a generic fuel conversion step.

Technologies and learning rates

GALLMT has 17 separate fuel conversion technologies, where batteries and fuel cells are considered to be a fuel conversion technology (albeit situated directly on modes of transport), 14 different types of fuels, 6 forms of road transport and 6 forms of non-road transport. The fuel conversion technologies, their components and learning rates are shown in Table 11.2.

Table 11.2 Fuel conversion technologies and their associated components, where the learning occurs with the learning rate

FUEL CONVERSION TECHNOLOGY	COMPONENT	SOURCE OF LEARNING	LEARNING RATE (%)
Battery	-	Global	15
Fuel cell	-	Global	20
Anaerobic digestion	-	-	-
1st generation biodiesel production	-	-	-
HEFA[9] process for jet fuel	-	-	-
1st generation ethanol production	-	-	-
2nd-3rd generation ethanol production	Global and Local	Global and Local	10 both global and local
Biomass-to-Liquids (BTL) via Fisher-Tropsch (FT) synthesis route or methanol route	BTL preparation	Global and Local	10 both global and local
	Fuel synthesis (same technology used in CTL[10], CTL	Global	5

---

[9] HEFA = hydro-processed esters and fatty acids

[10] CTL = coal to liquids

FUEL CONVERSION TECHNOLOGY	COMPONENT	SOURCE OF LEARNING	LEARNING RATE (%)
	with CCS and GTL[11]) via FT route		
	Methanol-to-Gasoline (MTG) (same technology used in CTL, CTL with CCS and GTL) via methanol route	-	-
Fast pyrolysis of lignocellulosic feedstocks	Novel component of technology	Global	20
	Mature component of technology	-	-
Hydrothermal liquefaction of lignocellulosic feedstocks	Novel component of technology	Global	20
	Mature component of technology	-	-
Coal-to-Liquids via FT or methanol route	CTL preparation	Global and Local	5 both global and local
	Fuel synthesis (same technology used in BTL, CTL with CCS and GTL) via FT route	Global	5
	MTG (same technology used in BTL, CTL with CCS and GTL) via methanol route	-	-
Coal-to-Liquids with CCS via FT or methanol route	CTL with CCS preparation	Global and Local	10 both global and local
	Fuel synthesis (same technology used in BTL, CTL and GTL) via FT route	Global	5
	MTG (same technology used in BTL CTL and GTL) via methanol route	-	-
Gas-to-Liquids via FT or methanol route	GTL preparation	-	-
	Fuel synthesis (same technology used in BTL, CTL and CTL with CCS) via FT route	Global	5
	MTG (same technology used in BTL, CTL and CTL with CCS) via methanol route	-	-

All X-to-liquids technologies can produce a fuel via Fisher-Tropsch (FT) or methanol-to-gasoline (MTG) routes. Both of these routes are considered to be separate technologies i.e. gas-to-liquids (GTL) via FT and GTL via MTG are two separate fuel conversion technologies. However, the FT component is shared among all technologies that use FT and the MTG component is shared among all technologies that use MTG. XTL preparation (where X is either biomass (B), coal (C) or gas (G)) is shared among both XTL via FT and XTL via MTG. All of these technologies also have the option of including CCS. The remaining fuel conversion technologies in GALLMT do not share components.

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[11] GTL = gas to liquids

Electric and fuel cell electric vehicles

Electric vehicles (EVs) and fuel cell EVs (FCEVs) are assumed to be available for road forms of transport only. For the purposes of projecting cost reductions in batteries for EVs and fuel cells for FCEVs, batteries and fuel cells are considered to be fuel conversion technologies. The fuel (electricity in the case of batteries and hydrogen in the case of fuel cells) is converted to electricity to power the electric motors. The capacity of the batteries and fuel cells included in the road vehicle types is proportional to the vehicle size and workload.

There is shared learning of these technologies with GALLME. Therefore, uptake of EVs and FCEVs leads to cost reductions in Li-ion batteries and fuel cells in both models. In ANO 2019, GALLMT is run before GALLME and thus battery and fuel cell uptake from GALLMT contributes to cost reductions in GALLME. The amount of these technologies installed in GALLME is also fed back into GALLMT in an iterative process. However, it has been found that the installed Li-ion battery and fuel cell capacity in GALLME is insignificant relative to the installed capacity of batteries in EVs and FCEVs in GALLMT and thus the iterative process is not required as it does not lead to any further cost reductions in GALLMT.

Government policies

As with GALLME, the carbon price is the main assumption about government policy that has an impact on the results. Other government policies that are consistent with either the *Working Together* or *Nation First* scenario include ethanol fuel targets (e.g. targets for blends of ethanol), biofuel targets and concessions on the purchase of an EV, plug-in hybrid EV (PHEV) or FCEV. It has also been assumed that under the *Working Together* scenario there would be no new CTL developments without CCS, given that CTL is a highly emissions-intensive technology.

Resource constraints

Competition for CO_2 storage sites for CCS occurs with GALLME as both models include CCS. However, given the higher value of fuels over electricity, GALLMT technologies have priority for these storage sites.

Biomass feedstock availability has been sourced from the GLOBIOM emulator and this constrains the amount of this resource available on an annual basis.

Exogenous data assumptions

The price of all biomass feedstocks has been sourced from the GLOBIOM emulator. Fossil fuel prices are sourced from the EIA (2017b). Fuel conversion efficiencies, O&M costs and capacity factors were sourced from EIA (2017a) and Hayward et al. (2015). Information on improvements in airline efficiencies were found in GEA (2012). Information on shipping was sourced from Stopford (2009).

GTAP.ME3 provided projections of GDP/capita and population which were converted into passenger demand for transport in passenger km (pkm) using the equations of (Schafer and Victor, 2000). Demand for freight transport was sourced directly from GTAP.ME3. Information on average vehicle km travelled and number of passengers or tonne typically carried were taken from (IEA, 2009). Data on historical vehicle numbers, travel per mode and number of passenger per mode were sourced from International Road Federation (2015), ICCT (2012), IEA (2017), WLPGA (2012).

Historical air travel passenger km was sourced from ICAO (2006, 2012). Information on international and regional shipping and rail freight was sourced from International Road Federation (2009) and Stopford (2009). Information on vehicle base cost and efficiencies was sourced from Reedman and Graham (2016).

11.3.3 GALLME results

Nation First scenario

The projected global electricity generation by technology for the *Nation First* scenario is shown in Figure 11.1 for the years 2015 to 2060.

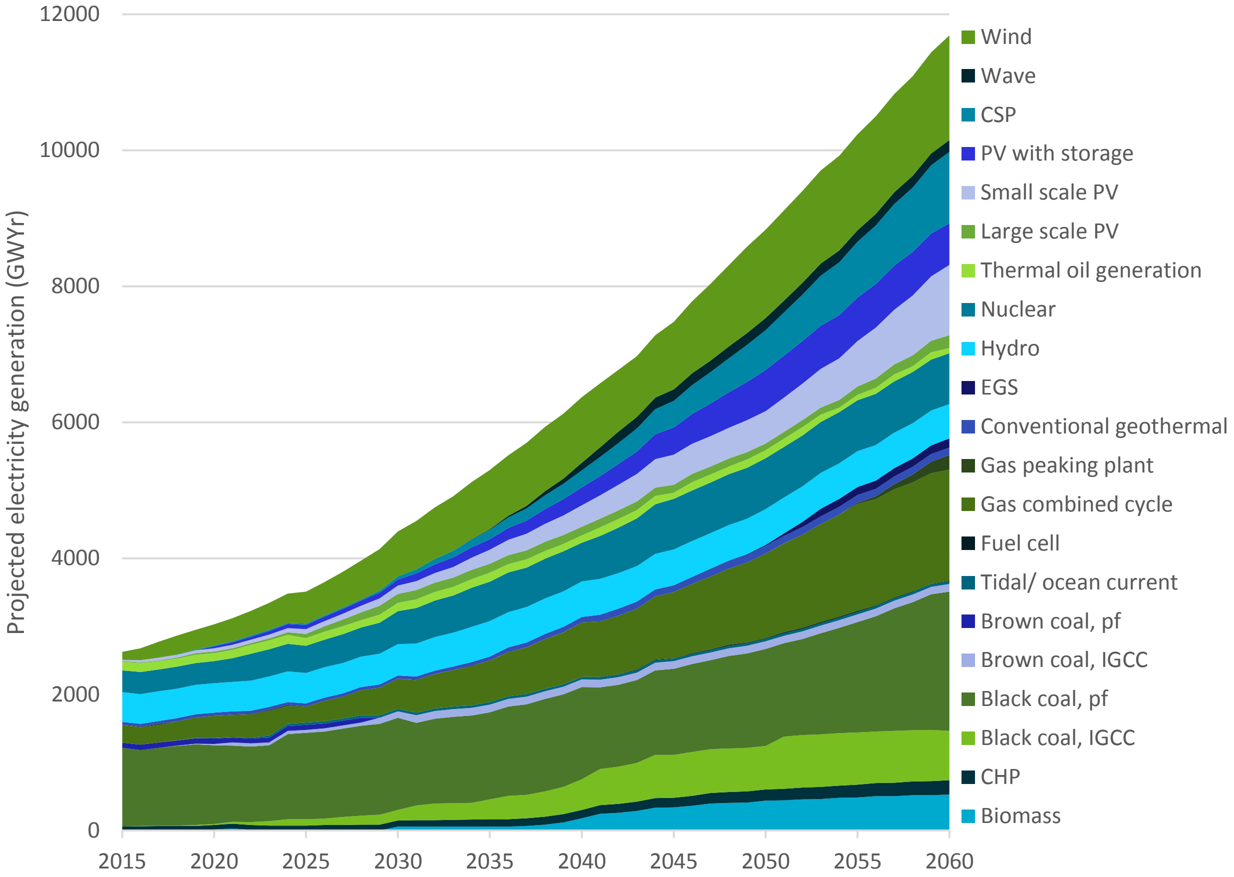

Figure 11.1 Projected global electricity generation under *Nation First* scenario

It can be seen from the Figure 11.1 that generation from CHP, black coal pf, nuclear and hydro remains fairly constant throughout the projection period. New demand for electricity is being met by black coal IGCC, renewables (including biomass) and gas combined cycle. There is no generation from CCS under this scenario. This means that the carbon price is not high enough to make CCS economically attractive.

The projected share of electricity generation by broad technology category is shown in for selected regions in Figure 11.2. Europe is a combination of GALLME regions Western Europe (EUW) and Eastern Europe (EUE) and Asia includes China (CHI), India (IND), Japan (JPN), OECD-Pacific (PAO) and Rest of Asia (SEA). ‘Solar’ refers to both photovoltaic and thermal systems. Brown and black coal are aggregated into ‘Coal’.

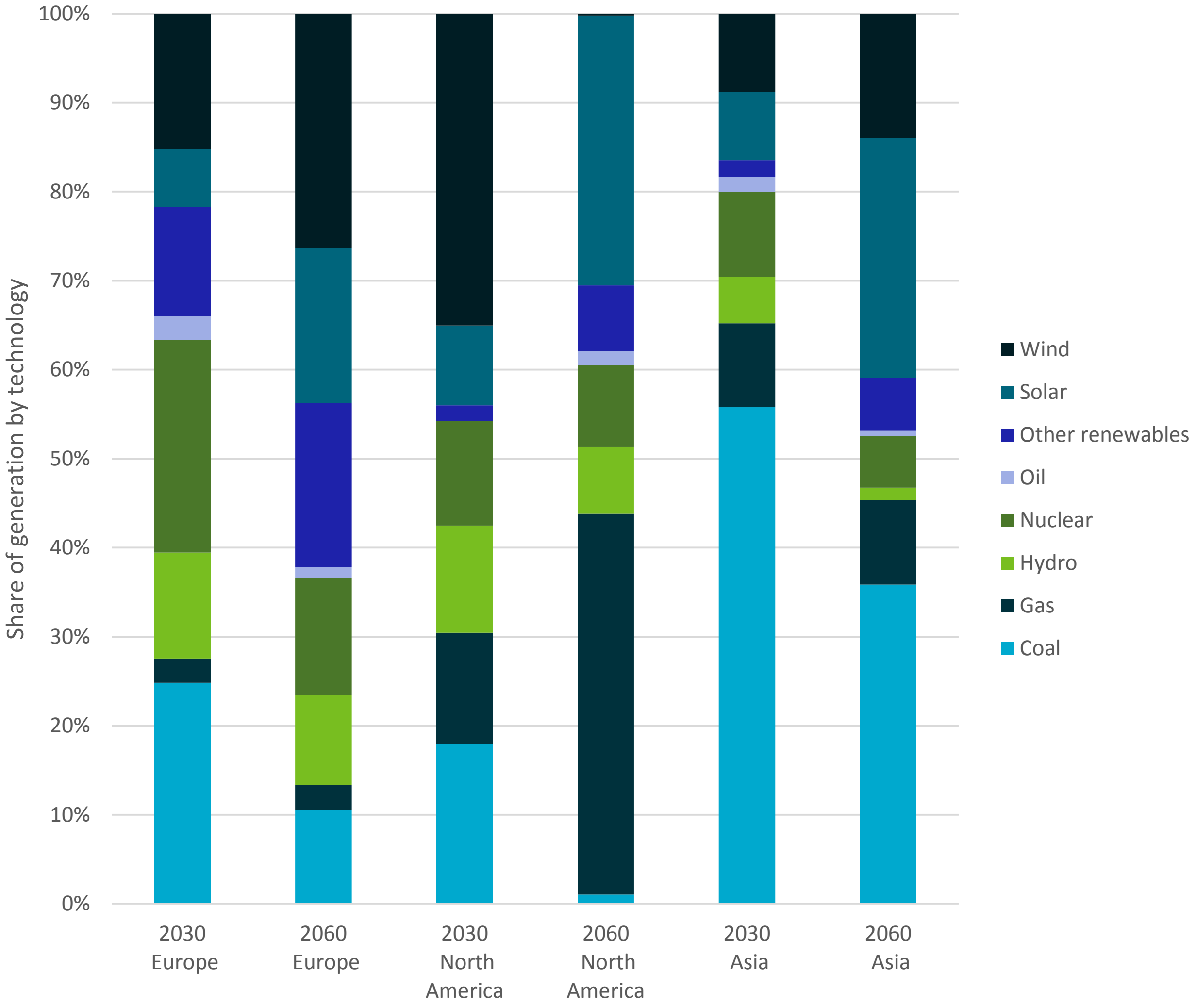

Figure 11.2 Projected share of electricity generation by technology in selected regions in the years 2030 and 2060 under the *Nation First* scenario

All regions see a large drop in coal-fired electricity generation and an increase in solar between 2030 and 2060. A small reduction in nuclear and a general increase in other renewables is also observed. However, the shares of other technologies are more variable. This is due to saturation of available renewable resources which means that the maximum share of these technologies reduces as demand increases. For instance, North America sees a large reduction in the share of wind generation but also has a large increase in gas, solar and other renewables generation. Other renewables includes geothermal and ocean energy. Asia has only a slight increase in gas generation between 2030 and 2060 but a larger increase in solar. Europe sees a large increase across wind, solar and other renewables.

Working Together scenario

The projected global electricity generation by technology for the *Working Together* scenario is shown in Figure 11.3 for the years 2015 to 2060. The slight dip in the results just after the year 2020 is due to a dip in the projected electricity demand.

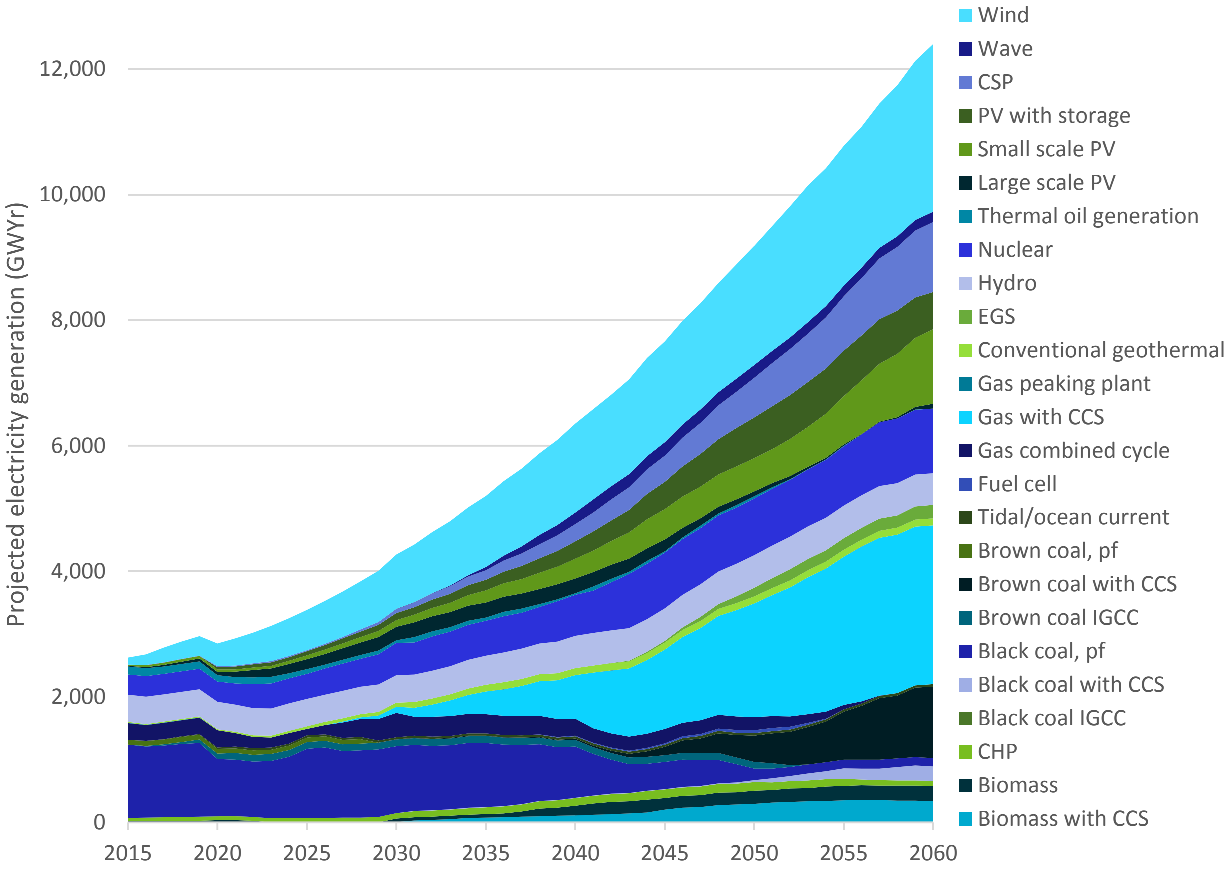

Figure 11.3 Projected global electricity generation under *Working Together* scenario

It can be seen from Figure 11.3 that generation from conventional coal-fired electricity reduces quite dramatically from the year 2040 onwards. This is replaced by both brown and black coal with CCS generation. Generation from gas combined cycle begins reducing from 2050 while gas with CCS expands from 2030 and makes the largest contribution to electricity generation of all technologies by 2060. All non-hydro renewables increase their share (except for large scale PV which is crowded out by other solar deployment) and along with gas with CCS are responsible for meeting the majority of new demand for electricity.

There is approximately the same amount of generation from renewables in each scenario, the differences are in fossil-fuel generation. Under the *Working Together* scenario the carbon price is sufficient to force the emissions-intensive coal-fired generation out of the market to be replaced with low emission gas with CCS and coal with CCS. Overall the total amount of fossil fuel (in GJ) consumed from the year 2015 to 2060 is just slightly lower (less than 1%) under the *Working Together* scenario however those emissions are being stored.

The projected share of electricity generation by broad technology category and for selected combined regions is shown in Figure 11.4

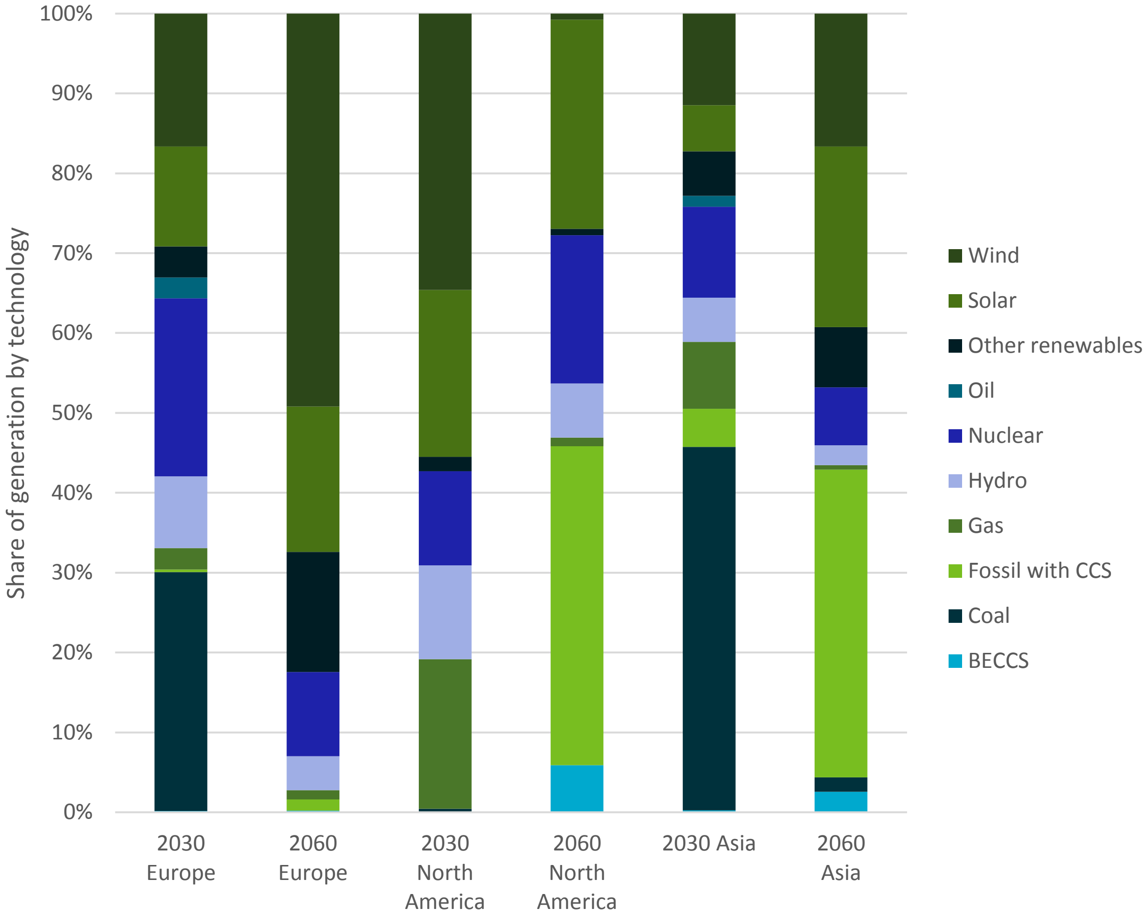

Figure 11.4 Projected share of electricity generation by technology in selected regions in the years 2030 and 2060 under the *Working Together* scenario

CCS technologies make a large contribution to electricity generation in North America and Asia by 2060. Wind makes the largest contribution to electricity generation in Europe by 2060, which is more than double that of 2030 as well as year 2060 of the *Nation First* scenario. The contribution of solar by 2060 is the same in both scenarios for all regions. This means the uptake of solar is not impacted by the level of the carbon price, at least when it is above 30 $/tCO_2$, because solar is a low cost technology. There is a greater share of other renewables by 2060 in North America under this scenario compared to *Nation First* and a large decrease in gas generation to be replaced by fossil CCS and bioenergy with CCS (BECCS). Unlike the other regions shown, fossil CCS makes a ~5% contribution to electricity generation in 2030. Between 2030 and 2060 the share of generation from nuclear reduces in Asia and the share of wind, solar, other renewables and BECCS increases.

Technology cost projections

Selected key technology cost projections are shown in Figure 11.5 for the two scenarios. It can be seen that the capital costs for renewable technologies and batteries under the two scenarios are similar, which reflects the fact that the installed capacity of these technologies is insensitive to the two carbon price trajectories modelled. However, the capital cost of gas with CCS and black coal with CCS is markedly different between the scenarios. CCS is installed in the *Working Together* scenario and thus it achieves some capital cost reductions due to learning-by-doing but it is not installed in the *Nation First* scenario and the cost declines only because of the 0.5% annual reduction in cost on mature components.

Gas combined cycle is a mature technology and thus has a low learning rate which means it has limited cost reduction potential. Similarly wind has a low learning rate in the turbines but a higher rate for local installation costs, which help to reduce the capital cost. Small-scale PV and batteries both have a high learning rate and see rapid cost reductions.

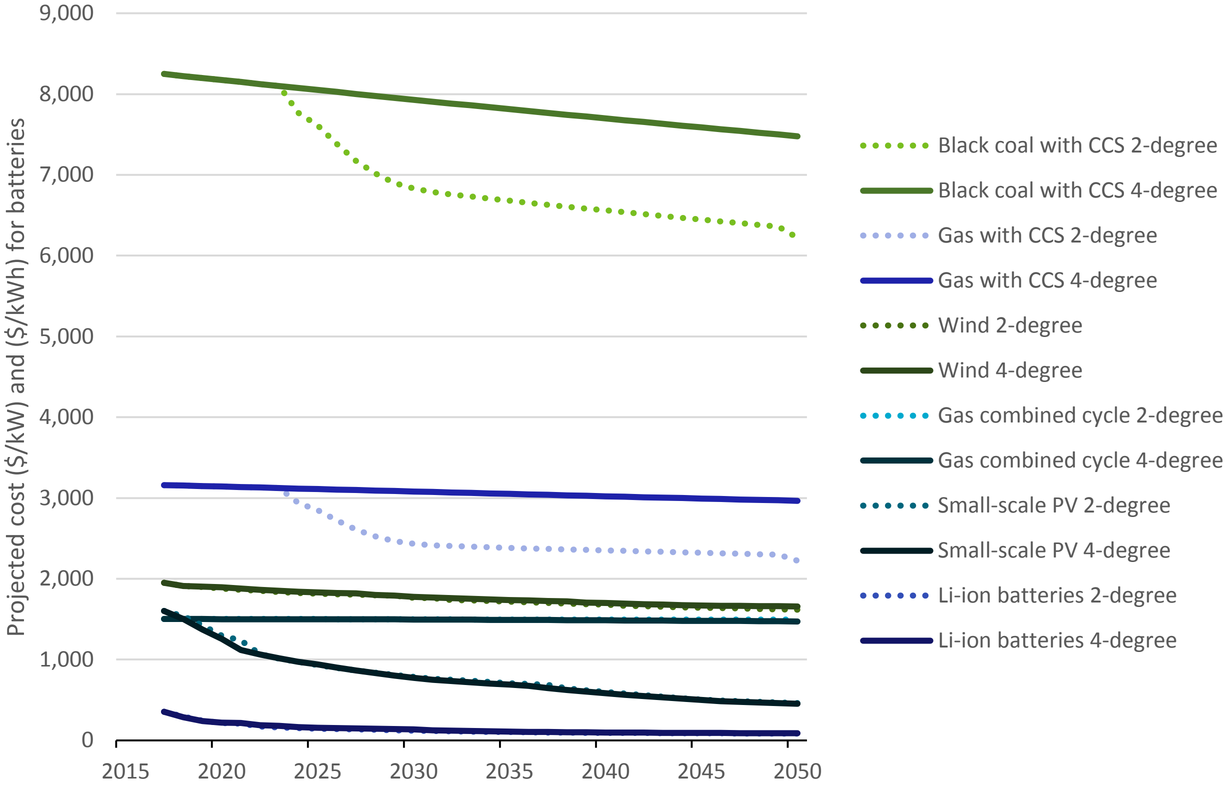

Figure 11.5 Projected technology cost projections under the *Working Together* and *Nation First* scenarios

11.3.4 GALLMT results

The projected global fuel use by broad fuel category is shown in Figure 11.6 for the years 2030 and 2060 by scenario. Broad fuel category means for example that 'petrol' includes both conventionally produced petrol (from oil) and petrol produced from an XTL or an XTL with CCS process or from fast pyrolysis or hydrothermal liquefaction. 'Gas' includes fossil methane and biogas.

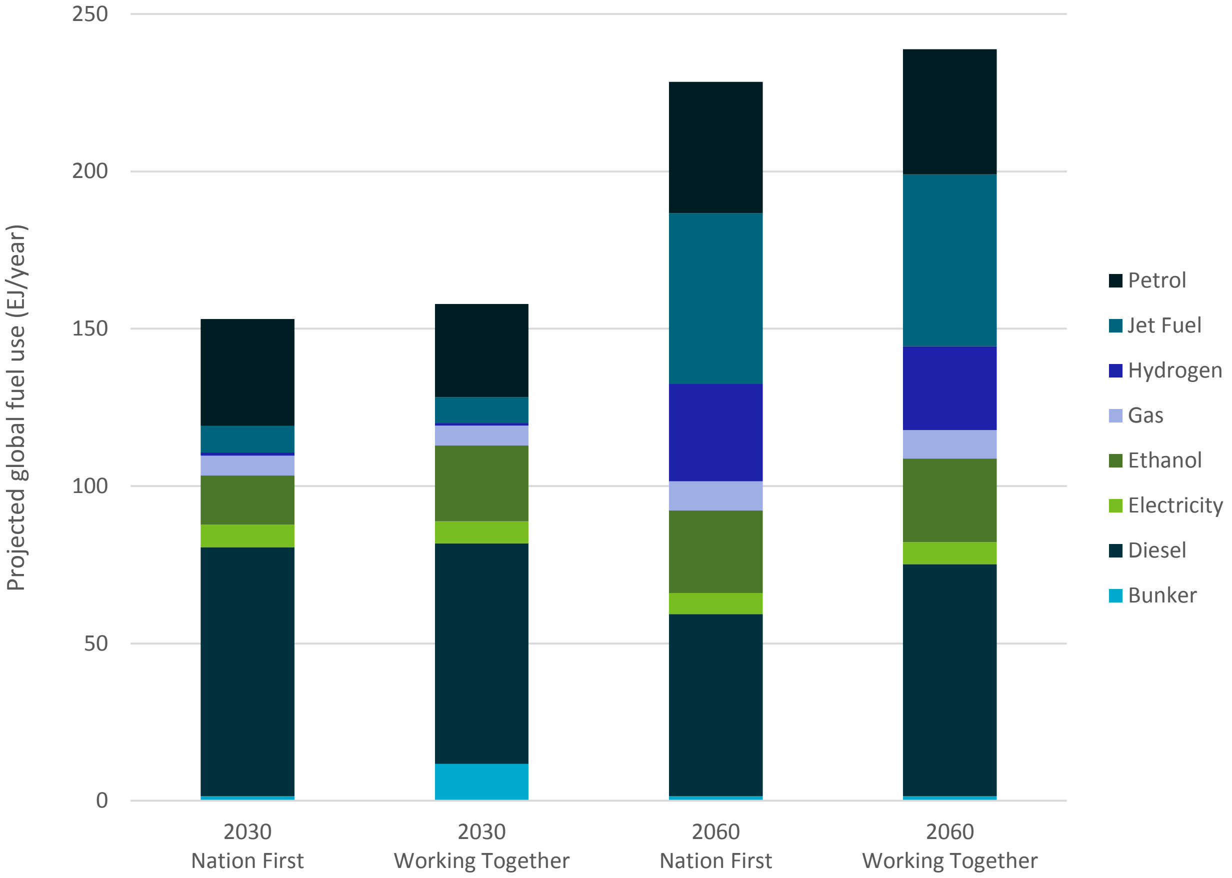

Figure 11.6 Projected global fuel use in the years 2030 and 2060 for the *Nation First* and *Working Together* scenarios

The *Working Together* scenario has higher GDP growth and thus demand for travel is higher compared to the *Nation First* scenario. This results in greater fuel use. Higher GDP means travel shifts to faster modes, which is reflected in the increase in jet fuel consumption between 2030 and 2060. This is composed of fossil and bio-jet fuels. Diesel use is lower by 2060 and petrol use is slightly higher. Hydrogen fuel use has increased dramatically in both scenarios as the travel by hydrogen-fuelled vehicles has increased. Electricity use is similar in 2030 and 2060, however, electric vehicles are more efficient and require less energy to travel the same distance as internal combustion engine or fuel cell vehicles. Consequently, electricity displaces around three times the amount of liquid fuel in terms of energy units required at the point of end-use.

Under the *Nation First* scenario CCS is used in conjunction with XTL technologies and biofuel processes such as BTL via FT are used to produce unconventional fuels whereas the installed capacity of these technologies is lower under the *Working Together* scenario, as can be seen in Figure 11.7. The installed capacity of batteries and fuel cells is high compared to other technologies because these technologies are deployed at small scale for each vehicle whereas other fuel conversion technologies are deployed at large scale further up the fuel supply chain. The centralised fuel conversion technologies have a high capacity factor (85%) and produce fuel on a virtually continuous basis. The batteries and fuel cells in GALLMT are installed on-board vehicles and thus are only used when the vehicles travel and private vehicles are not normally used 85% of the time on an annual basis. However, the batteries and fuel cells also need to be sufficiently large to provide enough power for acceleration. This means a large battery and fuel cells is needed not just for providing range but also for effective acceleration.

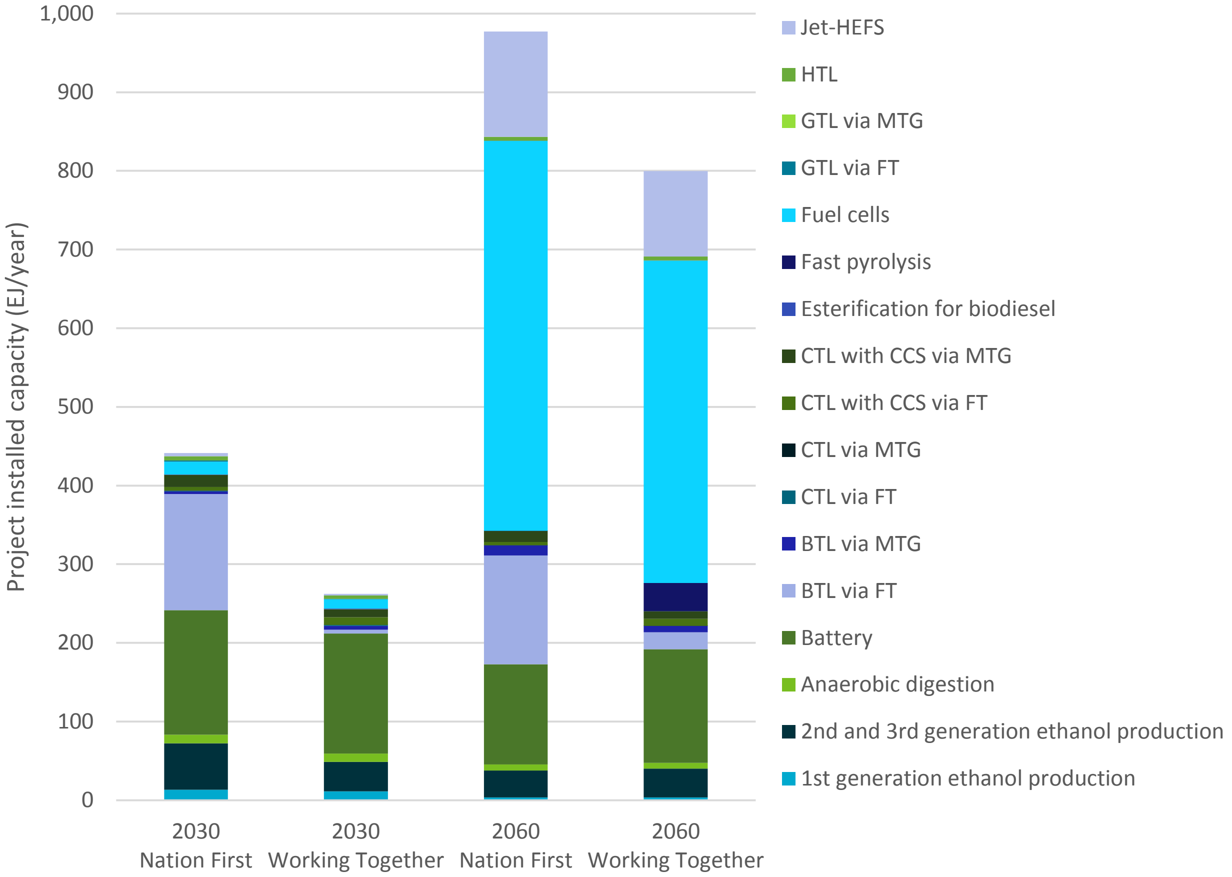

Figure 11.7 Projected installed capacity by technology under all scenarios for the years 2030 and 2060

Projected global road vehicle kms is shown in Figure 11.8 by engine type under both scenarios for the years 2030 and 2060. There is very little difference between the two scenarios except there is slightly higher demand under the *Nation First* scenario. What is most striking is the transformation in engine type between 2030 and 2060, where EVs and FCEVs replace petrol ICE as the dominant engine type. EVs and FCEVs are projected to provide more than 60% of global vehicle kms by 2060.

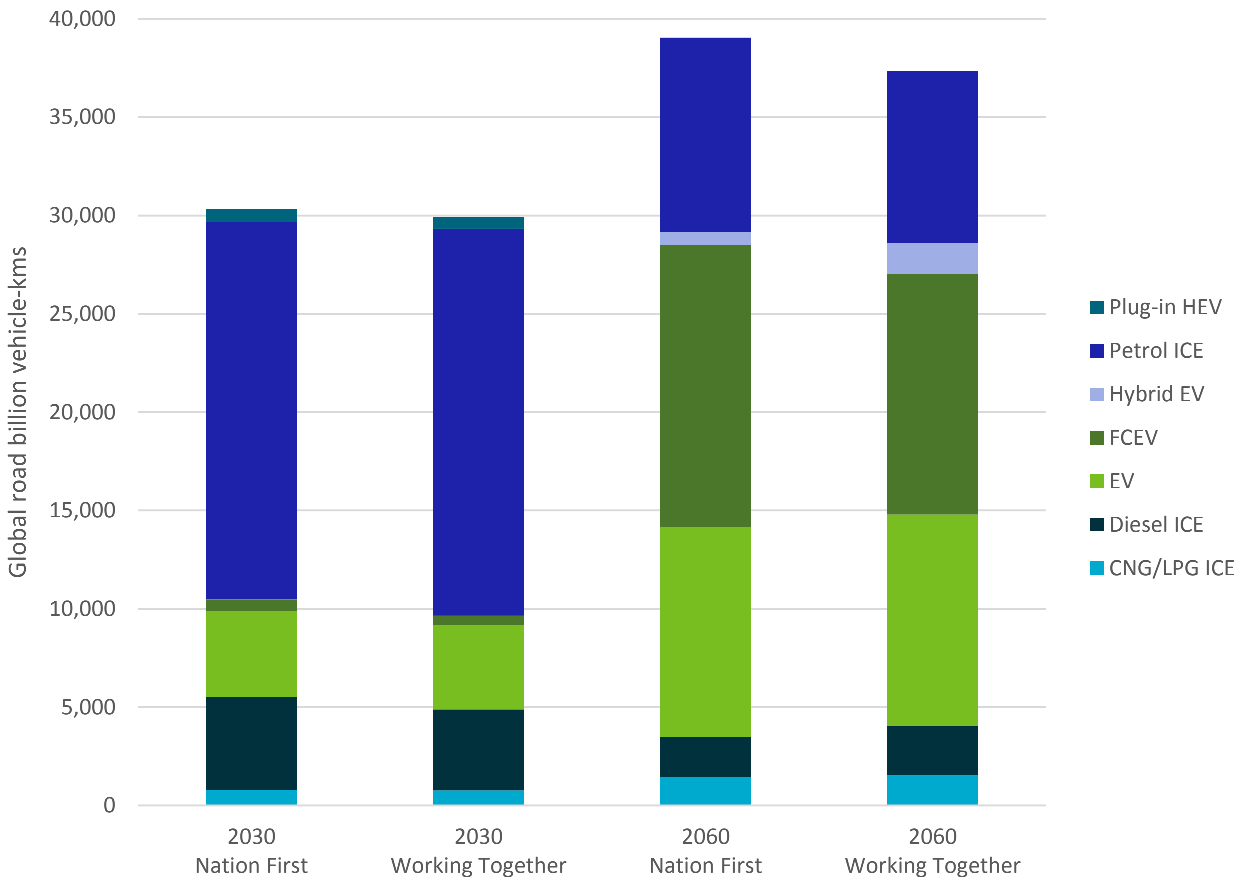

Figure 11.8 Projected road vkm under the *Nation First* and *Working Together* scenarios for the years 2030 and 2060. HEV=hybrid electric vehicle, FCEV=fuel cell electric vehicle, CNG=compressed natural gas, ICE=internal combustion engine

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12 GLOBIOM and emulator

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Model at a glance

Model summary	GLOBIOM-Aus (Global Biosphere Management Model-Australia) is a partial equilibrium model of global agriculture and land use change with 30 world regions. Developed at the International Institute for Applied Systems Analysis (IIASA).
Key ANO scenario drivers	• Shared Socioeconomic Pathway scenario selection.
Key inputs and assumptions	• Complete database of ten yearly simulated GLOBIOM scenarios for all combinations of a discrete selected set of biomass prices and carbon prices. • Global biomass market prices by year • Global CO_2 prices by year.

12.1 Introduction

In response to peer review comments on the Australian National Outlook 2015 (CSIRO, 2015), the Australian National Outlook 2019 (CSIRO and NAB, 2019) relies on a global agricultural and land use model to represent parameters and variables associated with land use and bioenergy production. The Global Biosphere Management (GLOBIOM) model (Havlik et al., 2011, 2014 and IIASA 2018) was selected given its scientific reputation (Barker and Bashmakov et al., 2017, citing Havlik et al., 2014) and existing collaboration between CSIRO and the GLOBIOM custodian, the International Institute for Applied Systems Analysis (IIASA). Results from previously executed scenarios calculated by GLOBIOM for the Shared Socioeconomic Pathway (SSP) Database (IIASA 2016) were recalculated by IIASA [acknowledgement Stefan Frank et al] and provided to CSIRO for ANO 2019. The recalculation was required to provide results for an extensive range of discrete alternative global price assumptions for carbon dioxide emissions and biomass fuel, and a slightly more highly regionally resolved version of GLOBIOM results that represents Australia as a distinct region.

The resulting set of GLOBIOM reporting variables represents a generalised look-up table (a comprehensive database of results sampled across several time, space, space and scenario dimensions). This dataset contains results at decadal time intervals from 2000 to 2100 (see also the public database at IIASA 2016) for numerous, but necessarily limited, settings of parameters such as carbon price and biomass prices and other global economic settings. For application in ANO 2019 a GLOBIOM emulator tool was developed to interpolate results extracted from the database of selected scenarios to approximate GLOBIOM results at annual time resolution and arbitrary (within a bounded continuous range) carbon and biomass price trajectories.

To verify satisfactory model calibration, results for Australia from both multiple GLOBIOM scenarios represented in the database and selected interpolated scenarios were compared with historical FAOSTAT (2018) data and published projections from other global and national land sector models, e.g. projections from the Agricultural Model Inter-comparison and Improvement Project (von Lampe et al., 2014) and land sector projections from ANO 2015 (CSIRO, 2015). Our assessment is that for the purposes required for ANO 2019 (regional scale emissions and land use projections, biomass supply and prices), interpolated GLOBIOM results are sufficiently robust and represent an improvement on the 2015 ANO approach of off-model estimates of land use change emissions.

The GLOBIOM emulator output is linked with ANO 2019's global economic (GTAP-ANO, see Chapter 10), electricity (GALLME, see Chapter 11), transport (GALLMT, see Chapter 11) and climate (MAGICC, see Chapter 13) models to produce consistent projections of land use and agricultural emissions, biomass and first generation biofuel supply and prices. GLOBIOM does not replace the agriculture sectors of the global CGE model. Rather, the whole ANO 2019 global suite is run with consistent carbon price, population, GDP and fossil fuel projections, and results are sourced from the global model most suited to deriving global context for the national modelling suite.

12.2 Model description

The GLObal BIOsphere Management (GLOBIOM) model (Havlik et al., 2011; 2014; see also IIASA, 2018) has been used to simulate numerous key scenarios associated with the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports (Barker and Bashmakov et al., 2017, citing Havlik et al., 2014) and the Shared Socioeconomic Pathway scenarios (Riahi et al., 2017) consistent with one or more Representative Concentration Pathways (Moss et al., 2008). A broad range of pre-existing scenario projection results generated by GLOBIOM as part of the international climate change research community's (O'Neill et al., 2017) investigation into global futures based on the SSP framework appears in the SSP database (IIASA 2016).

For details of the GLOBIOM model internal workings, see Krey et al. (2016) and Valin et al. (2014). GLOBIOM is a recursive dynamic partial equilibrium model of three highly (geographically and) biophysically constrained global economic sectors: agriculture, forestry and bioenergy (Havlik et al., 2011, 2014, and IIASA 2018). The model parametrisation is based on comprehensive socioeconomic and geospatial data, representing crop and livestock production and a range of forestry and bioenergy products. These, and other, land-uses are represented in a spatially explicit manner so that competition for alternative land-uses both among and within these economic sectors must be resolved as part of the modelling analysis. The modelled use of land for agriculture and forestry production is sensitive to both management choices and geographical constraints: land, water availability and weather characteristics. Spatial resolution within regions permits technological costs and environmental constraints to vary spatially.

GLOBIOM's general principle of analysis is the economically standard, partial equilibrium, framework of maximising the sum of consumer and producer surplus, subject to physical constraints including competition for land and natural resources and technology performance constraints, as well as policy and land management constraints. Prices and trade flows are endogenously determined at time intervals of 10 years across several dozen world regions. The standard version has a single combined region for Australia and New Zealand; for ANO 2019, data was provided for Australia and New Zealand as separate regions.

12.2.1 Inputs to GLOBIOM

Results data were calculated by GLOBIOM consistently with scenarios available in IIASA (2016) as a key informational basis for the ANO 2019 land use projections. In particular, the global socioeconomic settings in the ANO 2019 scenarios (see Chapter 2) were aligned to scenarios in IIASA (2016), both of which are based on the SSP framework described in O'Neill et al. (2017). This facilitates model calibration and comparison of results.

The GLOBIOM results were interpolated to produce 'GLOBIOM emulator' projections. The following briefly describes the relevant results database, and then further describes the choice of interpolating variables and the interpolation process.

The population and economic productivity assumptions required by the ANO2019 global scenarios (see Chapter 3), namely SSP1 (Sustainability, Taking the Green Road, low challenges to mitigation and adaptation) and SSP2 (Middle of the Road, medium challenges to mitigation and adaptation) had been selected for compatibility with an international research community investigation into global future scenarios settings across a comprehensive range of agreed 'Shared Socioeconomic Pathway' (see Riahi et al., 2017) settings – population and GDP assumptions, and Representative Concentration Pathways (RCP, anthropogenic emissions assumptions and global greenhouse response), to which GLOBIOM has contributed. Hence existing GLOBIOM results corresponding exactly to those SSP settings, for a broad range of carbon and biomass prices expected to overlap with the ANO2019 aim of consistency with RCP6.0 and RCP2.6 respectively.

For energy sector modelling outside the land use sector, GLOBIOM is coupled with the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) as part of the IIASA Integrated Assessment Modelling framework (Fricko and Havlik et al., 2017, see also Krey et al., 2016).

In particular the ANO 2019 global scenarios design is such that the socioeconomic settings equivalent to those for the MESSAGE-GLOBIOM SSP2-60 was used to generate the results in the database for the *Nation First* scenario, and those for the MESSAGE SSP1-26 was used for the *Working Together* global scenario.

12.2.2 GLOBIOM outputs

GLOBIOM represents a comprehensive set of reporting output variables covering economic (demand and production quantities and price) variables by region in global agricultural and forestry economic sectors. This includes 18 of the globally most important crops, six livestock products (including meat, dairy and eggs), a broad range of forestry biomass products, and bioenergy production including second generation biofuels as well as first generation. The 18 globally most important crops represented in GLOBIOM are barley, dry beans, cassava, chick peas, corn, cotton, groundnut, millet, potatoes, rapeseed, rice, soybeans, sorghum, sugarcane, sunflower, sweet potatoes, wheat, and oil palm. Livestock and livestock products include beef, pork, sheep/goat meat, poultry, eggs and dairy. In addition to demand and production quantities and prices for markets in the key land-based economic sectors, GLOBIOM represents environmentally relevant outcomes such as emissions of several of the most important greenhouse gases, carbon storage, land cover, fertiliser use, and water consumption.

IIASA provided a comprehensive dataset effectively equivalent to a ‘look-up’ tables with projections for variables associated with crop, livestock, forestry and bioenergy supply and demand for all world regions for the period 2000-2100 at ten-year time steps. Projections of each variable were provided for twelve carbon prices scenarios and eight biomass prices scenarios under environmental, socioeconomic and greenhouse gas emissions assumptions associated with the Shared Socioeconomic Pathways 1 and 2. Table 9.1 shows some relevant parameters included in GLOBIOM’s look-up tables.

Table 12.1 Summary of parameters included in GLOBIOM's look-up tables

PARAMETER	DESCRIPTION / PARAMETER SPACE
COORDINATES	
Regions	World, Australia, Brazil, Canada, China, Congo basin, Eastern Africa, European Union: Baltic, European Union: Central East, European Union: Mid West, European Union: North, European Union: South, former USSR, India, Japan, Mexico, Mid East North Africa, New Zealand, Pacific Islands, Central America, Rest of Central Eastern Europe, Rest of Western Europe, South America, Rest of South Asia, South East Asia, South East Asia (ex or planned economies), South Korea, South Africa, Southern Africa, Turkey, USA, Western Africa and Rest of Sub-Saharan Africa,
Time	From 1990 to 2100 in ten-yearly intervals
SCENARIOS	
Reference Shared Socioeconomic Pathways	SSP1: Low challenges for climate change adaptation and mitigation. SSP2: Moderated challenges for climate change adaptation and mitigation.
Reference prices	Biomass: 1.5, 3.0, 5.0, 8.0, 13.0 (USD2000 per primary GJ). CO_2: 0, 5, 10, 20, 40, 50, 100, 200, 400, 600, 1000, 2000 (USD2000 per tCO2eq.).
RESULT VARIABLES	
Agricultural production, cultivated area, yields and prices	Barley, chick peas, corn, cotton, dry beans, groundnuts, millet, oil palm, potatoes, rapeseed, rice, sorghum, soybeans, sugar cane, sunflowers, sweet potatoes, wheat, beef, sheep/goat meat, poultry, pork, milk, eggs, forestry.
Agricultural supply and demand	Food, feed, bioenergy (1st and 2nd generation), forestry.
Land cover	Cropland, forests (managed, natural), pasture, other natural land.
Land use emissions	Methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O)
Fertiliser use	Nitrogen, Phosphorus

12.3 GLOBIOM dataset discussion

12.3.1 Global and Australian land use projections from look-up tables data

Average global and Australia-specific projections corresponding to the SSP2 scenario from 2000 to 2060 were assessed to ensure consistency with ANO 2019 requirements. The averages represent unweighted combinations of the projections contained in GLOBIOM's look-up tables. Relative to 2000 data, average global projections indicate an increase of 16% and 6% in cropland and forest surface to 2060, around 241 and 238 million hectares (Mha) respectively (Figure 12.1a). Managed forests are projected to increase around 163% (1,038 Mha) and expanding agricultural land is accompanied of reductions in grasslands and native forests, around 485 and 800 Mha lost respectively.

Food demand is projected to increase around 9% for crops and 23% for livestock (Figure 12.1b). Non-energy crop and livestock production increase 104% and 90% to 2060. Average results project a significant increase in energy crops (million tons of dry matter per hectare) after 2040 (Figure 12.1c) in response to increasing bioenergy demand (Figure 12.1d). Yields (tDM/Ha/year) are projected to increase 96% for cereals, 109% for oil crops and 83% for sugar crops (Figure 12.1e). Although there are some small differences between roundwood production and demand, a global market equilibrium is satisfied (Figure 12.1f). Fertiliser use is projected to increase around 80% (Figure 12.1g) while agricultural and forestry emissions decrease 13% for methane (CH_4) and increase 31% for nitrous oxide (N_2O). Carbon dioxide (CO_2) emissions become negative (due to offsets) after 2050 (Figure 12.1h). This result is generated by the range of carbon prices used in the projections (0 to 2,000 US$2005/t CO_2). Projected prices for non-energy crops and livestock are 46% higher than 2000 prices (Figure 12.1i).

For Australia, the average projections show an expansion of cropland (4.3 Mha) and forests (22.5 Mha) and a decrease in pasture land (66.7 Mha), all relative to 2000 levels (Figure 12.2a). Food demand (kilocalories per capita per day) decrease around 6% for crops and 20% for livestock products (Figure 12.2b). Increases in livestock and non-energy crops production follow trajectories similar to the global averages (Figure 12.1c and Figure 12.2c). Energy crop production become the main agricultural output after 2020. Bioenergy demand increases at rates significantly higher than the global average between 2010 and 2030 (Figure 12.2d). Yield increases are projected to double for cereals, triple for oil crops and increase around 46% for sugar crops (Figure 12.2e). A significant increase in roundwood demand and production between 2010 and 2020 is projected for Australia (Figure 12.1f). Nitrogen and phosphorus fertilisation increases at around half the global rates (Figure 12.2g). A transition to net offset CO_2 emissions is projected to occur between 2050 and 2060 (Figure 12.2h). Prices for livestock and crop products are projected to increase around 128% in real terms relative to 2000 (around three times the average global rate) (Figure 12.2i).

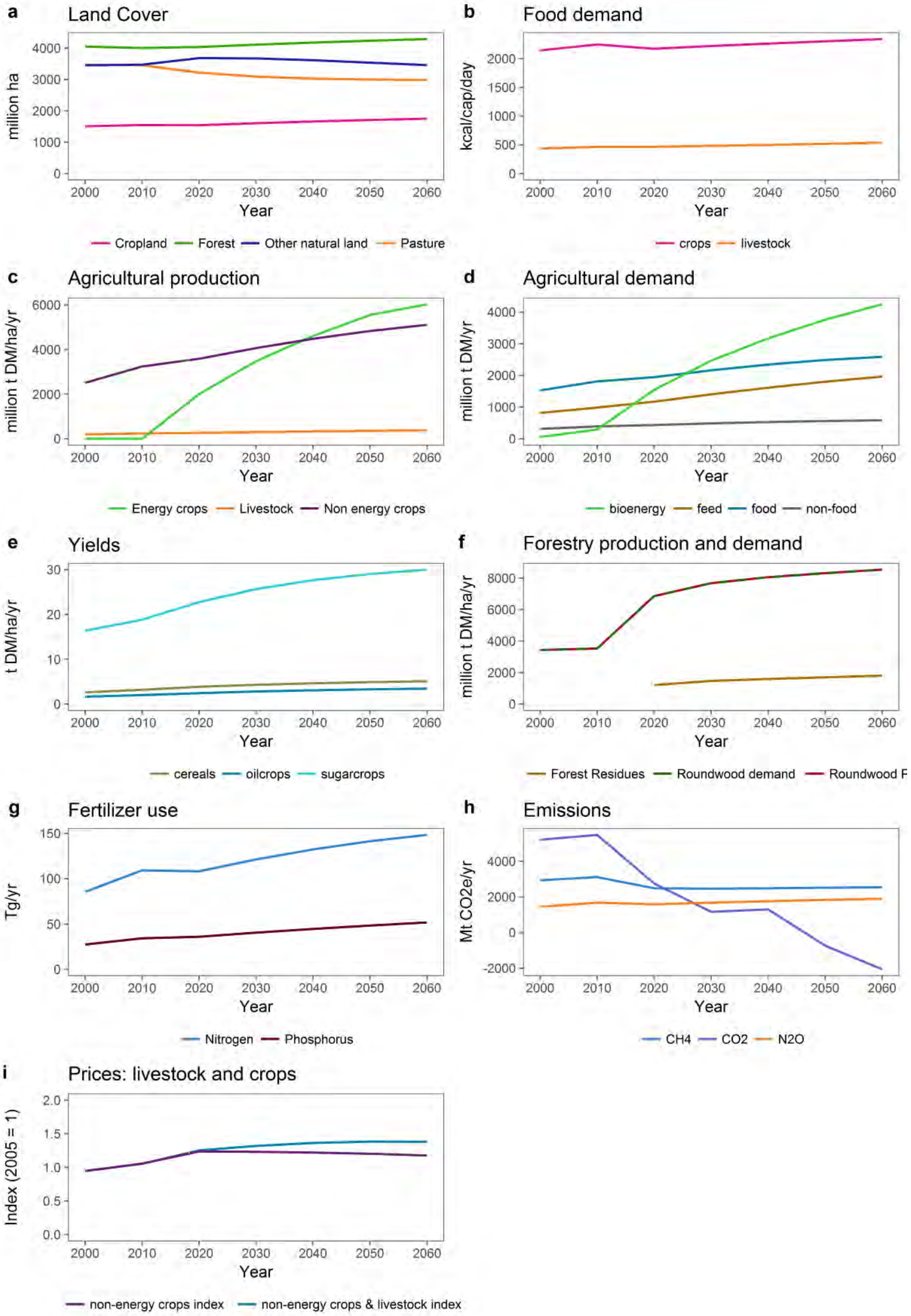

Figure 12.1 World projections for the forest and agricultural sectors (averages across all carbon and biomass prices)

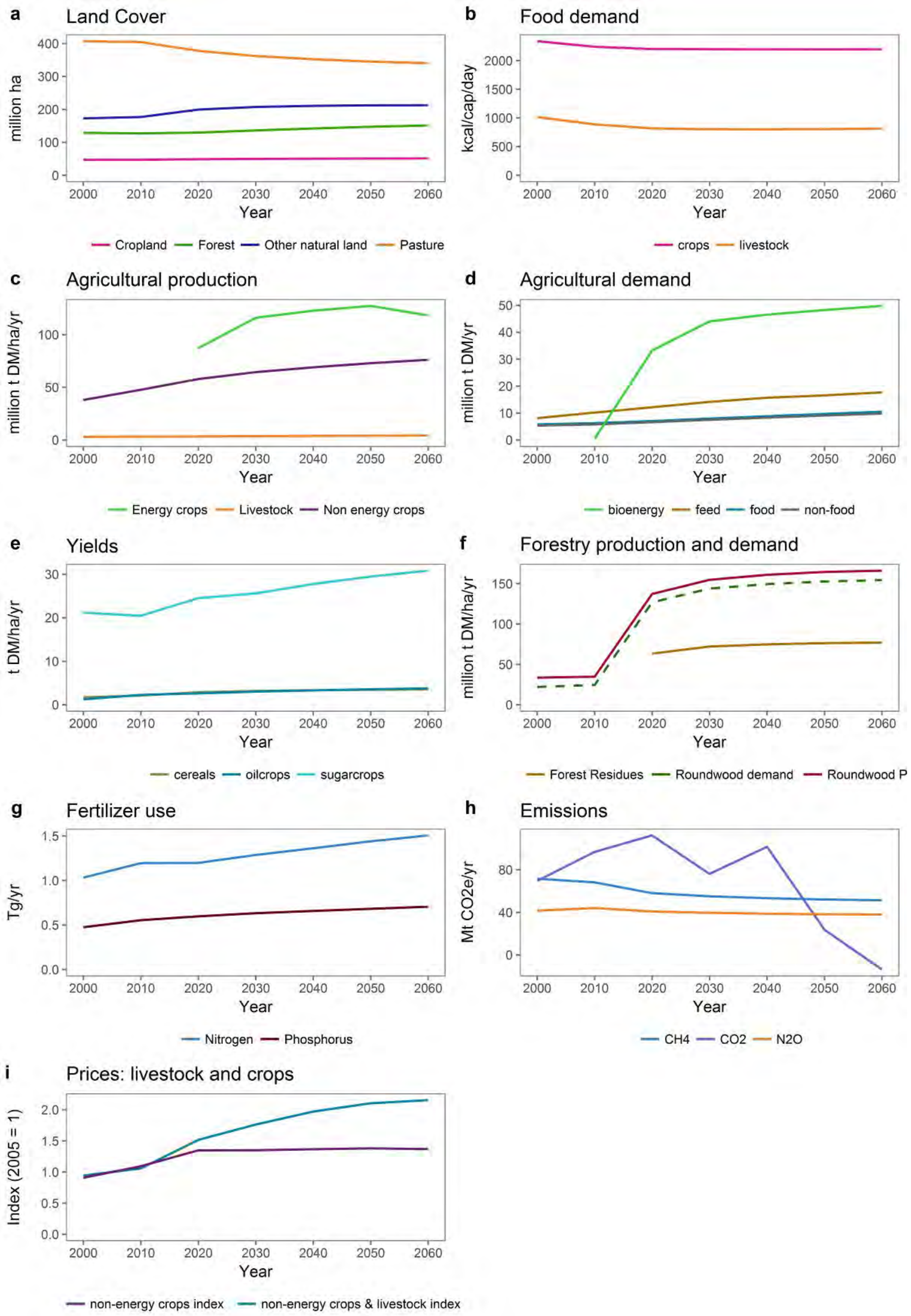

Figure 12.2 Australia-specific projections for the forest and agricultural sector (averages across all carbon and biomass prices)

12.3.2 Australian crop and livestock projections

GLOBIOM's projections of Australian livestock and agricultural production, cultivated surface and producer prices (under the assumed carbon and biomass price levels and conditions associated with the SSP2) were also compared with Food and Agriculture Organisation of the United Nations statistics (FAOSTAT) reports for the period 2000–2014. The purpose was to test the calibration of GLOBIOM-Australia and to identify and correct potential errors. GLOBIOM's decadal projections were interpolated to annual time series.

Land use

GLOBIOM's cropland and forest cover projections are consistent with observed data during the period 2000-2014 (Figure 12.3a, b, c). GLOBIOM's forest cover projections did not capture the high deforestation rates observed during the period 1997-2007, mostly in Queensland. Changes in State level land clearing regulations resulted in a shift from net forest loss to gains (i.e. a forest transition) in Australia around 2008 (Marcos-Martinez et al., 2018). The long-term forest cover projections of the *Working Together* and *Nation First* scenarios are consistent with a sustained forest transition process. Cropland area follows similar trends under the *Working Together* and *Nation First* scenarios, for grassland cover the trends deviate after 2020.

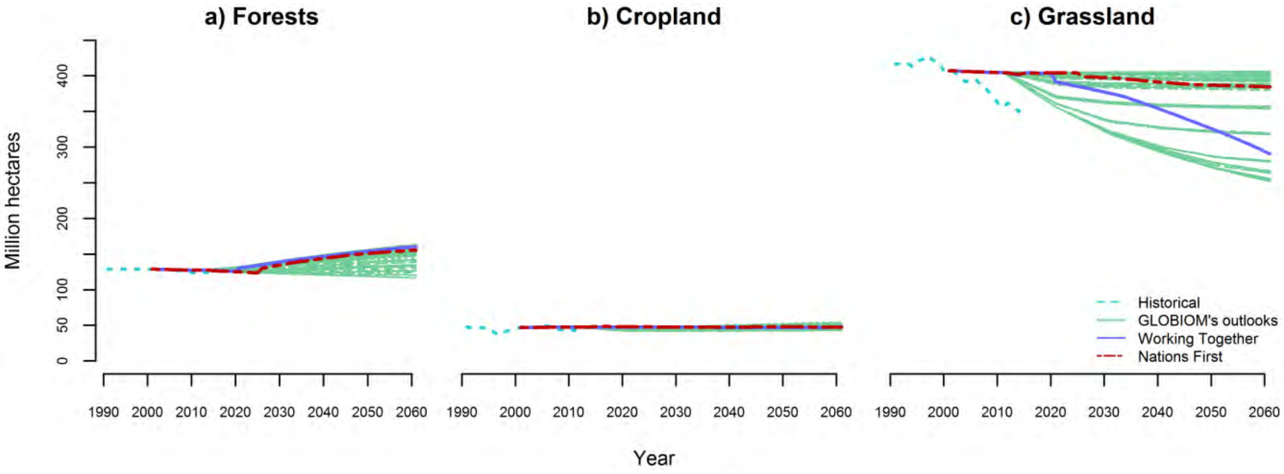

Figure 12.3 Projected land cover change for Australia. Historical land use (1990–2014) and GLOBIOM's projections (2000–2060) for a) forest, b) cropland, and c) grassland surface

Livestock production and price projections

Beef, and sheep & goat meat production projections are within the range of historical observations (Figure 12.4a, b). Australian producer prices for those products were higher than the GLOBIOM estimates during the period 2000-14. On aggregate no significant anomalies were identified across livestock projections i.e., there are not drastic shifts in trajectories or significant deviations from historical data. Price paths for beef and sheep and goat follow relatively similar trajectories under the *Working Together* and *Nation First* scenarios. However production trajectories diverge after 2020.

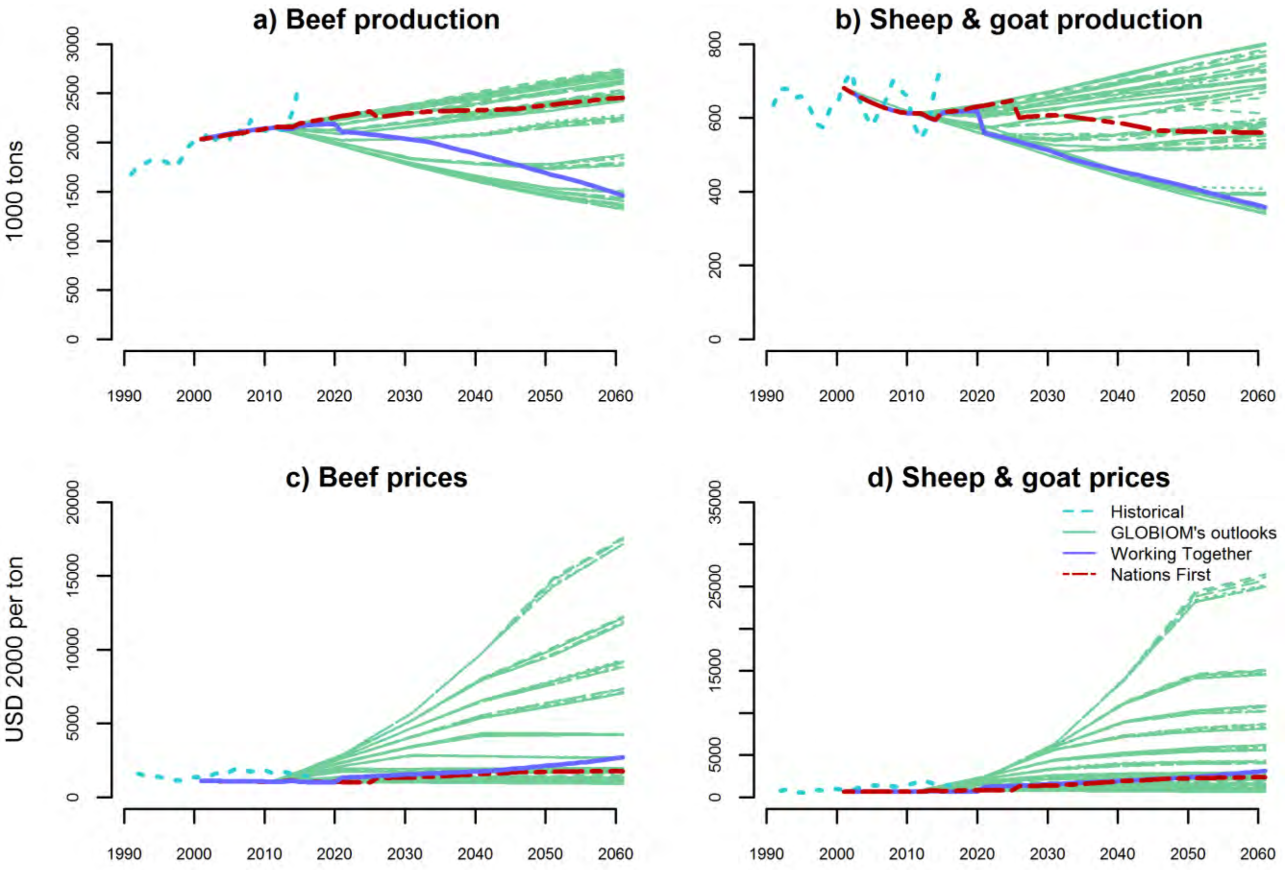

Figure 12.4 Projected beef and sheep and goat meat production and prices.

Crop cultivated area, production and price projections

Projections for main crops (in terms of cultivated area) are within the bounds of historical variability and do not present drastic changes in trajectories. Land-uses with small cultivated surface usually present large variability in their projections. Wheat cultivated area projections are significantly lower than historical trends (Figure 12.5a), declining from 2000 to 2020 and then increasing in most scenarios. The short-term trends (2000-2010) of those projections are opposite to historical trends. Wheat production and price projections are consistent with historical trends (Figure 12.5b, c). Barley production and cultivated area projections deviate from observed trends after 2010 (Figure 12.5d, e), average price projections for this crop are consistent with long-term historical trends (Figure 12.5f). Rapeseed cultivated area, production, and price projections for the period 2000-2020 follow historical increasing trends (Figure 12.5g, h, i). After 2020 those projections change direction. Projections for sorghum are within the bounds of historical variability and trends (Figure 12.5j, k, l). Sugar cane production and cultivated surface projections do not reflected observed trends during the period 2000-2014 (Figure 12.5m, n). All sugar cane production projections are larger than the long-term historical average. The variance of cultivated area and production projections for cotton is very small across all modelled scenarios for the period 2000-2030 with trends consistent with observed data (Figure 12.5p, q). After 2030 some scenarios show drastic changes in projected trajectories. Cotton prices are significantly lower than observed domestic prices (Figure 12.5r). Most of the trajectories generated with the GLOBIOM emulator are within the range of the GLOBIOM’s look-up tables (Figure 9.6).

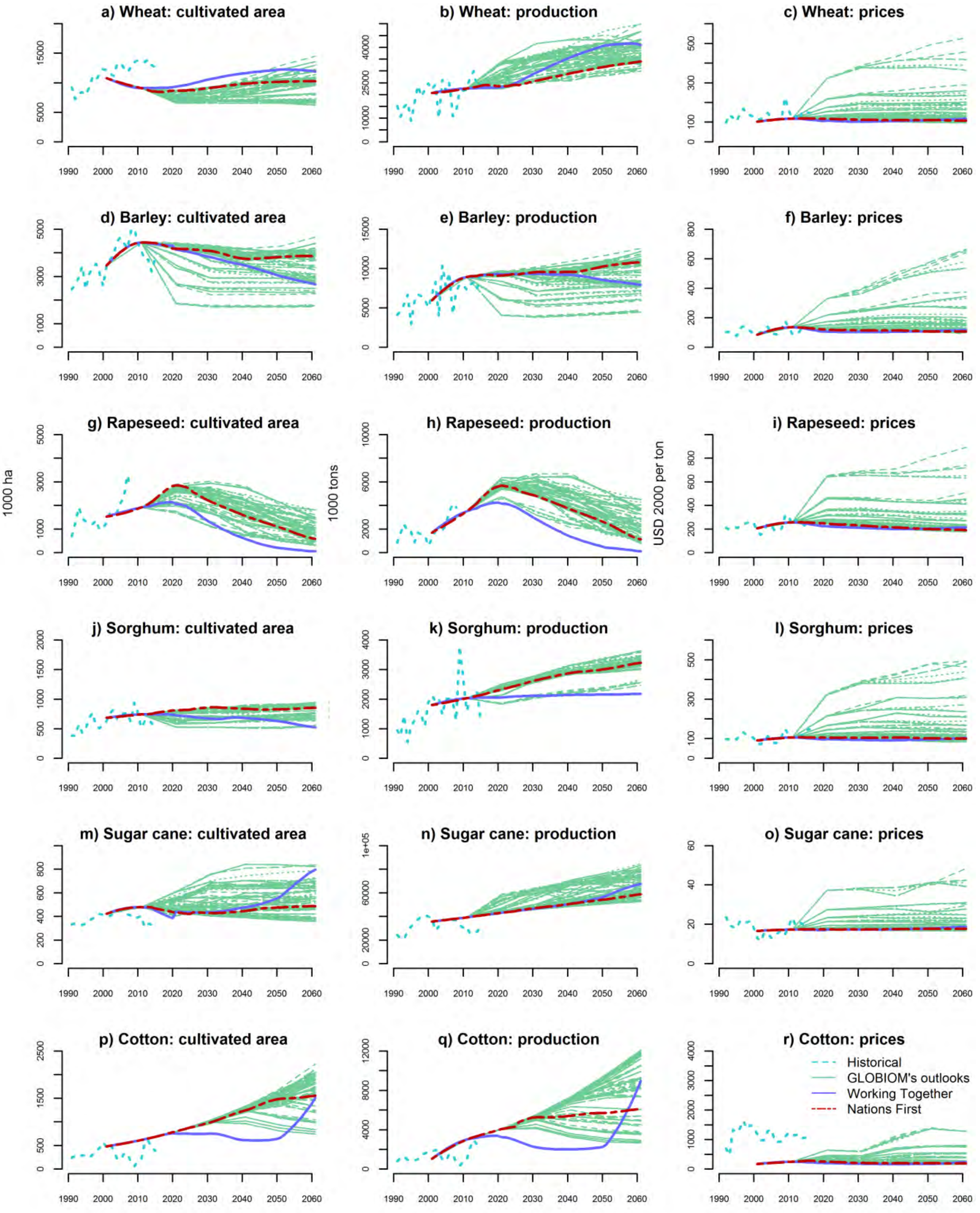

Figure 12.5 Projected cultivated area, production and prices for main crops: Wheat, barley, rapeseed, sorghum, sugar cane and cotton

12.4 GLOBIOM emulator

GLOBIOM's projections interpolated from decadal to annual time steps were used to generate an emulator that estimates outcomes corresponding to discrete alternative global carbon and biomass prices not included in the static ‘look-up’ tables. The GLOBIOM emulator is based on weighted interpolation procedures.

12.4.1 Emulator inputs

Key model inputs for the GLOBIOM emulator are:

- Database of simulated GLOBIOM scenarios results (to be interpolated) for two SSPs: SSP1 and SSP2, all combinations of a discrete selected set of biomass prices and carbon prices at ten-year steps
- Global biomass market prices by year (an interpolating parameter)
- Global CO_2 prices by year (an interpolating parameter).

The key parameter inputs is a complete database record of simulated GLOBIOM scenarios for all combinations of a discrete selected set of biomass prices and carbon prices at ten-year steps for two SSP scenarios. The key scenario inputs are global CO_2 prices (Figure 12.6) and biomass prices by year and by region (for ANO 2019 a price series from MESSAGE: see Section 12.2.1, consistent with the SSP scenarios, was used).

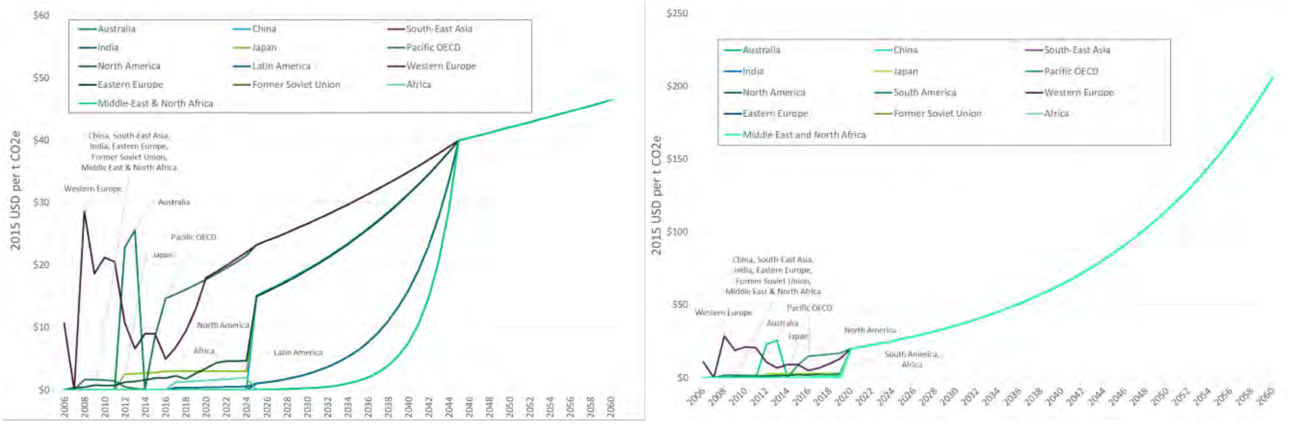

Figure 12.6 Global CO_2 price assumptions: ANO 2019 scenarios [Left: *Nation First*, Right: *Working Together*]

12.4.2 GLOBIOM emulator – interpolation and aggregation method

The GLOBIOM emulator is written in python, making extensive use of the *pandas* dataframe library (McKinney 2010) and relying on the *scipy* library (Jones et al., 2001-) for some interpolation operations. The process starts by ensuring that the range of interpolating CO_2 prices and biomass prices lies within the range $[m, M]$ represented in the parameter input set using an upper and lower saturation function $y = \max(\min(x, M), m)$.

The next step is to interpolate results across time from decadal to annual, for each region and for each constant biomass and carbon price scenario with relevant biomass and CO_2 prices, for all years (including years for which the corresponding constant prices are not relevant which gives scope for efficiency improvement in the computation). The interpolation method for each time series exploits the *scipy* interpolation toolbox, with a preference for *pchip* (piecewise cubic hermite polynomial) where possible as default, or quadratic or linear interpolation in cases where there is insufficient, or poorly conditioned, data. This gives estimates of annual parameter values for selected discrete biomass and CO_2 prices.

Then for each results variable for each region and year, an interpolation across biomass and CO_2 prices is calculated from the yearly interpolated series. This is given by the weighted sum of the interpolated series from the four constant price scenarios with the closest biomass and CO_2 prices from the discrete set of values for the original data. The weights depend on the arithmetic or geometric distance of the interpolating reference price and the discrete corresponding values for the interpolated data. The interpolation weights are arithmetic (linear) for biomass prices and geometric (log-linear) for CO_2 prices.

$$y(u,v) \approx w_{u1}w_{v1}\, y(u_1,v_1) + w_{u2}w_{v1}\, y(u_2,v_1) + w_{u1}w_{v2} y(u_1,v_2) + w_{u2}w_{v2}\, y(u_2,v_2)$$

$$w_{u1} = \frac{u_2 - u}{u_2 - u_1}$$

$$w_{v1} = \frac{\ln(v_2) - \ln(v)}{\ln(v_2) - \ln(v_1)}$$

Implicit in the assumption that such a first order interpolation is appropriate is that the relationship between dependent and independent variables is essentially monotonic. This is generally a valid assumption in standard economic models of price and quantity.

We interpolate all result parameters provided – biomass data (production and prices), crop market data (production and prices) and land use data (emissions, quantities). There is potential inconsistency with allowing different prices in different regions whereas the global computational general equilibrium model would have assumed globally identical prices across regions. For the purposes of informing GTAP-ANO, the 32 region GLOBIOM emulator results were re-aggregated across region and sectoral category according to the regional mappings in Table 12.2.

The aggregated price indices were weighted by value rather than physical units, that is

$$\frac{P_{t+1}}{P_t} = \frac{\sum_i P_{i,t+1} V_{i,t}}{\sum_i P_{i,t} V_{i,t}}$$

$$V_{i,t} = \tfrac{1}{2}\left(P_{i,t+1} Q_{i,t+1} + P_{i,t} Q_{i,t}\right)$$

rather than $\frac{P_{t+1}}{P_t} = \frac{\sum_i P_{i,t+1} Q_{i,t+1}}{\sum_i Q_{i,t+1}} / \frac{\sum_i P_{i,t} Q_{i,t}}{\sum_i Q_{i,t}}$ or $\frac{P_{t+1}}{P_t} = \frac{\sum_i P_{i,t+1}\left(Q_{i,t+1} + Q_{i,t}\right)}{\sum_i P_{i,t}\left(Q_{i,t+1} + Q_{i,t}\right)}$.

The data provided to GTAP-ANO was a price and quantity index for agricultural crops, livestock, and forestry products GLOBIOM emulator results

Table 12.2 Regional mapping from GLOBIOM region [32 regions] to ANO 2019 global regions [13 regions]

GLOBIOM REGION	ANO 2019 REGION
Australia	Australia
CongoBasin	Africa
Eastern Africa	
South Africa	
Southern Africa	
Western Africa and rest of sub-saharan Africa	
China	China
European Union Baltic	Eastern Europe
European Union CentralEast	
Rest of Central Europe	
Former_USSR	Former Soviet Union
India	India
Japan	Japan
Brazil	Latin America
Rest of Central America	
South America	
Turkey	Middle East and North Africa
Middle East and North Africa	
Canada	North America
Mexico	
USA	
NewZealand	Pacific OECD
South Korea	
South East Asia, Other Pacific Asia	South East Asia
Pacific_Islands	
Rest of South Asia	
South East Asia – ex planned economies	
European Union South	Western Europe
European Union MidWest	
European Union North	
Rest of Western Europe	

Source: IIASA and CSIRO

12.4.3 Sample emulated projections for ANO 2019

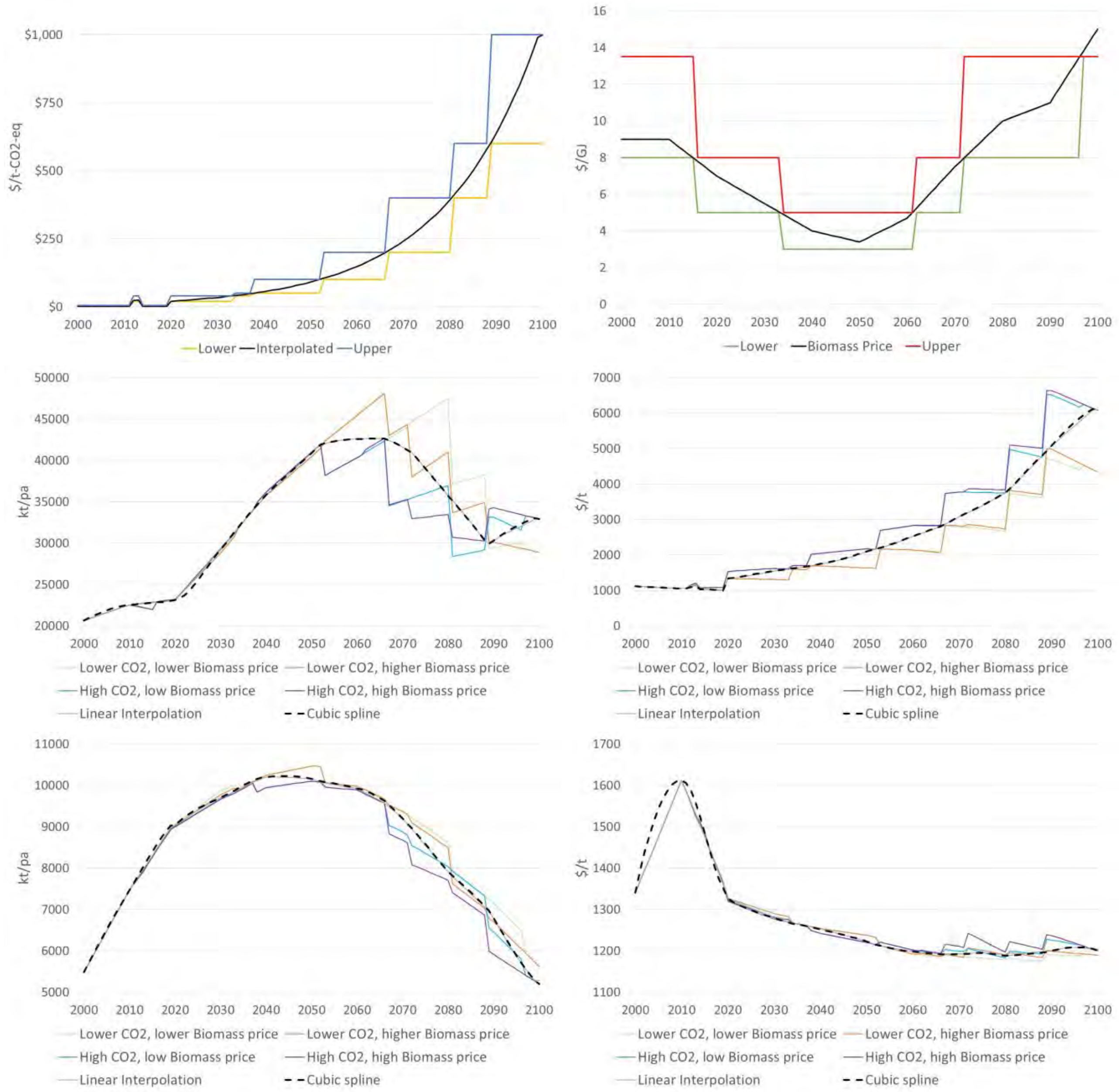

Figure 12.7 Interpolation of SSP1 Australian wheat production [mid-left] and beef prices [mid-right] and Indian Chickpea production [lower-left] and prices [lower-right] from GLOBIOM for selected Carbon [top-left chart] and Global Biomass [top-right chart] prices

This section provides an example of two sample variables from the GLOBIOM emulator, comparing interpolated projections to original results data from the database. Figure 12.7 shows the output from the GLOBIOM emulator for beef production in Australia and India, for the Shared Socioeconomic Pathway 1. These sectors were selected for comparison as they both have a reasonable sensitivity to carbon price. For comparison, the global biomass and regional carbon prices are shown relative to their approximating threshold values represented in the database, as are the corresponding database reference values for the target outputs for the corresponding biomass and carbon prices.

Note that the emulator results are relatively smooth and lie within the range of the GLOBIOM values, as expected. Strictly speaking, the GLOBIOM emulator results are not scenario consistent– the emulator results are a hybridisation of results from multiple scenarios. In particular, they are comprised of piecewise across time changes in biomass and carbon price scenarios, and permit regional differences in carbon prices, such as the differences between India and Australia from 2000 to 2020. These price trajectories are not consistent with any one of the source data scenarios, which were calculated with settings of constant prices across time and region.

For further comparison we provide emulator results for the input data corresponding to Figure 12.2 and Figure 12.1.

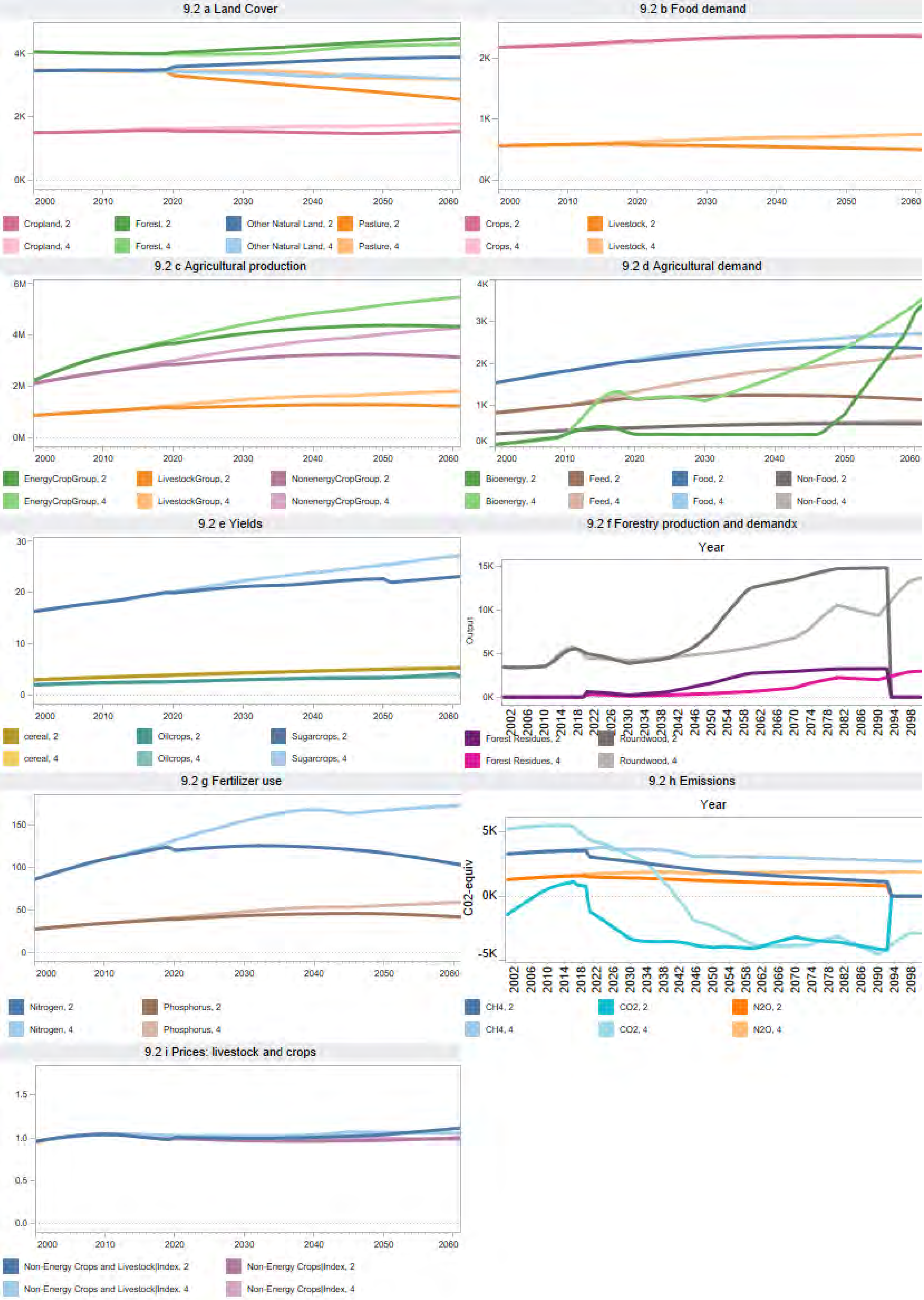

Figure 12.8 World projections for the forest and agricultural sectors [*Nation First* (4) and *Working Together* (2) interpolated projections]

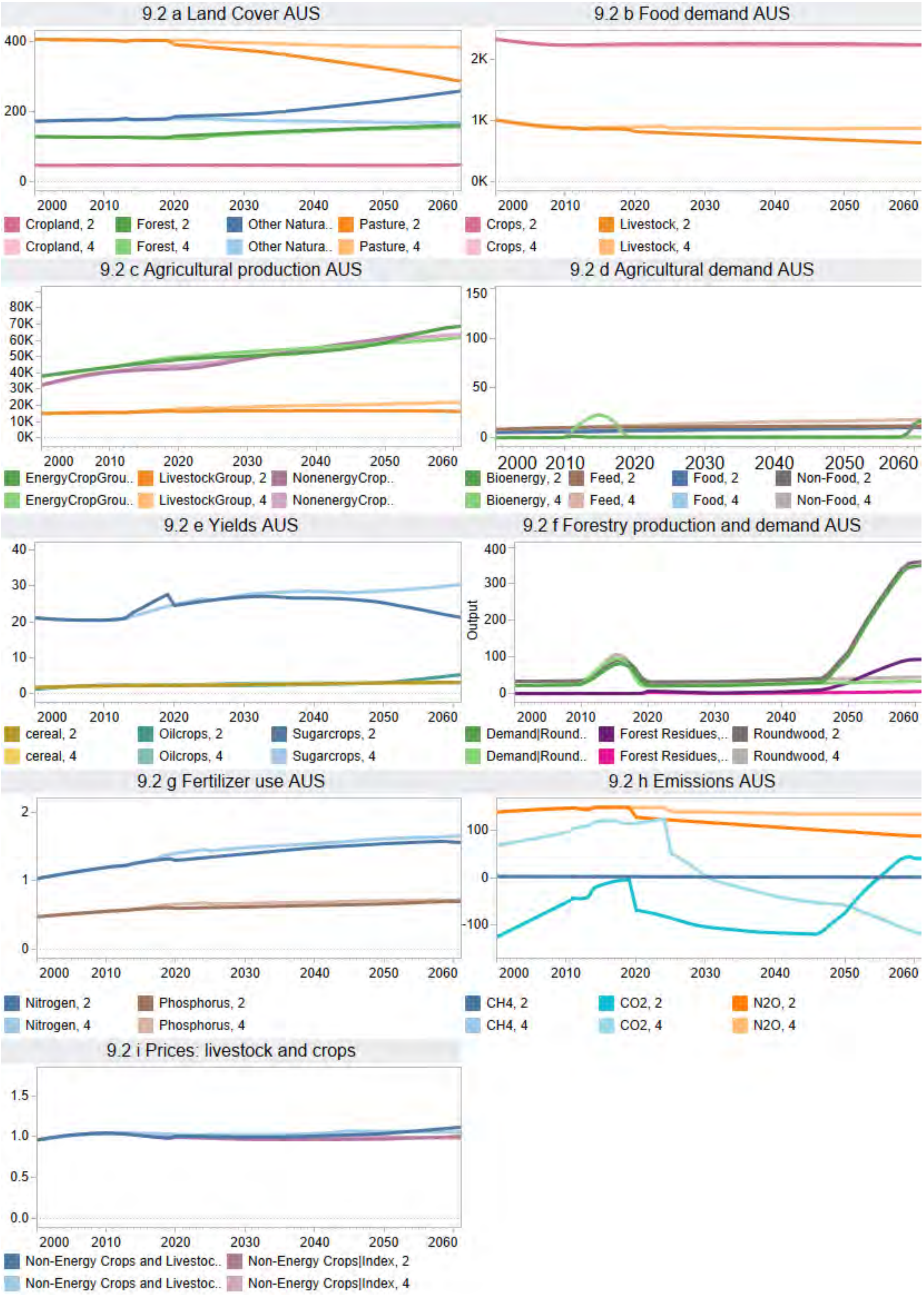

Figure 12.9 Australia-specific projections for the forest and agricultural sectors [*Nation First* (4) and *Working Together* (2) interpolated projections]

The emulator projections show some modest differences between the two global scenarios, with land use for pasture giving way to other natural land in the *Working Together* scenario compared to *Nation First*. Global demand for food, and also agricultural production is lower in the *Working Together* scenario, consistently with the larger population. Fertiliser use globally is also correspondingly lower in the *Working Together* scenario, particularly nitrogen. Global demand for feed is moderately lower in the *Working Together* scenario, but global production of bioenergy is significantly lower, with higher forestry production instead.

12.5 Emulated agricultural price projections

Crop and livestock price projections (Figure 12.10) for the existing trends scenario and *Nation First* and *Working Together* carbon price trajectories (Figure 12.6) and biomass price trajectories corresponding to SSP2 and SSP1 respectively (see Chapter 3) are within the range of historical price variability. Note that the data provided to the GLOBIOM emulator distinguishes only two alternative global SSP scenarios, without specific identification of any particular RCP, and hence does not represent the impacts of climate change on global land use due to climate induced impacts on agricultural or forestry productivity. For the *Working Together* case, crop prices decrease around 7% and livestock prices increase around 63% relative to 2015 levels. Crop and livestock prices increase around 10% and 36% respectively, under the *Nation First*. Projections for crop (*Working Together*) and livestock prices (*Nation First*) are similar to the World Bank's grains and agricultural price indexes forecasted from 2017 to 2025 (Figure 12.10) and diverge afterwards.

The results are consistent with global agricultural models that project average agricultural price increases due to non-CO_2 greenhouse emissions penalties, increasing food demand, and agricultural land demand for biofuel production or carbon sequestration, which are implicitly represented in the GLOBIOM data, or due to climate change impacts, which are not (see Baldos and Hertel, 2016; Robinson et al., 2014; Valin et al., 2014; von Lampe et al., 2014 for results from computable general and partial equilibrium models). While some models project a potential continuation of declining price trends (Baldos and Hertel, 2016), such a possible future is significantly dependent on assumptions regarding agricultural land availability and adoption patterns of technical change (Baldos and Hertel, 2016; Smeets Kristkova et al., 2016).

The higher crop prices under the *Nation First* global scenario, relative to the *Working Together* scenario, although not due to climate change impacts, are consistent with reports indicating that climate change could have significant negative impacts on biophysical productivity and result on yield shocks and crop prices increases (von Lampe et al., 2014) (Figure 12.10). Instead, relatively higher crop prices in the *Nation First* global scenario may be due to greater demand for feed for livestock, given that both livestock and crop production is higher than in the *Working Together* scenario. Carbon price impacts on livestock prices appear to be small until 2045 (Figure 12.10). Differences in the trajectories after that year can be explained by the gradual increase in demand for carbon offsets and biofuels production under the *Working Together* scenario that could result in the reduction of land for livestock production (Wright and Wimberly, 2013).

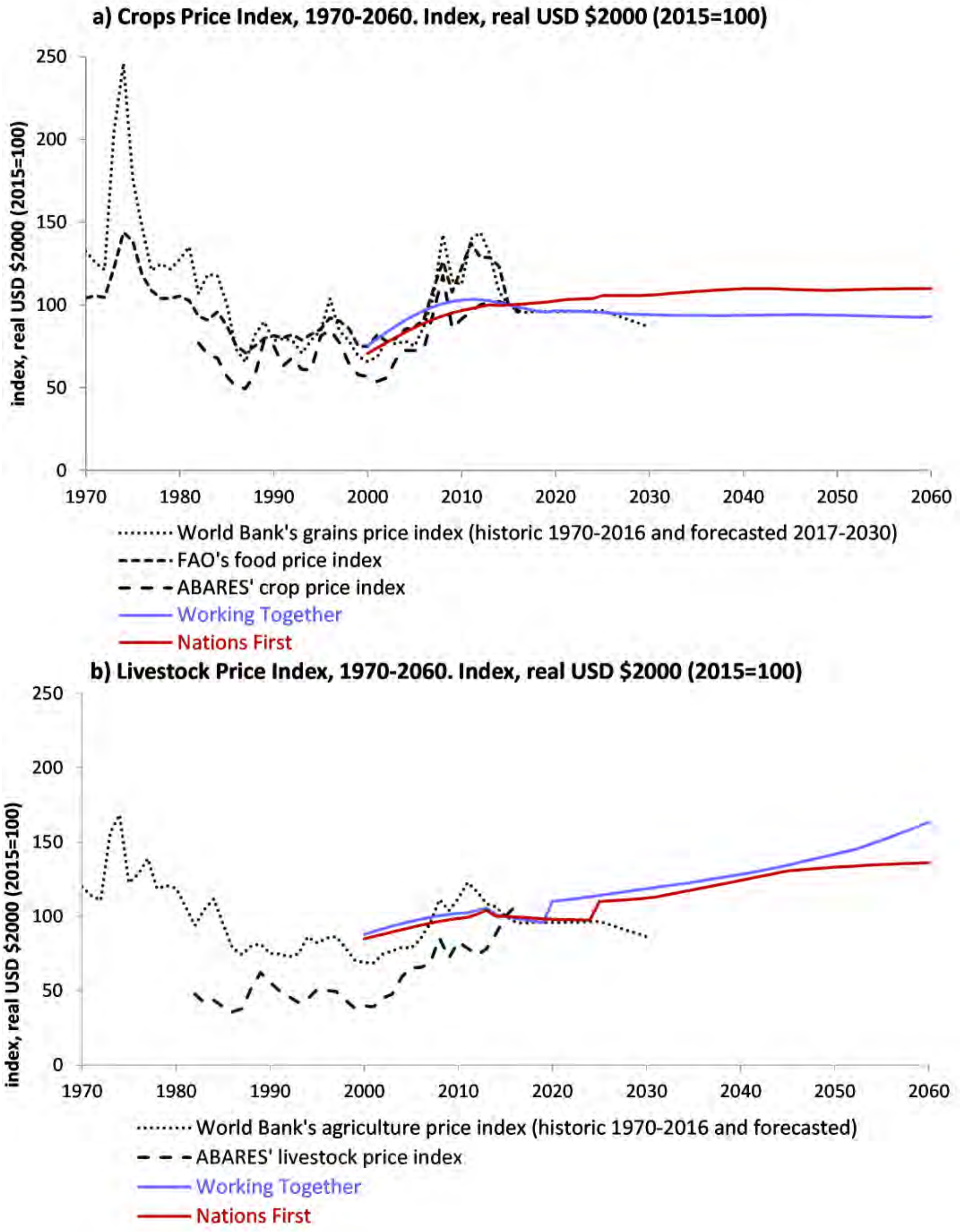

Figure 12.10 Historical and projected changes in crop (a) and livestock (b) price indexes.

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13 MAGICC

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Model at a glance

Model summary	MAGICC (Model for the Assessment of Greenhouse-Gas Induced Climate Change) is a reduced complexity climate model that emulates the global and annual mean behaviour of significantly more complex carbon-cycle models.
Key ANO scenario drivers	• Projected exogenous emissions assumptions • Global warming potential factors by gas
Key inputs	• Projected global greenhouse gas emissions, primarily CO_2, CH_4, N_2O and F-gases, by year
Key outputs	• Projected greenhouse gas global atmospheric concentrations • Projected global radiative forcing and mean surface air temperature change relative to pre-industrial levels

13.1 Introduction

For the Australian National Outlook (ANO) 2019, it was desired for the global modelling suite to include climate change outcomes, in order to investigate the extent to which the projected carbon price and consequential CO_2 emissions were consistent with the global scenarios. Note that the global scenarios *Nation First* and *Working Together* (see Chapter 2 and Chapter 3) are intended to project climate consequences consistent with the 'four degrees track' and the 'two degrees track' settings on the Global Climate Action issue in the ANO 2019 scenarios. Of the Representative Concentration Pathways in IPCC (2014, see p. 57), the ANO 2019 'four degrees track' is intended to be close to RCP6.0 (Meinshausen et al., 2010) and the 'two degrees track' is intended to be close to RCP2.6. The economic growth assumptions associated with *Nation First* is the 'protectionist' Geopolitics setting and the Global Population growth assumption is the 'central projection' setting. These are both consistent with Shared Socioeconomic Pathway 2 (Riahi et al. 2017, SSP2, Middle of the Road, medium challenges to mitigation and adaptation). The *Working Together* global scenario is defined by the 'cooperative' Geopolitics setting and the 'lower growth' Global Population assumptions. These have been selected to be consistent with SSP1 (Sustainability, Taking the Green Road, low challenges to mitigation and adaptation) and the net result is greater economic growth in the *Working Together* global scenario.

For the ANO 2019 global scenarios we assumed international action on climate change is implemented by a carbon price on both CO_2 and non-CO_2 emissions, with emissions price trajectory magnitudes consistent with the range of prices in Clarke et al. (2014, Chapter 6, p. 450) for RCP6.0 and RCP2.6. The ANO 2019 projected consequences for greenhouse emissions are derived, and the consequential impact on climate modelled with MAGICC.

A significant limitation of the ANO 2019 modelling suite is the time horizon restriction to 2060 of the non-land-use sector models: the global economy – the ANO 2019 Global Trade Analysis Project model (GTAP-ANO, see Chapter 10); electricity sector- Global and Local Learning Model of

Electricity (GALLME, see Chapter 11) and transport sector- Global and Local Learning Model of Transport (GALLMT, Chapter 11).

This time horizon is importantly limiting because there are significant time lags in the response of the earth's climate system to changes in greenhouse emissions rate. This is because the atmospheric concentrations that correlate with radiative forcing are the result of the accumulation of emissions. Furthermore, the accumulation of heat in the thermal mass of the world's oceans lags any change in the global net thermal energy balance that is correlated with radiative forcing rates. This means that the full effects on temperature and sea level changes of different greenhouse gas emission trajectories would only begin to be seen decades later and last for hundreds to many thousands of years. For this reason, ANO 2019 climate change modelling is undertaken to 2100, well beyond the 2060 time horizon of the emissions modelling suite, with emissions projections beyond 2060 based on those from results from the Shared Socioeconomic Pathways (SSP) database (IIASA, 2016). We used the Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) to project approximate climate change consequences of the ANO 2019 global emissions projections, and note again that ANO 2019 has not incorporated the direct impacts of climate change within the quantitative modelling global analysis.

The ANO 2019 global emissions projections to 2060 for four major classes of greenhouse gas emissions, aggregated across four global models, are higher than that required to match emissions in target scenarios from the SSP Database (IIASA, 2016), particularly for the *Working Together* scenario. This is most likely due to the particularly strong growth in electricity demand resulting from economic growth, fuel switching away from direct fossil fuel use, the rebound effect and conservative assumptions about the prospects of energy efficiency. Note that there is only limited inclusion of negative emissions technologies in the ANO 2019 global energy models. To approach consistency with the global scenario qualitative descriptions in the longer term, we have assumed that global emissions converge from ANO 2019 modelled results in 2060 towards target scenario trajectories during the period 2060–2100. Even so, the resulting atmospheric concentration of greenhouse gases produces temperature increases exceeding the two degrees aspiration under the *Working Together* scenario assumptions. Under the *Nation First* scenario, using a default modelled climate sensitivity setting of 3.0^{o}C per doubling of eq-CO_2 concentration, the global temperature increase is projected to be 3.2–3.5°C above a pre-industrial baseline by 2100.

13.2 Model description

The Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC, version 5.3.v2) is a climate model implemented in software developed by Meinshausen, Wigley and Raper and maintained by the University Corporation for Atmospheric Research. It allows comparison of global and regional climate change and sea level rise given alternative scenario projections of anthropogenic emissions of greenhouse gases into the atmosphere (Wigley, 2008, see also http://www.magicc.org/). It is a simplified global dynamical model (Meinshausen et al. (2011a), see also Meinshausen et al., (2011b)) that uses climate energy balance and ocean upwelling and diffusion equations for earth system global mean temperature projections, the same key physical processes that are represented in climate models used by the Intergovernmental Panel on Climate Change (IPCC, see for example Chapter 8 in Randall et al. (2007) and Chapter 10 in Meehl et al. (2007)).

MAGICC represents global gas cycles, ice dynamics, and climate; and global thermodynamics across land, oceans, and the atmosphere. It is populated with annual historical data from 1765 and simulates atmospheric greenhouse gas concentrations, global mean surface air temperatures (by hemisphere and over land versus over ocean) and sea levels.

Model input data includes global emissions of some two dozen greenhouse gas species including

- Three globally significant individual species
  - carbon dioxide (CO_2)
  - methane (CH_4)
  - nitrous oxide (N_2O)
- reactive gases
  - Carbon monoxide, other nitrogen oxides (nitric oxide NO and nitrogen dioxide NO_2) and non-methane volatile organic compounds (CO, NO_x, NMVOCs)
- various halocarbons – primarily fluorinated gases (F-gases) that are not controlled by the Montreal Protocol including hydrochlorofluorocarbons, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride (Metz et al. (2005): HCFCs, HFCs, PFCs and SF_6)
- sulfur dioxide (SO_2), black carbon aerosol (soot, BC), organic carbon aerosol (OC) and Ammonia (NH_3)
- Montreal Protocol controlled gas emissions

MAGICC also permits changes in various parameters, such as radiative forcing sensitivities to atmospheric greenhouse gas concentration or temperature sensitivity to radiative forcing (see for example the choice of user parameters described in Wigley (2008)). Default settings in MAGICC are for ‘best-estimate’ sensitivity parameters based on the models used in the Fourth Assessment Report of the Intergovernmental Panel on Climate change (IPCC, 2007). The default climate sensitivity setting is 3.0° per doubling of CO_2 atmospheric concentration, and users may set various model parameters to differ from the default settings within a suggested uncertainty range. Although the ANO 2019 project made no use of this feature, it acknowledges that there is uncertainty regarding the exact values of some of these parameters, and that some of them may exhibit a dependence on time or other factors (Kunreuther et al. (2014), but see also revision of parameter estimates in Wigley (2008) and Myhre et al. (1998). The default 90% confidence interval range for climate sensitivity in version 5.3.v2 of MAGICC is 1.5-6.0° warming per CO_2 concentration doubling.

13.3 Method

13.3.1 Model inputs

To simulate global economic scenarios within the ANO 2019 model suite we have imposed CO_2 emissions pricing on the four global scale models, with price assumptions estimated from results presented in Clarke et al. (2014, Chapter 6, p. 450), and appearing in Table 13.1 and Figure 13.1 (see Chapter 2 for more details). Pricing of non-CO_2 emissions is also represented in the global economic model GTAP-ANO, at consistent prices in terms of \$/CO_2-eq (using 100-year global warming potentials, Greenhouse Gas Protocols 2015).

Table 13.1 Carbon price assumptions: ANO 2019 global scenarios

ANO 2019 Scenario	CO_2 price assumptions pre-convergence	Regionally Uniform Global CO_2 price (USD 2015)	Long term carbon price growth rate
Nation First	Existing policies to 2025, Regional convergence 2025-2040	\$40.00/t-CO_2eq at 2040	1.0% pa from 2040
Working Together	Existing policies to 2020	\$20.00/t-CO_2eq at 2020	5.0% pa from 2020

Although MAGICC represents more than twenty species of greenhouse relevant gas, the ANO 2019 models that represent global anthropogenic emissions collectively represent only four emissions categories: three of the most significant species, CO_2, N_2O, and CH_4 and F-gases (fluorinated gases) These four categories are those, of anthropogenic emissions, that are the most significant contributors to changes in atmospheric radiative forcing (responsible for the greenhouse effect, Wigley and Raper (1992)) over time. Global greenhouse emissions projections for different economic sectors are aggregated from the four other (that is, not including MAGICC) global models in the ANO 2019 global suite as the input to MAGICC:

i) emissions from the land-use sector, including agriculture, are sourced from the GLOBIOM emulator (see Chapter 12),

ii) from the global electricity generation,

iii) transport sectors are sourced from GALLME and GALLMT (see Chapter 11), and

iv) emissions from the remaining economic sectors, including stationary energy use (fossil fuels) outside of the electricity sector, are sourced from GTAP-ANO (see Chapter 10).

Note that GTAP-ANO implements a marginal abatement cost curve for non-CO_2 emissions, which results in an emissions price dependent reduction in emissions intensity. The source data for the GLOBIOM emulator also derives from an economic model that implements a price on non-CO_2 emissions, which particularly impacts agriculture.

In the following we explain how estimates of the four main categories of greenhouse gas are derived in the ANO 2019 global suite for the modelled years to 2060, including N_2O emissions estimates for the electricity and transport sectors and the disaggregation of the combination category of F-gases. We also explain data sources for projections of emissions not represented in the ANO 2019 global suite, such as aerosols, and of projected post-2060 emissions.

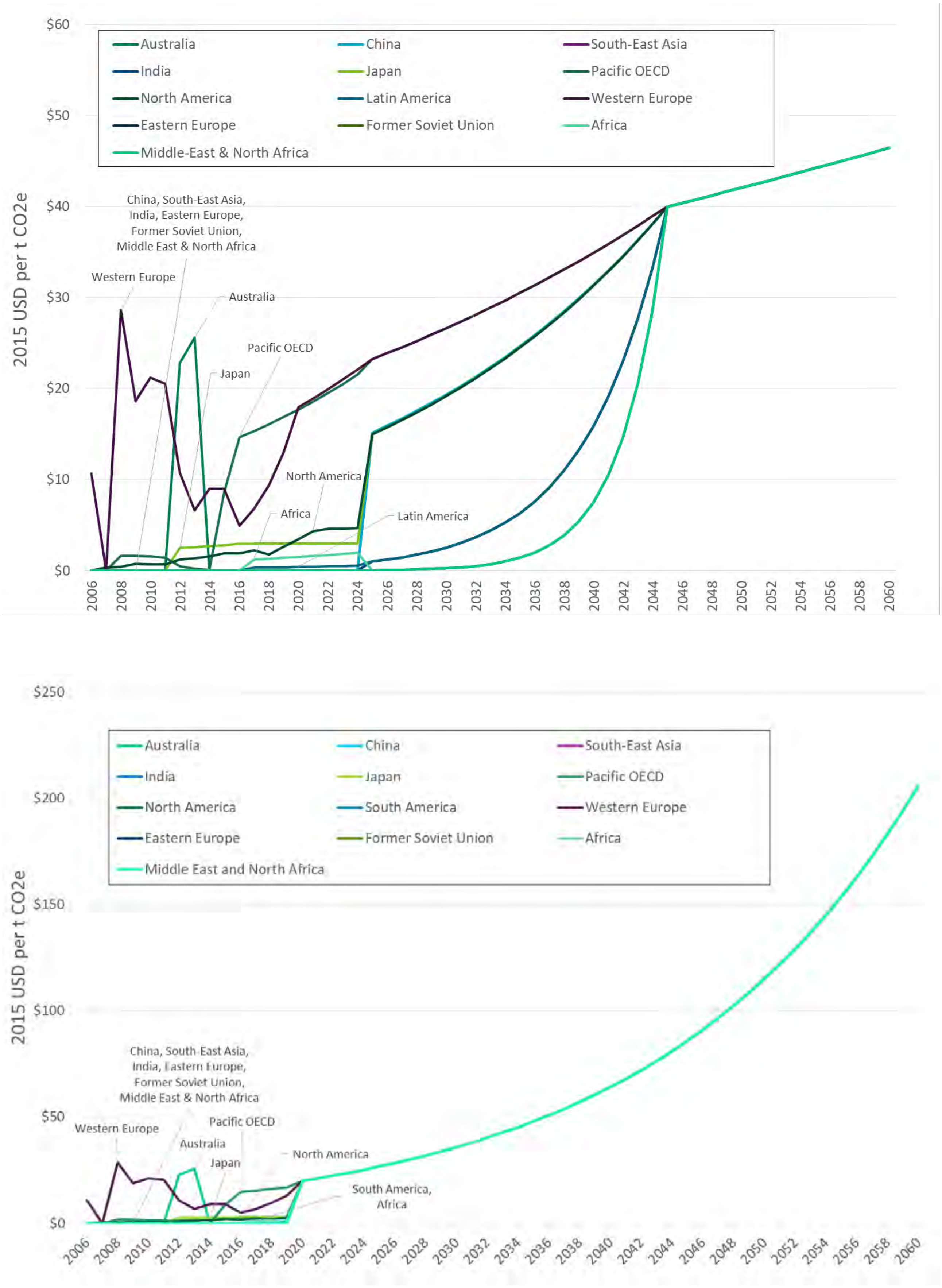

Figure 13.1 Global CO_2 price assumptions: ANO 2019 scenarios [Top: *Nation First*, Bottom: *Working Together*]

Although both GTAP-ANO and GLOBIOM represent, as results, each of the four greenhouse gas categories identified above as significant, the global models specific to the energy sector, GALLME and GALLMT explicitly represent only CO_2 emissions from the electricity and transport sectors respectively. The exclusion of CH_4 is justified because despite the projection of significant increase in gas fired electricity generation, and a limited uptake of compressed natural gas (CNG) and liquefied natural gas (LNG) vehicles, direct emissions of CH_4 attributable to the global electricity and transport sectors are negligible. Most fugitive emissions are accounted for in upstream sectors. Also, emissions of fluorinated gases from these sectors is assumed to be negligible (see Figure 6 in Irfanoglu and van der Mensbrugghe (2015)).

Direct emissions of N_2O from the electricity and transport sectors are assumed to be due to the combustion of fossil fuels, which are the only source of CO_2 emissions from those sectors represented in the global modelling suite. For the ANO 2019 modelling suite, N_2O emissions for electricity and transport are approximated as being proportional to projected CO_2 emissions each year. For the ANO 2019 *Nation First* global scenario (see Chapter 2), the factor of proportionality remains constant at 2010-2012 levels (see UNEP 2013, p. 26) over the projection period.

For the global *Working Together* scenario, it is assumed that the N_2O emissions intensity per unit of CO_2 emissions from fossil fuel combustion will be improved over the projection period, consistently with the context of SSP1 (Sustainability, low challenges to mitigation, Riahi et al. 2017). Based on technical potentials suggested in UNEP (2013, p. 26–30) we assume improvement in N_2O emissions intensity in (stationary) electricity generation (per MWh) of 2% pa for ten years to 2020, 1.5% pa to 2050 and zero thereafter. Achievable emissions intensity improvement in transport is assumed to be 2% pa for ten years to 2020, then 0.5% to 2050 after which there is again no further improvement. Emissions intensity of N_2O from the sectors covered by GTAP-ANO is assumed to improve by 2% pa over the projection period, in line with other non-CO_2 emissions from that model. This time dependent emissions intensity improvement in non-CO_2 emissions is assumed in addition to the emissions price dependent intensity improvement implemented via the marginal abatement cost curve. See Table 13.2 below for a comparison of modelled assumptions about N_2O emissions intensity improvement (not explicitly costed in GTAP-ANO) compared to indicative technical possibility reported in UNEP (2013).

In order to avoid the double counting of emissions, the projected emissions from some sectors of the GTAP-ANO results were subtracted from the totals before their contribution to the total projections provided to MAGICC. In order to avoid double counting with GALLME (the energy generation sector), emissions associated with the production in the electricity industry in GTAP-ANO were subtracted. To avoid double counting with GLOBIOM (global land-use including agriculture) emissions, emissions associated with production in the Agricultural industry were subtracted. To avoid double counting with GALLMT (the transport sector) emissions, GTAP-ANO emissions associated with the consumption of the oil commodity was subtracted. This method somewhat overestimates the GTAP-ANO transport emissions because, although the majority of the projected consumption of oil will be used in transport, a small proportion will be due to use in industrial production, including the electricity industry and agriculture. A more accurate method would replace emissions due to oil use in industrial applications.

Table 13.2 N_20 Emissions Intensity Reduction - Technical potential & assumptions for *Working Together* scenario

SECTOR	ASSUMED REDUCTION (ANNUALISED)	ASSUMED REDUCTION (ACCUMULATED)	COMPARISON SECTOR	COMPARISON SECTOR TECHNICAL POTENTIAL (UNEP, 2013)
ELECTRICITY GENERATION **(GALLME)**	2.0% pa 2010-2020 1.5% pa 2020-2050	18.3% in 2020 48.1% in 2050	Stationary Energy (Section 5.2, p. 27)	16% in 2020 48% in 2050
TRANSPORT **(GALLMT)**	2.0% pa 2010-2020 0.5% pa 2020-2050	18.3% in 2020 30.7% in 2050	Transport (Section 5.3.3, p. 28)	20% in 2020 30% in 2050
OTHER INDUSTRIAL **(GTAP-ANO, EX-AG., EX-TRANSPORT, EX-ELECTRICITY)**	2.0% pa 2010-2050	18.3% in 2020 33.3% in 2030 55.6% in 2050	Nitric, Adipic acid production (Section 5.4.2, p. 30)	48%, 84% in 2020 71%, 89% in 2030 90%, 95% in 2050

Note: Section references in this table refer to UNEP (2013).

Projections of F-gases are included in GTAP-ANO as aggregated into CO_2-eq units (see Greenhouse Gas Protocol (2015)). The twelve F-gases represented in MAGICC are CF_4, C_2F_6, C_6F_{14}, HFC-23, HFC-32, HFC-43-10, HFC-125, HFC-134a, HFC-143a, HFC-227ea, HFC-245fa, and SF_6. For conversion to mass units of individual species, it was assumed that F-gases represented in GTAP-ANO consisted of these twelve gas species, in relative proportion identical to those in RCP6.0 from MAGICC (the data file: RCP6.SCEN) at years 2020, 2030, 2040, 2050 and 2060. For each of the identified years, the projected F-gas emissions from GTAP-ANO were rescaled so that when the 100 year AR5 Global Warming Potential (GWP) factors from the GWP datasheet (Greenhouse Gas Protocol (2015), see also Chapter 8 in Myhre et al. (2013)) are applied, the target F-gas quantity in CO_2-eq units is recovered. Although the factors used for the GTAP database (Table 7 in Irfanoglu and van der Mensbrugghe (2015)) correspond to the Second Assessment Report (SAR), factors from the 2014 Fifth Assessment Report (AR5) are used for this scaling resulting in an underestimate of F-gas projections from GTAP-ANO.

Greenhouse gas emissions unit conversions are necessary among ANO 2019 models, with the mass used as the common unit, consistent with the requirements of MAGICC. The MAGICC units for CO_2 is Gt of C, for CH_4 is Gt of CH_4, and for N_2O is kt of N. The twelve F-gases represented in MAGICC, are quantified in kt units of gas. In contrast, CO_2 emissions units for both GTAP-ANO and GLOBIOM are Gt of CO_2. GTAP-ANO emissions of not only F-gases, but also CH_4 and N_2O are in CO_2-eq units using 100 year Second Assessment Report global warming potential factors of 21 and 310 respectively (Table 7, GWP datasheet in Irfanoglu and van der Mensbrugghe (2015)) rather than the more up-to-date factors from the fifth assessment report, and this must be borne in mind for conversion to mass units. Finally, in order to report equivalent carbon dioxide (eq-CO_2) atmospheric concentration results, we use the radiative forcing results from MAGICC and apply

$$C = C_o \exp\left(\frac{RF}{\propto}\right) \approx 280 \exp\left(\frac{RF}{5.35}\right)$$

with pre-industrial concentration of atmospheric CO_2 as C_o =280ppm, and $\propto$=5.35 a semi-empirically derived constant (Table 3 in Myhre et al. (1998)).

13.3.2 Emissions projections – comparison against benchmarks

In this section we provide some comparisons of the ANO 2019 aggregated global emissions projections against selected scenarios from the SSP Database. The *Nation First* global scenario has the ‘four degrees track’ Global Climate Action setting and Global Population and GDP growth settings aligned with SSP2. Because the ‘four degrees track’ Global Climate Action setting is intended to be qualitatively similar to an RCP6.0 emissions trajectory, we compare it to a particular SSP2 RCP6.0 in the SSP Database, GLOBIOM-MESSAGE SSP2-60. Because this particular SSP Database scenario reaches a maximum warming of only 3.23°C to 2100, we also compare against a composite scenario comprising four scenarios from the SSP Database that result in a projected temperature increase in 2100 of close to 4.0 °C above pre-industrial levels: AIM-CGE/ SSP2-Baseline, AIM-CGE/ SSP3-Baseline, IMAGE/ SSP3-Baseline, and REMIND-MAGPIE/ SSP2-Baseline. Note that the higher end of the 90% confidence interval range (1.5-6.0^{o}C per CO_2 doubling) of temperature sensitivity to greenhouse gas concentrations is further from the default ‘best’ estimate (3.0^{o}C per doubling) than the lower end of that range.

Table 13.3 Diagnostic Data for selected comparison SSP Database scenarios

	SSP DATABASE MODEL/ SCENARIO	2100 TEMPERATURE (K)	2000-2100 MAX TEMPERATURE (K)	2100 RADIATIVE FORCING (W/M2)
Example SSP2/ RCP6.0	**GLOBIOM-MESSAGE SSP2-60**	**3.23**		**5.47**
Composite Scenario **4 degrees warming at 2100**	AIM-CGE/ SSP2-Baseline	4.13		7.12
	AIM-CGE/ SSP3-Baseline	4.07		7.17
	IMAGE/ SSP3-Baseline	3.85		6.71
	REMIND-MAGPIE/ SSP2-Baseline	4.08		6.96
	Composite Average	**4.03**		**6.99**
Example SSP1/ RCP2.6	**IMAGE/ SSP2-26**	**1.76**	**1.85**	**2.71**
Composite Scenario **2 degrees warming at 2100**	GCAM4/SSP4-26	1.80	1.93	2.67
	MESSAGE-GLOBIOM/ SSP3-34	2.12	2.12	3.38
	REMIND-MAGPIE/ SSP2-26	1.82	2.06	2.66
	WITCH-GLOBIOM/ SSP3-34	2.13	2.11	3.39
	Composite Average	**1.97**	**2.03** **Av. Max. 2.06**	**3.03**

[Source: SSP Database, IIASA 2016]

The ANO 2019 *Working Together* global scenario (with the ‘two degrees track’ Global Climate Action setting, qualitatively similar to RCP2.6) with global population and GDP growth settings aligned with SSP1, we compare against an SSP1-RCP2.6 scenario, the IMAGE SSP1-26 scenario. Again, this particular SSP Database scenario remains below 1.85 °C warming, and so for comparison against the ‘two degrees track’ qualitative description of the *Working Together* global scenario we consider another composite scenario comprising four SSP Database scenarios with a projected temperature increase in 2100 close to, in this case, 2.0 °C: GCAM4/SSP4-26, MESSAGE-GLOBIOM/ SSP3-34, REMIND-MAGPIE/ SSP2-26 and WITCH-GLOBIOM/ SSP3-34. See Table 13.3 for a comparison of projected temperature increase and radiative forcing for these selected comparison scenarios.

Note that some of the scenarios contributing to the two composite comparison scenarios correspond to RCP scenarios different from RCP6.0 and RCP2.6 (in particular, “Baseline” scenarios without CO_2 emissions reduction policies as well as RCP3.4 scenarios), as they were selected on the basis of their temperature projections at 2100. Some exceed both the 2100 temperature and radiative forcing targets, although the *average* corresponding temperatures at 2100 are close to the target. On the other hand, the radiative forcing projections for all scenarios contributing to the composite comparisons exceed the radiative forcing targets of 6.0W/m^2 and 2.6 W/m^2.

The consequence is that the emissions, radiative forcing and temperature projections for the composite comparison scenarios are higher than their corresponding individual comparison. Because of challenges of projecting low emissions trajectories from the ANO 2019 global model suite, particularly for the *Working Together* global scenario, it has proven easier for ANO 2019 to approximately match the less ambitious composite “four degrees” and “two degrees” comparison scenarios than to match the individual, more ambitious RCP6.0 and RCP2.6 comparisons.

Comparison of aggregate global emissions projections from the ANO 2019 suite to the comparison scenarios from the SSP Database appear as Figure 13.2 and Figure 13.7. Recall that the data from the comparison scenarios is provided only for decadal time steps, and emissions projections from the rest of the ANO 2019 global suite are only to 2060 (excluding the GLOBIOM emulator, which provides projections to 2100).

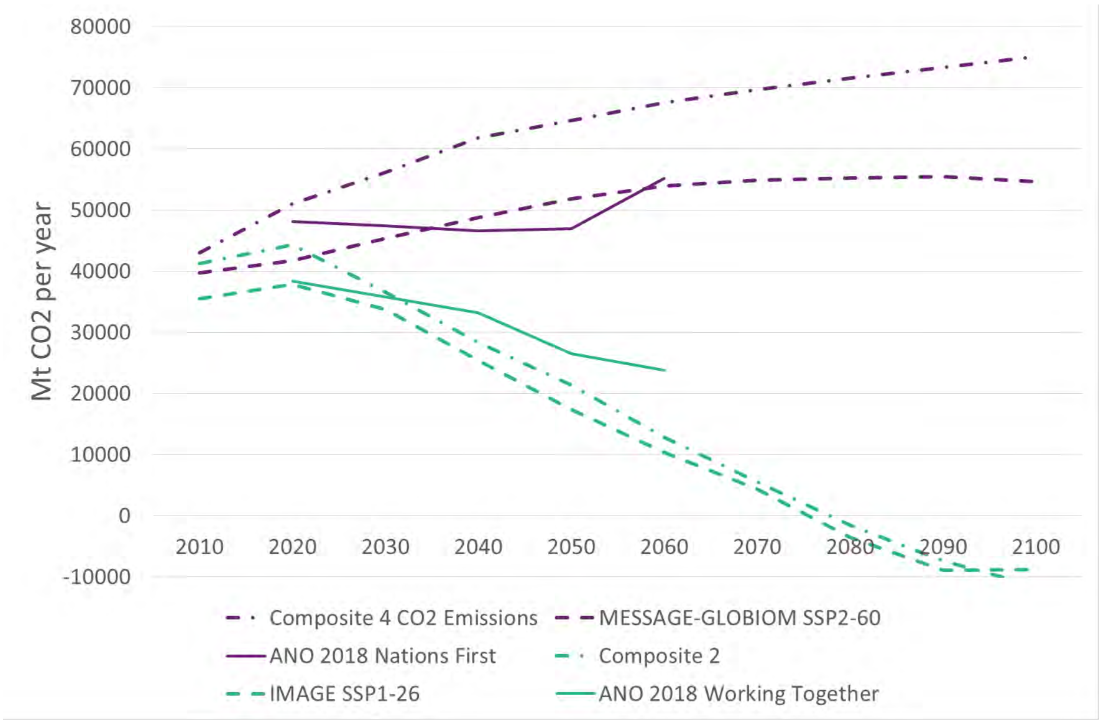

Figure 13.2 Decadal emissions projections: ANO 2019 models to 2060 versus SSP Database comparisons (CO_2)

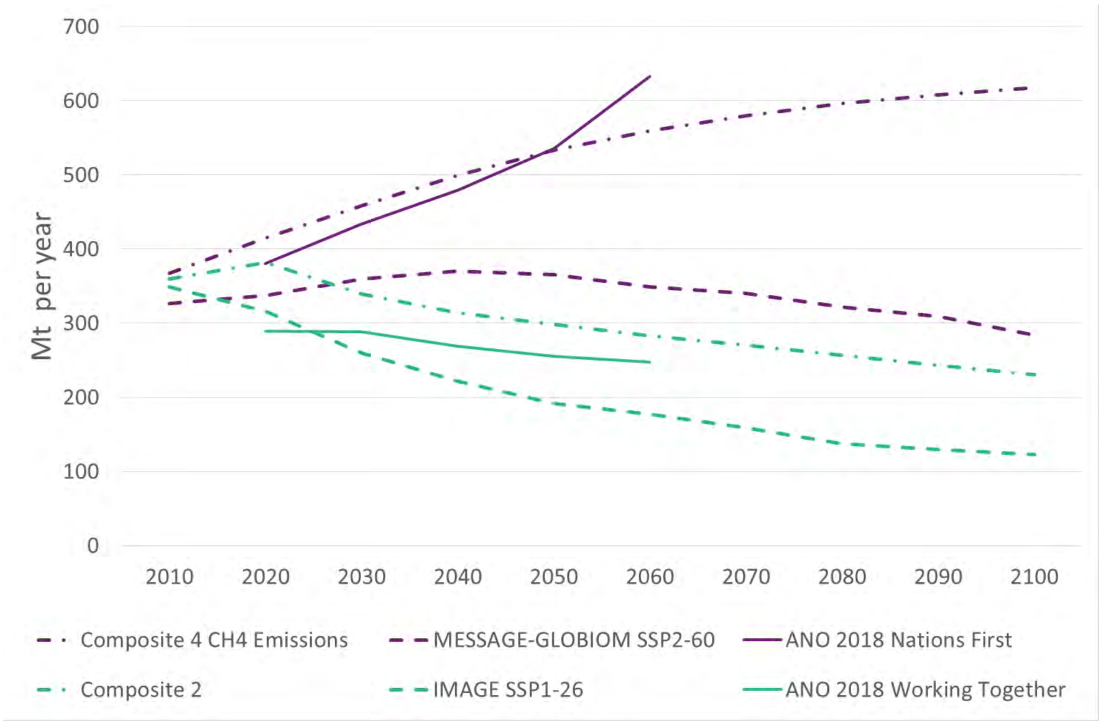

Figure 13.3 Decadal emissions projections: ANO 2019 models to 2060 versus SSP Database comparisons (CH_4)

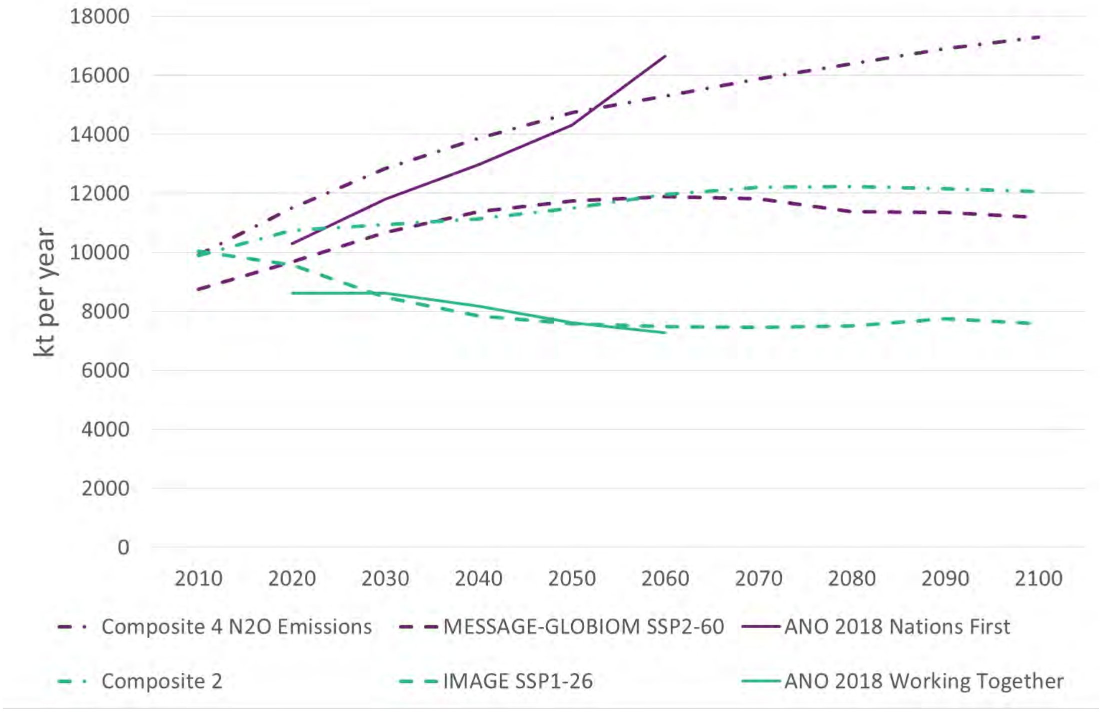

Figure 13.4 Decadal emissions projections: ANO 2019 models to 2060 versus SSP Database comparisons (N_2O)

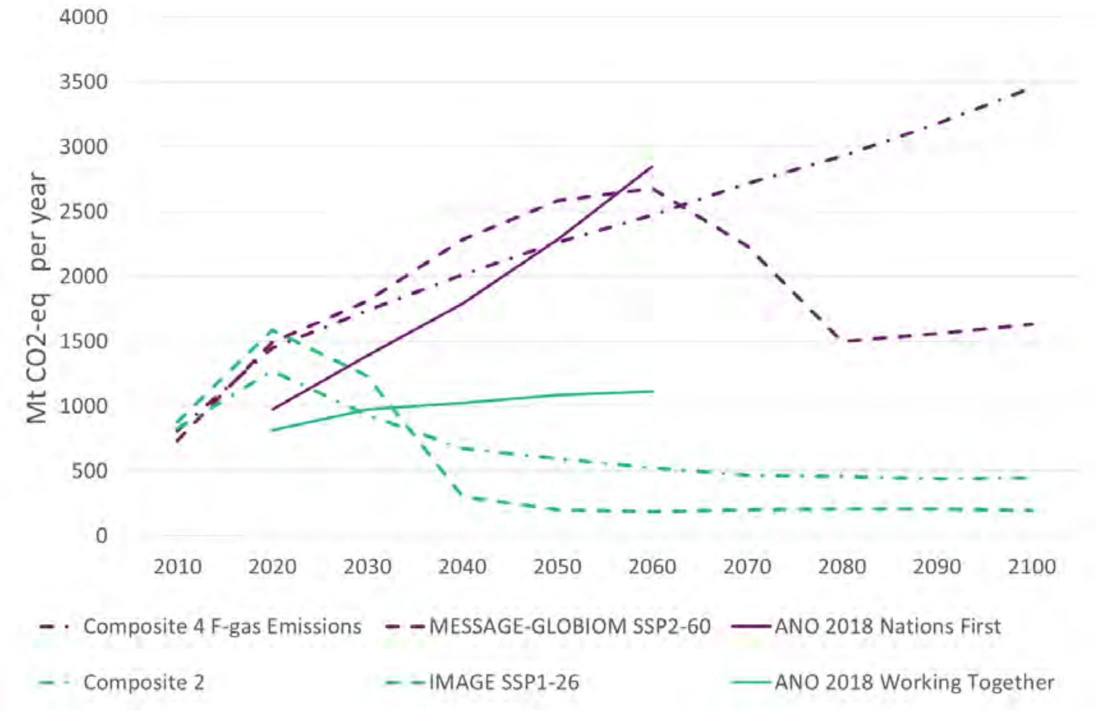

Figure 13.5 Decadal emissions projections: ANO 2019 models to 2060 versus SSP Database comparisons (F-gases)

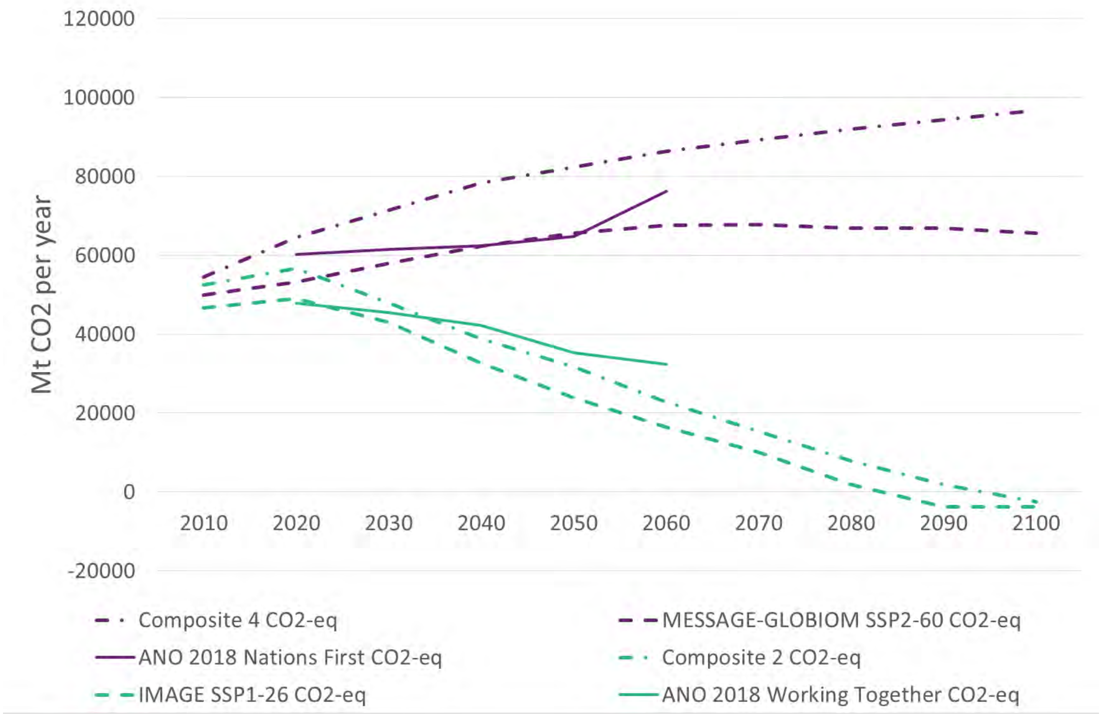

Figure 13.6 Decadal emissions projections: ANO 2019 models to 2060 versus SSP Database comparisons (Aggregate CO_2-eq)

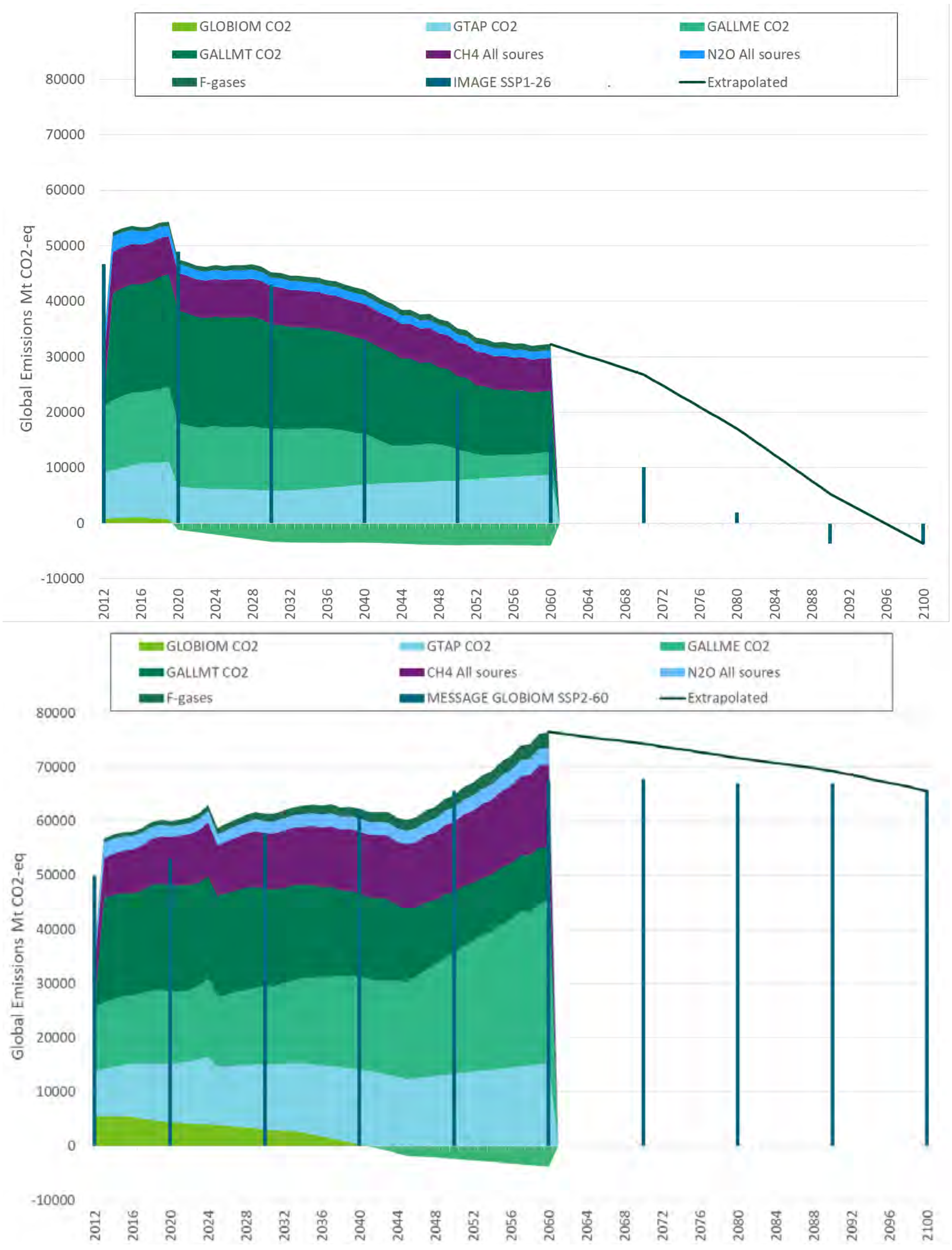

Figure 13.7 Greenhouse emissions projections: ANO 2019 models and decadal SSP Database comparisons [Top *Nation First* global scenario, Bottom *Working Together* global scenario]

From Figure 13.2 and Figure 13.7, it can be seen that the projections of all four emissions categories from the ANO 2019 modelling suite that contribute to the high aggregate CO_2–eq emissions relative to the comparison SSP Database scenarios. Note that the data from the composite scenarios have a dash-dot representation, and those from the individual comparison scenarios have a dashed representation. The projection of F-gases, primarily from GTAP-ANO, and primarily from the electronics sector (Figure 6 in Irfanoglu and van der Mensbrugghe (2015)), and particularly in the *Working Together* global scenario where they are assumed to result from a 2% pa intensity improvement, provide a less aggressive reduction trajectory than the comparisons.

It can be seen that emissions from all sources in the *Nation First* global scenario are higher in the ANO 2019 modelling than MESSAGE/GLOBIOM SSP2-60 by approximately 7000-8000 Mt CO_2-eq pa in 2060. In the *Working Together* global scenario, the ANO 2019 projections are higher than the IMAGE SSP1-26 data particularly in the later years within the modelling time horizon, and almost double that of the comparison scenario at 2060. This highlights some of the technological challenges of achieving a global emissions trajectory consistent with RCP2.6 under a high economic growth SSP1 scenario (for more detailed discussion see Chapter 2 and Chapter 3). Note that there is only limited inclusion of negative emissions technology such as biomass energy production with carbon capture and storage (BECCS) in the global energy models – they are available in GALLME and show only a low uptake, but are not available in GALLMT. These modelling results suggest that negative emissions technologies may be necessary to achieve United Nations Framework Convention on Climate Change (UNFCC, 2018) Paris Agreement climate ambitions.

13.3.3 Unmodelled greenhouse gas emissions and post-2060 extrapolation assumptions

The emissions projections from the ANO 2019 modelling suite do not extend beyond 2060, however we would like to model climate impacts to 2100. In order to do so, we have based our ANO 2019 scenarios global emissions in 2070, 2080, 2090 and 2100 on the aspirational comparison emissions scenarios from the SSP Database, MESSAGE-GLOBIOM SSP2-60 and IMAGE SSP1-26. Although these aspirational scenarios achieve greater emissions abatement in 2060 than *Nation First* and particularly *Working Together* their emissions trajectory is consistent with the climate action settings qualitative description and for the purpose of global scenario analysis they represent an appropriate target for a global emissions trajectory in the later years.

For the four categories of emissions represented in the global ANO 2019 suite, emissions extrapolated beyond 2060 are a weighted combination of the projections from the comparison scenarios and the 2060 projections from the ANO 2019 suite. The scaling weights are pro-rated along the time axis, so that by 2100 the weight corresponding to the ANO 2019 projection at 2060 vanishes. In Figure 13.7, the decadal extrapolated emissions post-2060 for the ANO 2019 inputs to MAGICC are represented as a brown line, and the emissions of the individual comparison scenarios are represented as dark blue columns. Note that emissions projections are not provided to MAGICC for every year for every gas species, as it can (linearly) interpolate across years as the exogenous and post-2060 emissions projections are provided to MAGICC for decadal years only.

For greenhouse gas species other than the CO_2, N_2O, CH_4, and F-gases, emissions projections are also taken from the same two scenarios in the SSP Database (IIASA 2016). In particular, emissions trajectories exogenous to the ANO 2019 suite are for NO_x, SO_x, (non-methane) volatile organic compounds, black carbon and organic carbon. Emissions projections from 2000-2100 for these other species are taken directly from the SSP Database, without modification. Aerosol emissions, which play an important role in atmospheric cooling (Boucher et al. 2013, p. 622) were therefore not modelled at all within ANO 2019, but taken directly from external data sources.

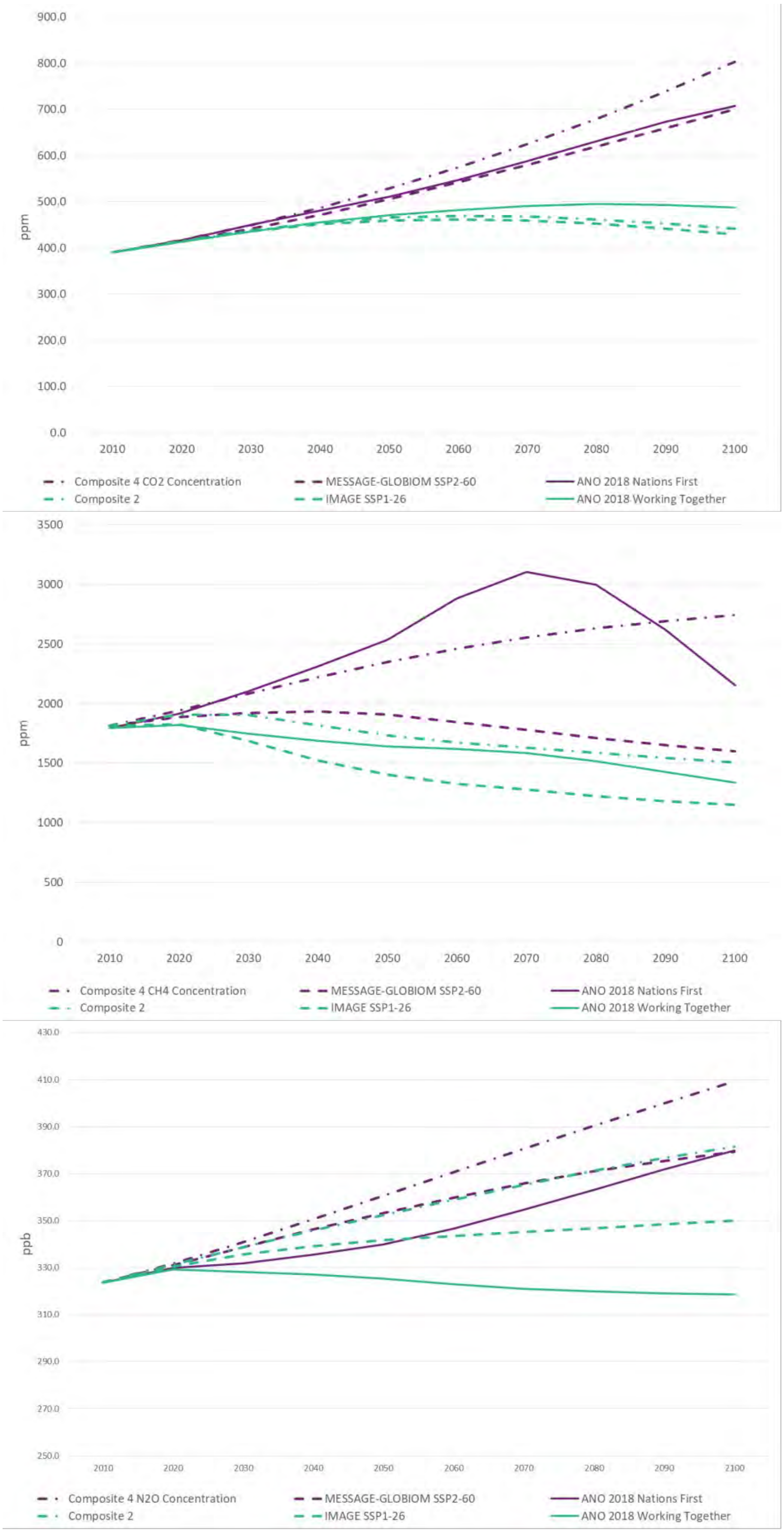

Figure 13.8 Emissions concentration projections: Decadal ANO 2019 models and SSP Database comparisons [Top - CO_2, middle - CH_4, bottom - N_2O]

13.4 MAGICC results

After executing MAGICC with the aggregated emissions projections from the ANO 2019 global scenarios we are able to compare atmospheric greenhouse concentrations, radiative forcing, and temperature projections with the comparison scenarios from Section 13.3.2. We can see from Figure 13.8 and Table 13.4 that, as would be expected from the comparison of emissions projections, which tend to be higher than the comparison scenarios, the resultant atmospheric concentrations of emission are also higher. As above in Figure 13.2 the data from the composite (individual) comparison scenarios are represented (respectively) by a dash-dot (dashed only) line.

Table 13.4 Diagnostic results data for selected comparison SSP Database scenarios

	CO_2 CONC. (PPM)		CH_4 CONC. (PPM)		N_2O CONC. (PPB)		**RADIATIVE FORCING (W/M2)**		**EQ-CO_2 CONC. (PPM)**		**TEMP INCREASE (°C)**		
	2060	**2100**	**2060**	**2100**	**2060**	**2100**	**2060**	**2100**	**2060**	**2100**	**2060**	**2100**	**MAX**
ANO 2019 ***Nation First***	547	707	2883	2154	347	380	5.0	6.1	707	876	2.59	3.53	"
GLOBIOM-MESSAGE SSP2-60	542	700	1845	1599	360	379	4.2	5.5	614	779	2.28	3.23	"
Composite Scenario 4K warming at 2100	575	803	2460	2743	371	409	4.8	7.0	691	1034	2.57	4.03	"
ANO 2019 ***Working Together***	482	487	1619	1336	323	319	3.1	3.4	551	529	1.96	2.05	2.06
IMAGE/ SSP2-26	462	430	1328	1153	343	350	3.1	2.6	500	457	1.82	1.76	1.85
Composite Scenario 2K warming at 2100	470	441	1673	1506	359	382	3.4	3.0	533	493	1.97	1.97	2.03

[Source: SSP Database, IIASA 2016 and CSIRO modelling]

Given the broad range of projections in the comparison scenarios, we did not expect any improvement in matching SSP scenarios from adjusting the ANO 2019 assumed carbon price trajectories any further to potentially more precisely represent any particular scenario diagnostic target such as a particular emissions trajectory, atmospheric concentration of greenhouse cases or radiative forcing value at a particular year. Furthermore, for reasons that we explain further in the chapter on global scenario results (see Chapter 3) we are unable to provide scenario parameters to our global modelling suite that significantly reduce emissions projections in the *Working Together* global scenario. This is due to a relatively high electrification due to emissions induced substitution, our assumptions about global GDP growth and energy (including transport energy) demand intensity, and regional constraints imposed on the availability of renewable energy resources.

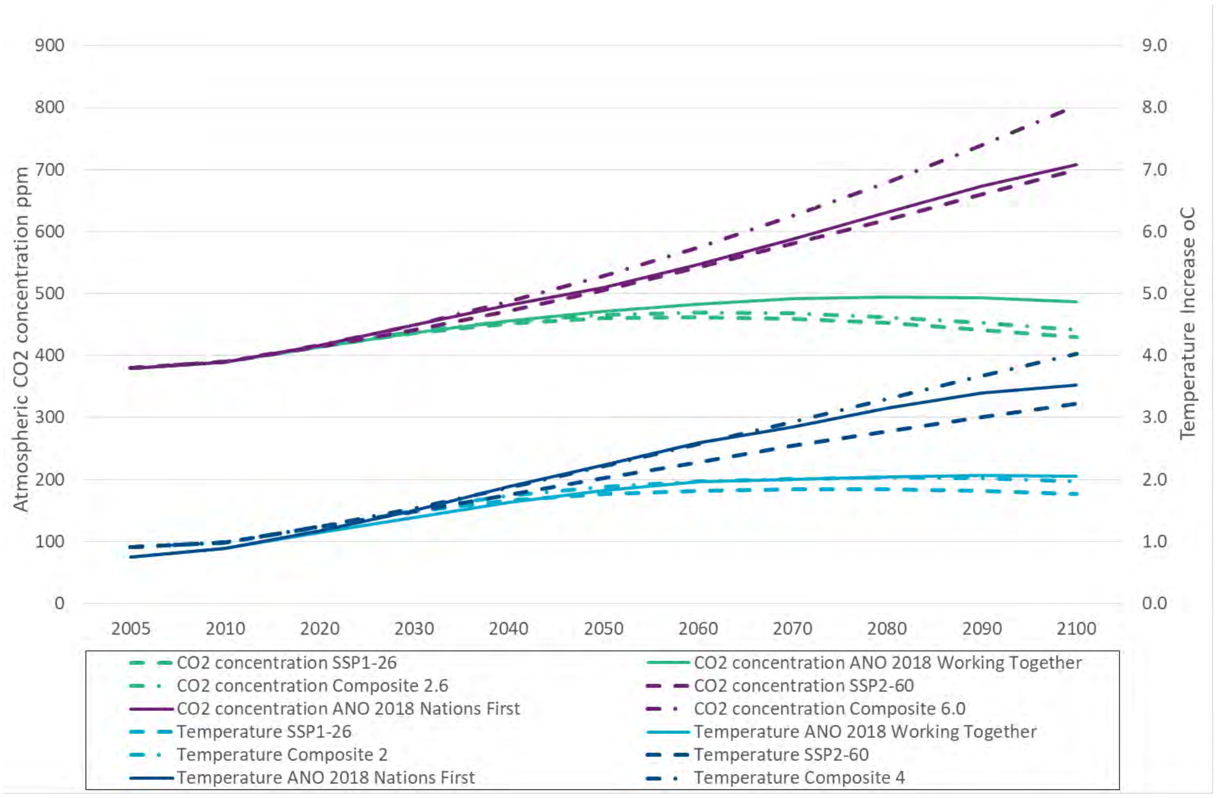

Figure 13.9 CO₂ concentration and temperature projections: Decadal ANO 2019 models and SSP Database comparisons

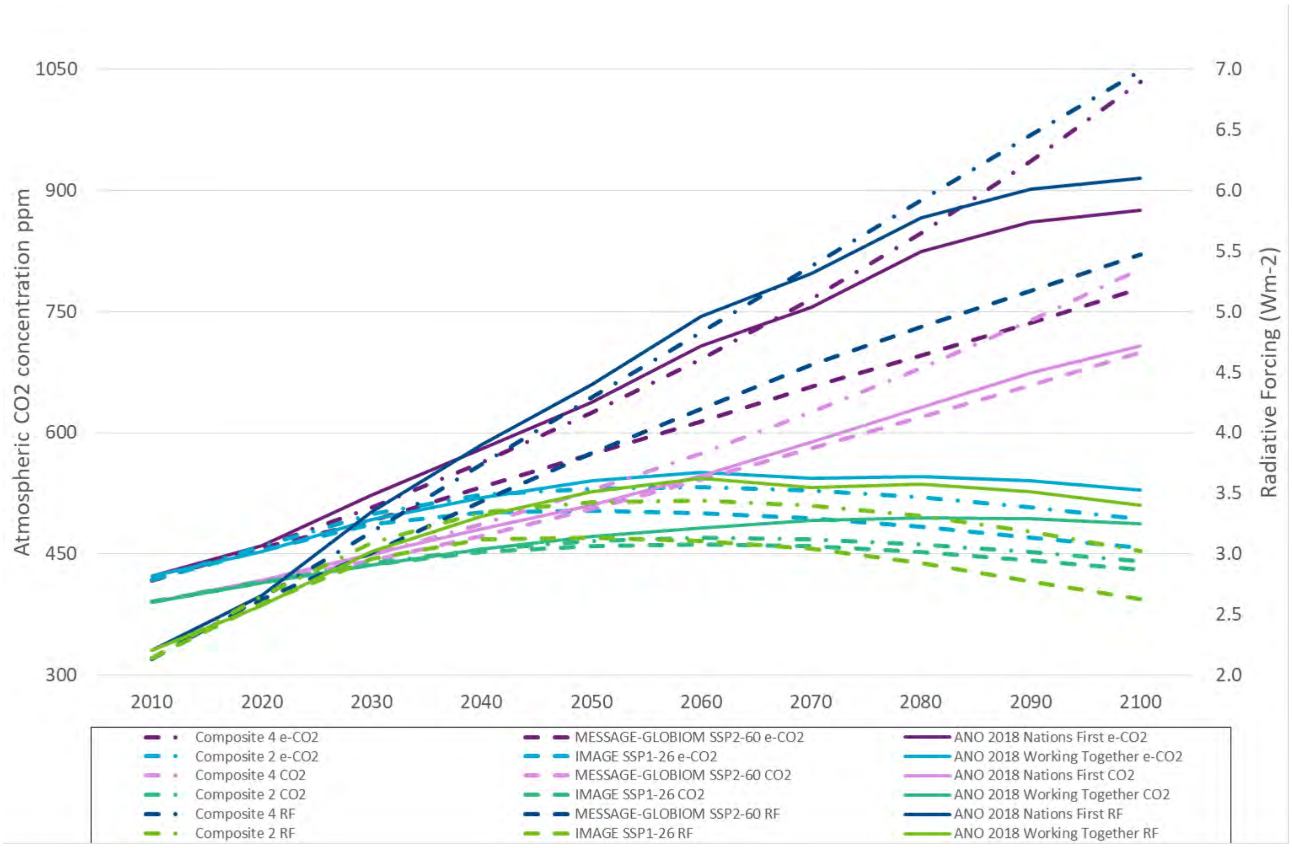

Figure 13.10 Radiative forcing and eq-CO₂ atmospheric conc.- Decadal ANO 2019 models and SSP Database comparisons

Consistent with relatively high projections of atmospheric concentrations of individual greenhouse emissions relative to the comparison scenarios, the consequential projected radiative forcing, equivalent CO_2 atmospheric concentrations, and mean global temperature increases projected by the ANO 2019 scenarios are all higher than those in the comparison scenarios. See Table 13.4 for comparative results in tabular format, Figure 13.9 for temperature and CO_2 concentrations, or Figure 13.10 for CO_2 concentrations, radiative forcing and greenhouse gas eq-CO_2 concentrations.

Table 13.5 compares ANO 2019 temperature projections to those from a range of models reported by the IPCC (2013). At 2100, the temperature projection for *Nation First* is lower than the 4.0 °C target guiding the selection of scenarios for the corresponding composite SSP comparison, and that for *Working Together* is higher than the target guiding the selection of the 4.0 °C warming composite SSP comparison.

The ANO 2019 projections averaged across time exceed those presented in IPCC (2013) for RCP6.0 and RCP2.6 for the comparison year ranges 2046-65 and 2081-2100, although the ranges for the *Working Together* scenario are within those for RCP2.6, and the *Nation First* temperature ranges are within the corresponding RCP6.0 ranges. The temperature projections for the ANO 2019 *Working Together* scenario are arguably a closer match to the IPCC (2013) projections for RCP4.5 than for RCP2.6. The higher temperature range in RCP4.5 compared to RCP6.0 in 2046-65 in Table 13.5 is in the original source.

Table 13.5 Global warming estimates for ANO modelling and IPCC RCP scenarios

	2046-65		**2081-2100**	
	MEAN	**RANGE**	**MEAN**	**RANGE**
ANO 2019 *Nation First*	2.4	2.1 – 2.7	3.4	3.2 – 3.5
ANO 2019 *Working Together*	1.9	1.7 – 2.0	2.1	2.0 – 2.1
RCP2.6	1.5	0.9 – 2.1	1.5	0.8 – 2.2
RCP4.5	1.9	1.4 – 2.5	2.3	1.6 – 3.1
RCP6.0	1.8	1.3 – 2.3	2.7	1.9 – 3.6
RCP8.5	2.5	1.9 – 3.1	4.3	3.1 – 5.3

[Source: IPCC (2013), Table SPM, p. 23 adjusted by 0.6 °C to give changes relative to a pre-industrial temperature baseline from source data relative to a 1986-2005 average baseline, and CSIRO modellingDiscussion

A key goal of including a (simplified) climate model as part of the ANO 2019 global modelling suite is to confirm that the global emissions policies implemented within the global models, whose results set the context for the more detailed Australian national modelling, are consistent with the global scenario settings. The global scenario settings for *Nation First* and *Working Together* include particular population and GDP growth assumptions, consistent with SSP2 and SSP1, combined with particular global emissions outcomes consistent with a 'four degrees track' and a 'two degrees track', qualitatively similar to RCP6.0 and RCP2.6. The modelled results suggest that our projected global emissions are at the upper end of a range consistent with the guiding RCPs, with corresponding increases in mean global temperature also above those in the guiding scenarios. This interpretation is further reinforced by comparison of the temperature projections in Figure 13.9 from the ANO 2019 global suite and those from a more sophisticated climate modelling analysis that also more explicitly represents a temperature range (see Figure 13.11, which shows 10-90 percentile ranges for both global temperatures and Australian specific temperatures).

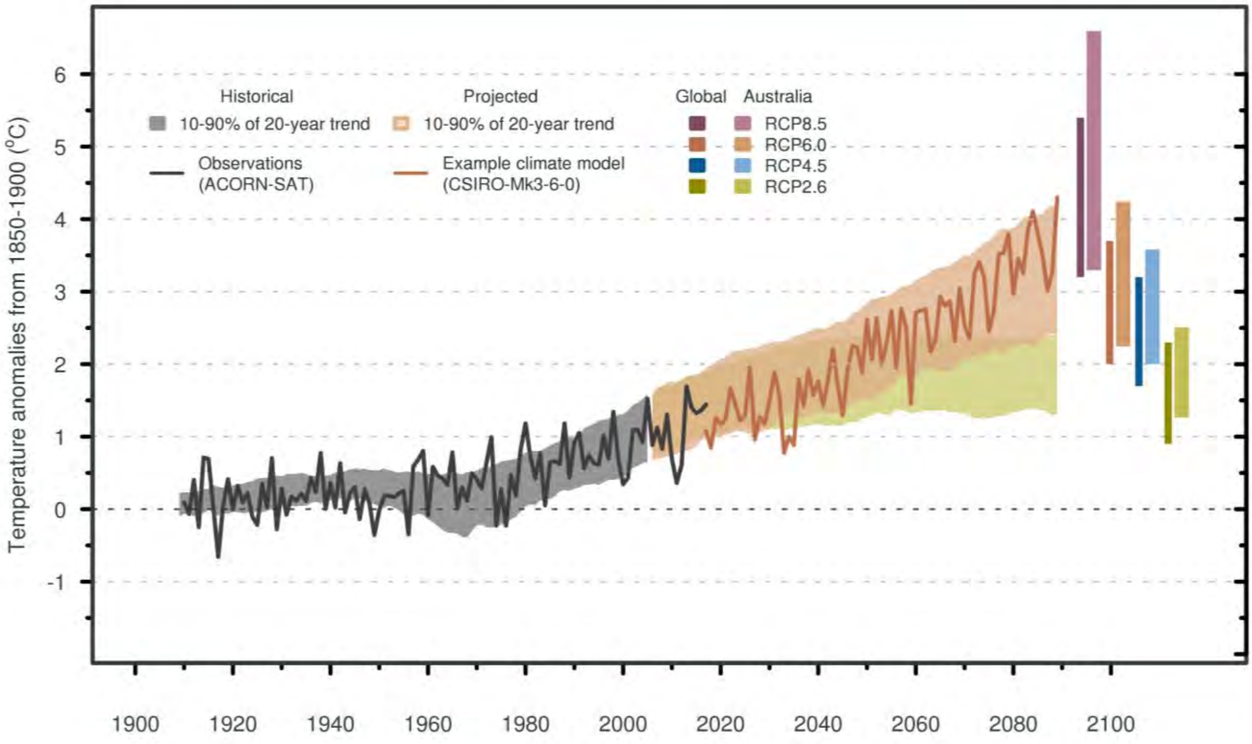

Figure 13.11 Australian temperature record and projections (for more details on data sources and methods see note for Figure 8.9 or visit www.climatechangeinaustralia.gov.au).

For a reminder of the limitations of ANO 2019 climate projections, we first point out some challenges in choosing target scenarios and benchmarking calibrations. Later we recapitulate some of the limitations with the construction of MAGICC input (emissions) data.

13.4.1.1 Forcing factor versus temperature targeting

We first note that a choice of a particular RCP target scenario still leaves a reasonable range of scientific and probabilistic uncertainty regarding the earth system temperature response (Kunreuther et al., 2014). Any particular execution of a MAGICC scenario is deterministic, based on best estimates of various earth system sensitivity parameters, and for ANO 2019 we have not used MAGICC to explore the impact of varying these parameters. Furthermore MAGICC does not explicitly represent stochastic intra-annual or inter-annual variation in global mean temperature in the same way that a more detailed global climate model might do based on an ensemble of simulations at higher time resolution.

Figure 13.11 suggests that RCP6.0 results in a 10-90 percentile range of temperature estimates of a global temperature increase of between about 2.2-3.9 °C averaged over 2081-2100. To target a deterministically projected 4.0 °C increase at 2100 as a ‘four degrees track’ is to not only to use a temperature target above the upper end of the range of estimates for RCP6.0, but also to overstate the extent to which a particular temperature increase can be targeted precisely and to understate the risk that even greater warming will eventuate than that expected. Similarly, we note that RCP2.6 is consistent with a range of global temperature increases at 2100 of between

0.8 – 2.2 °C, and targeting a deterministically projected 2.0 °C increase at 2100 as a ‘two degrees track’ is also to risk a worse outcome than probabilistically expected. In order to achieve a high degree of confidence that temperature increases will not be in excess of a 2.0 °C increase at 2100, a more stringent target is required than a 2.0 °C limit for the expected case.

We further note that some of the comparison scenarios comprising the 2.0 °C warming composite scenario overshoot their 2100 projected level prior to the end of the time horizon.Allowing such scenarios to contribute to a benchmark comparison makes it less challenging than if maximum temperatures over, rather than final temperatures at the end of, the time horizon are subject to a temperature target constraint. Furthermore, the nominal temperature constraint target that will be met with high likelihood is higher than the temperature projected as a probabilistic expectation (for a discussion of some of these definitional and interpretational differences in characterising scenarios by temperature projections, see Rogelj et al., 2017).

13.4.1.2 Emissions projections

Even given the uncertainty regarding projections of economic activity from GTAP-ANO and the global energy models, (e.g. no explicit cost/price feedback from the energy models to the economic model) there are a number of additional important assumptions about global greenhouse emissions that we have been required to make.

Firstly we have imposed pricing on non-CO_2 emissions completely aligned with the timing of CO_2 prices at a global warming equivalence price rate. To date, most countries have made limited efforts to reduce greenhouse gas emissions in agriculture, and pricing of these emissions is likely to be politically very difficult. We have underestimated emissions projections from GTAP-ANO by subtracting all emissions arising from oil use as a proxy for emissions from the transport sector, neglecting to account for use of petroleum products in agriculture, the electricity generation sector and other industrial activities. We have assumed as negligible, emissions of CH_4 and F-gases from the global electricity generation and transport sectors, and have approximated N_2O emissions as being proportional to CO_2 emissions from those sectors. We have assumed an improvement of emissions intensity in both CO_2 and non-CO_2 emissions in the *Working Together* global scenario in the broader economy (based primarily on an attempt to calibrate our model to benchmark scenarios), and N_2O in the energy sector based on indicative technical possibilities.

We have not modelled minor greenhouse gas emissions pre-2060, but relied on modelled projections by others in previously published scenarios. Finally, our emissions projections are only until 2060 and are discontinuous with our preferred benchmark scenarios that achieve more emissions abatement than for both of our global scenarios, and we have been required to create a blended projection to 2100.

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14 VURM

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Model at a glance

Model summary	The Victoria University Regional Model (VURM) is a dynamic economic model, assessing greenhouse emissions and policy options for eight Australian states and territories and up to 84 economic sectors. Developed by the University of Victoria. For more details see Adams et al. (2015).
Key ANO scenarios drivers	• projection of CO_2 prices, applied to both CO_2 and non-CO_2 emissions (source: IPCC and CSIRO) • global demand and prices for energy and agricultural commodities (from GTAP-ANO) • productivity assumptions including computational definitions for total factor productivity-to-capital ratios • labour market assumptions, including national unemployment and labour productivity changes by occupation • assumptions for autonomous energy efficiency, electrification, efficiencies of transport use in urban areas, etc. • vehicle use by vehicle type (source: BTRE and CSIRO) • land use constraints in forestry and agriculture (from LUTO).
Key inputs and assumptions	• global population and economic growth • foreign currency import prices and the positions of foreign export-demand schedules (from GTAP-ANO).

14.1 Introduction

The key distinguishing characteristic of computable general equilibrium (CGE) modelling in Australia is its orientation to providing *detailed* inputs to the policy-formation process. A practical demonstration is the work for Australian National Outlook (ANO) 2019.

National economic projections for ANO 2019 come from simulations of the Victoria University Regional Model (VURM). VURM is a dynamic, multi-sector, multi-region CGE model of Australia. Currently, it distinguishes 76 industries that produce 78 products in 8 states/territories.[1] Each of the regional economies are treated as economies in their own right, with region-specific industrial technologies, prices, consumers, etc.

Of the 76 industries, three produce primary fuels (coal, oil and gas), one produces refined fuel (petroleum products) and another produces liquefied natural gas (LNG) for export. Six industries generate electricity and one supplies electricity to final customers. The six generation industries are defined according to primary source of fuel:

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[1] Apart from two dwelling services industries, industries produce single products. One dwelling industry produces high-density dwellings for rent and owner-occupiers. The other produces low-density dwellings for rent and owner-occupiers. Previous versions of the model have also distinguished multiple production in agriculture and petrol refining (e.g. the grains industry would produce grains for animal and human consumption and biofuel used as feedstock, while the refinery industry would produce many products including gasoline, diesel, LPG, aviation fuel, and other refinery products such as heating oil). However, in the current version of the model no such multi-production is allowed.

- *Electricity-coal* includes all coal-fired generation technologies
- *Electricity-gas* includes all plants using turbines, cogeneration and combined cycle technologies driven by burning gas
- *Electricity-oil products* covers all liquid-fuel generators
- *Electricity-hydro* covers hydro generation
- *Electricity-other* covers the remaining forms of renewable generation from biomass, biogas, wind, etc.

Australia does not have a commercial nuclear power industry, but Electricity-nuclear is included in the model and can be triggered, if desired, at a specified emissions price.

This chapter is organised as follows. A general description of VURM is given in Section 14.2.[2] Enhancements of the general form of the model that are necessary for the ANO modelling are discussed in detail in Section 14.3. General aspects of simulation design are given in Section 14.4.

14.2 Model description

14.2.1 The nature of markets

VURM determines regional supplies and demands of commodities through optimising behaviour of agents in competitive markets. Optimising behaviour also determines industry demands for labour and capital. Labour supply at the national level is determined by demographic factors, while national capital supply responds to rates of return. Labour and capital can cross regional borders in response to relative regional employment opportunities and relative rates of return.

The assumption of competitive markets implies equality between the basic price (i.e. the price received by the producer) and marginal cost in each regional sector. Demand is assumed to equal supply in all markets other than the labour market (where excess supply conditions can hold). The government intervenes in markets by imposing *ad valorem* sales taxes on commodities. This places wedges between the prices paid by purchasers and the basic prices received by producers. The model recognises margin commodities (e.g. retail trade and road transport), which are required for the movement of commodities from the producers to the purchasers. The costs of the margins are included in purchasers' prices of goods and services.

14.2.2 Demands for inputs to be used in the production of commodities

VURM recognises two broad categories of inputs: intermediate inputs and primary factors. Firms in each regional sector are assumed to select the mix of inputs that minimises the costs of production for their levels of output. They are constrained in their choices by a three-level nested production technology. At the first level, intermediate-input bundles and a primary-factor bundle are used in fixed proportions to output.[3] These bundles are formed at the second level. Intermediate-input bundles are combinations of domestic goods and goods imported from

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[2] More complete descriptions are available from Adams and Parmenter (2013), and Adams, Dixon and Horridge (2015).

[3] A miscellaneous input category, *Other costs*, is also included and required in fixed proportion to output. The price of O*ther costs* is indexed to the price of private consumption. It is assumed that the income from O*ther costs* accrues to the government.

overseas. The primary-factor bundle is a combination of labour, capital and land. At the third level, inputs of domestic goods are formed as combinations of goods sourced from each of the eight domestic regions, and the input of labour is formed as a combination of inputs from nine occupational categories.

14.2.3 Domestic final demand: household, investment and government

In each region, the household buys bundles of goods to maximise a utility function subject to an expenditure constraint. The bundles are combinations of imported and domestic goods, with domestic goods being combinations of goods from each domestic region. A consumption function is usually used to determine aggregate household expenditure as a function of household disposable income.

Capital creators for each regional sector combine inputs to form units of capital. In choosing these inputs, they minimise costs subject to a technology similar to that used for current production, with the main difference being that they do not use primary factors directly.

State, territory and the Australian governments demand commodities from each region. In VURM, there are several ways of handling these government demands, including:

- by a rule such as moving government expenditures with aggregate household expenditure, domestic absorption or gross domestic product (GDP)
- as an instrument to accommodate an exogenously determined target such as a required level of government budget deficit
- exogenous determination.

14.2.4 Foreign demand (international exports)

VURM adopts the ORANI[4] (see also Chapter 10 for more information) specification of foreign demand. Each export-oriented sector in each state or territory faces its own downward-sloping foreign demand curve. Thus, a shock that reduces the unit costs of an export sector will increase the quantity exported, but reduce the foreign currency price. By assuming that the foreign demand schedules are specific to product and region of production, the model allows for differential movements in foreign-currency prices across domestic regions.

14.2.5 Regional labour markets

The response of regional labour markets to policy shocks depends on the treatment of three key variables – regional labour supplies, regional unemployment rates and regional wage differentials. The main alternative treatments are:

- to set regional labour supplies and unemployment rates exogenously and determine regional wage differentials endogenously

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[4] VURM and MONASH (Dixon and Rimmer, 2002) have evolved from the Australian ORANI model (Dixon et al., 1977).

- to set regional wage differentials and regional unemployment rates exogenously and determine regional labour supplies endogenously (*via* interstate migration or changes in regional participation rates)
- to set regional labour supplies and wage differentials exogenously and determine regional unemployment rates endogenously.

The second treatment is the one adopted for the simulations reported here, with regional participation rates exogenous. Under this treatment, workers move freely (and instantaneously) across state borders in response to changes in relative regional unemployment rates. With regional wage rates indexed to the national wage rate, regional employment is demand determined.

14.2.6 Physical capital accumulation

Investment undertaken in year *t* is assumed to become operational at the start of year *t*+1. Under this assumption, capital in industry *i* in region *q* accumulates according to a typical accumulation equation, with gestation lag for new investment of one year.

New investment in industry *i* in region *q* is modelled as a positive function of expected rate of return. In the current version of VURM, it is assumed that investors only consider current rentals and asset prices when forming expectations about rates of return (static expectations).

14.2.7 Lagged adjustment process in the national labour market

The simulations undertaken for the ANO are year-to-year recursive-dynamic simulations, in which it is assumed that deviations in the national real wage rate from its base-case level increase through time in inverse proportion to deviations in the national unemployment rate (Dixon and Rimmer, 2002). That is, in response to a shock-induced increase (decrease) in the unemployment rate, the real wage rate declines (increases), stimulating (reducing) employment growth. The coefficient of adjustment is chosen so that effects of a shock on the unemployment rate are largely eliminated after about 10 years.

Given the treatment of regional labour markets outlined above, if the national real wage rate rises (falls) in response to a fall (rise) in the national unemployment rate, then wage rates in all regions rise (fall) by the same percentage amount, and regional employment adjusts immediately, with regional labour supplies adjusting to stabilise relative regional unemployment rates.

14.3 Environmental enhancements

In this section, the key environmental enhancements of VURM are described. These are:

- an accounting module for energy and greenhouse gas (GHG) emissions that covers each emitting agent, fuel and region recognised in the model
- quantity-specific carbon taxes or prices
- equations for inter-fuel substitution in transport and stationary energy
- a representation of Australia’s National Electricity Market (NEM)

- the linking of VURM to a global model to enhance VURM's handling of global aspects of environmental policies and of changes to Australia's trading conditions
- the linking of VURM to a detailed electricity supply model
- modelling the abatement of non-combustion (non-CO_2) emissions
- modelling of carbon sequestration in forest industries.

14.3.1 Energy and emissions accounting

VURM tracks emissions of GHGs according to emitting agent (76 industries and the household sector), emitting state or territory (8) and emitting activity (4). Most of the emitting activities are the burning of fuels (coal, natural gas and petroleum products). A residual category, named *Activity*, covers non-combustion emissions such as emissions from mines and agricultural emissions not arising from fuel combustion. *Activity* emissions are assumed to be proportional to the level of activity in the relevant industries (animal-related agriculture, gas mining, cement manufacture, etc.).

The resulting 76 × 8 × 4 array of emissions is intended to include all emissions except those arising from land clearing. Emissions are measured in terms of carbon dioxide equivalents, CO_2-eq. Note that VURM accounts for domestic emissions only; emissions from combustion of Australian coal exports, for example, are not included, but fugitive emissions from the mining of the coal are included.

14.3.2 Carbon taxes and prices

VURM treats the price on emissions as a specific tax on emissions of CO_2-eq. For emissions from fuel combustion, the tax is imposed as a sales tax on the use of fuel. For *Activity* emissions, it is imposed as a tax on production of the relevant industries.

In VURM, sales taxes are generally assumed to be *ad valorem*, levied on the basic value of the underlying flow. Carbon taxes, however, are specific, levied on the quantity (CO_2-eq) emitted by the associated flow. Hence, equations are required to translate a carbon tax, expressed as per unit of $C0_2$-eq, into *ad valorem* taxes, expressed as percentages of basic values. The CO_2-eq taxes are specific but coupled to a single price index (typically the national price of consumption) to preserve the nominal homogeneity of the system. Suppressing indices, an item of CO_2-eq tax revenue can be written as:

$$TAX = S \times E \times I \tag{1}$$

where:

- *S* is the specific rate (A$ per tonne of CO_2-eq)
- *E* is the emission quantity (tonne of CO_2-eq)
- *I* is a price index (base year = 1) used to preserve nominal homogeneity.

Ad valorem taxes in VURM raise revenue

$$TAX = \frac{V \times P \times Q}{100} \tag{2}$$

where:

- V is the percentage *ad valorem* rate
- P is the basic price of the underlying taxed flow
- Q is the quantity of the underlying taxed flow.

To translate from specific to *ad valorem* the right hand sides of equations (1) and (2) are set equal to each other, yielding:

$$V = \frac{S \times E \times I \times 100}{P \times Q} \tag{3}$$

As can be seen from equation (3), to convert specific CO_2-eq taxes to *ad valorem* taxes, frequent use is made of the ratio of the indexed value of emissions ($E \times I$) to the value of the *ad valorem* tax base ($P \times Q$). Indeed, values for the ratio across all fuels and users and the matrix of specific tax rates are the primary additional data items added to VURM for carbon tax/emissions trading scheme modelling.

Production taxes in VURM are also assumed to be *ad valorem*, and levied on the basic value of production. Accordingly, the linking equation for a $C0_2$-e tax on *Activity* emissions is:

$$V = \frac{S \times E \times I \times 100}{P \times Z} \tag{4}$$

where Z is the volume of production for which P is the basic price.

14.3.3 Inter-fuel substitution

In the standard specification of VURM, there is no price-responsive substitution between units of commodities, or between commodities and primary factors. With fuel-fuel and fuel-factor substitution ruled out, CO_2-eq taxes could induce abatement only through activity effects.

This has been corrected in two ways:

1. first, by introducing inter-fuel substitution in electricity generation using a ‘technology bundle’ approach
2. second, by introducing a weak form of input substitution in sectors other than electricity generation to mimic ‘KLEM substitution’ (capital – K, labour, energy, materials).

Electricity-generating industries are distinguished based on the type of fuel used. There is also an end-use supplier (*Electricity supply*) in each state and territory and a single dummy industry (*NEM*) covering the six regions that are included in Australia’s National Electricity Market (NSW, Victoria, Queensland, SA the ACT and Tasmania). Electricity flows to the local end-use supplier either directly in the case of WA and the NT or *via NEM* in the remaining regions.

Purchasers of electricity from the generation industries (*NEM* in NEM regions or the *Electricity supply* industries in the non-NEM regions) can substitute between the different generation technologies in response to changes in generation costs. Such substitution is price-induced, with the elasticity of substitution between the technologies typically set at 5.

For other energy-intensive commodities used by industries, VURM allows for a weak form of input substitution. For example, if the price of cement rises by 10% relative to the average price of other inputs to construction, the construction industry will use 1% less cement and a little more labour, capital and other materials. In most cases, as in the cement example, a substitution elasticity of 0.1 is imposed. For important energy goods (petroleum products, electricity supply, and gas) the substitution elasticity in industrial use is 0.25.

14.3.4 The National Electricity Market

The NEM is a wholesale market covering nearly all of the supply of electricity to retailers and large end-users in NEM regions. VURM's represents the NEM as follows.

Final demand for electricity in each NEM region is determined within the CGE-core of the model in the same manner as demand for all other goods and services. All end users of electricity in NEM regions purchase their supplies from their own-state *Electricity supply* industry. Each of the *Electricity supply* industries in the NEM regions sources its electricity from a dummy industry called *NEM*, which does not have a regional dimension; in effect, *NEM* is a single industry that sells a single product (electricity) to the *Electricity supply* industry in each NEM region. *NEM* sources its electricity from generation industries in each NEM region. Its demand for electricity is price-sensitive. For example, if the price of hydro generation from Tasmania rises relative to the price of gas generation from NSW, then *NEM* demand will shift towards NSW gas generation and away from TAS hydro generation.

The explicit modelling of the NEM enables substitution between generation types in different NEM regions. It also allows for inter-state trade in electricity, without having to explicitly trace the bilateral flows. Note that WA and NT are not part of the NEM and electricity supply and generation in these regions is determined on a state-of-location basis.

14.3.5 Linking with a global model of energy and trade – GTAP-ANO

Much of the global modelling undertaken for the ANO 2019 was undertaken using a specially adapted version of the (Global Trade Analysis Project) GTAP model, designed for energy and greenhouse work. This model is called GTAP-ANO (see Chapter 10 for more information). Many of the enhancements are similar to those documented for the Global Trade and Environment Model (GTEM) (Pant, 2007).[5] Information from GTAP-ANO is used to inform simulations of VURM.

Linking economic models with different economic structures is not straightforward. For example, VURM and GTAP-ANO have similar production structures, but their industrial classifications are not identical. Also, the elasticities of supply and demand associated with comparable industries are not necessarily consistent across the two models.

In general, the degree of linking required will vary depending on the number and nature of variables that are common between the two models. For example, if the only common variables

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[5] GTEM was used for ANO 2015.

are exogenous in the primary model (VURM), then a relatively simple top-down linking from the secondary model (GTAP-ANO) is sufficient. On the other hand, if there are many common variables with some endogenous to both systems, a more complex linking with two-way transmission of results may be necessary.

The abatement scenarios introduced into the ANO 2019 scenarios involve a global permit price. GTAP-ANO was used to model the effects of the global price on Australia's trading conditions. These are as represented in VURM as changes in the positions of foreign export-demand and import-supply schedules. In VURM, import supply is assumed perfectly elastic and foreign-currency import prices are naturally exogenous, once again allowing for one-way transmission from GTAP-ANO to VURM.

For exports, however, foreign demand schedules are assumed to be downward sloping. In this case, one-way transmission is potentially problematic because export prices and quantities are endogenous in both models. Despite the in principle potential for feedback, the linking between GTAP-ANO and VURM for export variables was done *via* one-way transmission from GTAP-ANO to VURM, and justified on the basis that Australian market conditions are expected to have only a limited influence on global markets for most commodities.

14.3.6 Linking with a detailed electricity supply model – CSIRO's TIMES model

The idea that environmental issues could be tackled effectively by linking a CGE model with a detailed bottom-up energy model has a long history with Australian modellers.

TIMES simulates the least-cost expansion and operation of generation and transmission capacity in the Australian electricity system. In linking VURM to TIMES, the electricity sector in VURM is effectively replaced with the specification for TIMES. VURM provides information on fuel prices and other electricity-sector costs and on electricity demand from industrial, commercial and residential users. This is fed into TIMES, which generates a detailed description of supply, covering generation by generation type, capacity by generation type, fuel use, emissions, and wholesale and retail electricity prices. Retail electricity prices are a key endogenous variable in both systems. Information is passed back and forth between the two models in a series of iterations that stop when the average retail price in the electricity model has stabilised. Experience suggests that up to three iterations for each year are necessary to achieve convergence.

There are a number of reasons to prefer linking to a detailed electricity model over the use of VURM's standard treatment of electricity.

1. *Technological detail*. VURM recognises a handful of generation technologies. TIMES recognises many hundreds, some of which are not fully proved and/or are not in operation. For example, VURM recognises one form of coal generation, whereas TIMES recognises many forms, including cleaner gasification technologies and generation in combination with carbon capture and storage (CCS). Having all known technologies available for production now or in the future allows for greater realism in simulating the technological changes available in electricity generation in response to a price on emissions. TIMES also captures details of the interrelationships between generation types. A good example is the reliance by hydro generation on base-load power in off-peak periods to pump water utilised during peak periods back to the reservoir.

2. *Changes in capacity*. VURM treats investment in generation like all other forms of investment. Capital supply is assumed to be a smooth increasing function of expected rates of return, which are set equal to current rates of return. Changes in generation capacity, however, are generally lumpy, not smooth, and investment decisions are forward looking, given long asset lives. TIMES allows for lumpy investments and for realistic lead times between investment and capacity change. It also allows for forward-looking expectations, which aligns more with real-world experience than does VURM's standard static assumption. The demand for electricity is exogenous in TIMES but when demand is endogenised by running TIMES linked to VURM, investment in the electricity sector is essentially driven by model-consistent expectations.
3. *Policy detail*. Currently, in Australia there are around 100 policies at the state, territory and federal levels affecting electricity generation and supply. These include market-based instruments to encourage increased use of renewable generation, regulations affecting the prices paid by final residential customers and regional policies that offer subsidies to attract certain generator types. Associated interactions and policy details are handled well in TIMES but are generally outside the scope of stand-alone modelling in VURM.
4. *Sector detail*. In VURM, electricity production is undertaken by symbolic industries – *Electricity-coal Victoria*, *Electricity-gas NSW*, etc. In TIMES, actual generation units are recognised – unit *x* in power station y located in region *z*. Thus, results from the detailed electricity model can be reported at a much finer level and in a way that industry experts fully understand. This adds to credibility in result reporting.

14.3.7 Abatement of non-combustion emissions

Non-combustion (or *Activity*) emissions include agricultural emissions (largely from animals), emissions from land-clearing or forestry, fugitive emissions (e.g. gas flaring), emissions from industrial processes (e.g. cement manufacture) and emissions from land-fill rubbish dumps. In modelling with VURM, it is assumed that in the absence of an emissions price, non-combustion emissions move with industry output, so that non-combustion emissions intensity (emissions per unit of output) is fixed.

VURM's theory of abatement of non-combustion emissions in the presence of an emissions price is similar to that developed for GTEM. It assumes that as the price of CO_2-eq rises, *targeted* non-combustion emissions intensity (emissions per unit of output) falls (abatement per unit increases) through the planned introduction of less emission-intensive technologies. More specifically, for *Activity* emitter *i* in region *q* it is assumed that abatement per unit of output can be achieved at an increasing marginal cost according to a curve such as that shown in Figure 14.1. In this figure, units are chosen so that complete elimination of non-combustion emissions corresponds to an abatement level of 1. However, complete elimination is not possible. So as shown in the figure, the marginal abatement cost goes to infinity as the abatement level per unit of output reaches a maximum level, 1-MIN, where MIN is the proportion of non-combustion emissions that cannot be removed. From Figure 14.1 , an intensity function for emissions can be derived of the form:

$$Intensity_{i,q} = MAX_{i,q}\left\{MIN_{i,q},\ F_{i,q}(T)\right\} \tag{4}$$

where:

- $Intensity_{i,q}$ is the target level of non-combustion emissions intensity
- $MIN_{i,q}$ is the minimum possible level of emissions intensity
- $F_{i,q}$ is a non-linear monotonic decreasing function of the real level of the emissions price, T ($ per tonne of CO_2-e in constant 2016 prices).

This is illustrated in Figure 14.2, which shows for a typical *Activity* the relationship between targeted emissions intensity and emissions price, with intensity indexed to 1 for T = 0.

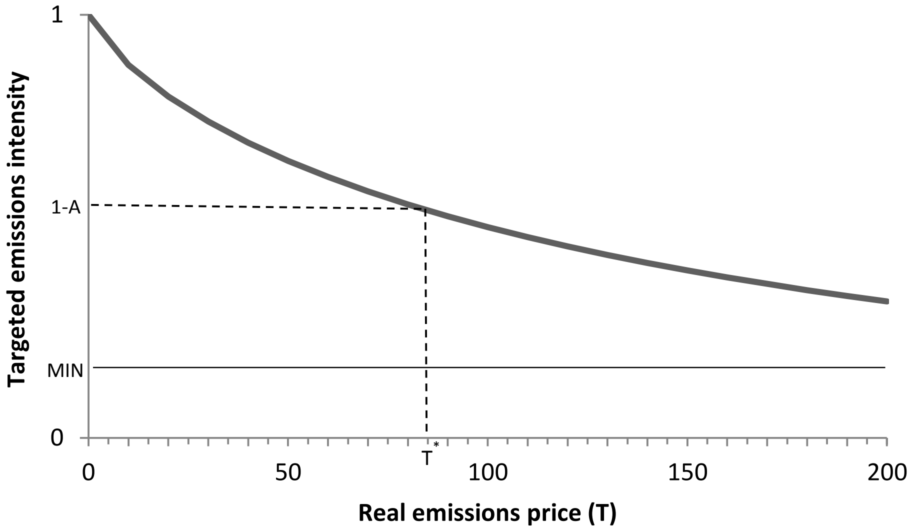

Figure 14.1 Marginal abatement cost curve for the hypothetical industry

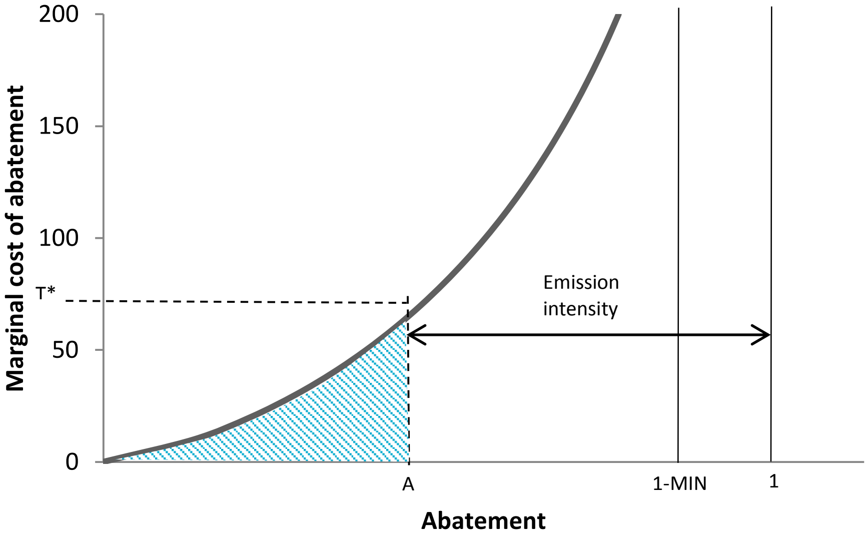

Figure 14.2 Emissions intensity as a function of the real carbon price

To ensure that emissions intensities do not respond too vigorously to changes in the emissions price, especially at the start of a simulation in which the price of CO_2-e rises immediately from zero, a lagged adjustment mechanism is also put in place, allowing actual emissions intensity to adjust slowly towards targeted emissions intensity specified by equation (4).

In VURM, the abatement cost per unit of output (the shaded area in Figure 14.1) is imposed as an all-input using technological deterioration in the production function of the abating industry.

14.3.8 Land use in forestry

In VURM, land is an input to production for the agricultural industries and forestry. For the projections in this report, land is considered region-specific but not industry-specific and there are regional supply constraints. This means that within a region, an industry can increase its land usage but that increase has to be met by reduced usage by other industries within the region. Land is assumed to be allocated between users to maximise the total return to land subject to a Constant Elasticity of Transformation (CET) constraint defining production possibilities across the various land-using sectors. This is the same treatment as adopted in GTAP and GTAP-ANO. With this mechanism in place, if demand for bio-sequestration offsets pushes up demand for land in the forestry sector, then forestry's use of land will increase, increasing the region-wide price of land and causing non-forestry industries to reduce their land usage and overall production.

14.4 General aspects of simulation design

14.4.1 Introduction

Using VURM, the Australian economy is projected forward with allowance for action directed at reducing GHG emissions. The projections start in 2016 and end in 2060. In the remainder of this section, the key inputs to the projections, and the main assumptions regarding the behaviour of the macroeconomy in the VURM modelling, are discussed.

14.4.2 Inputs

The main inputs to the VURM projections are:

- the emissions price covering CO_2 and non-CO_2 emissions, specified by CSIRO and applied world-wide in GTAP-ANO
- various aspects of electricity supply, as modelled by CSIRO's Electricity Supply Model (TIMES)
- vehicle use by vehicle type, as modelled by CSIRO
- land use in forestry and agriculture from CSIRO
- foreign-currency import prices and the positions of foreign export-demand schedules from GTAP-ANO modelling
- assumptions for autonomous energy efficiency, electrification, etc. from CSIRO
- aspects of the labour market, including national unemployment and labour-saving technological change by occupation and region from CSIRO
- changes in efficiencies of transport use in urban areas from CSIRO.

14.4.3 Emissions price and Australia's emissions target

The permit price (per tonne of CO_2-e) applied to Australian emissions is the global emissions price converted to Australian dollars as modelled in GTAP-ANO. Two basic scenarios for a global emissions target are considered. Both have a starting price in 2025 of around $20 per tonne of CO_2-e. One scenario has an emissions price progressively rising to restrain global emissions by 2060 to a level consistent with 4 ^{o}C warming. The other restrains global emissions to a level consistent with 2 ^{o}C warming. In the 4 ^{o}C world, the Australian price reaches around $120 per tonne in 2060. In the 2 ^{o}C world, the final price is around $220 per tonne.

The permit price is modelled as a tax imposed per unit of CO_2-e produced in Australia. It is imposed on all sources of emissions, including agriculture and transport. Initially, the price applied in some sectors is less than the full price to avoid modelling outcomes that are unrealistically large. However, from 2030 all emissions are priced at the same rate.

14.4.4 Electricity inputs from TIMES

TIMES provides projections for electricity generation, energy use, generation capacity, emissions and electricity prices. These projections are accommodated in the VURM modelling *via* a series of changes that essentially replace the existing modelling of electricity supply with TIMES results.

In TIMES, the electricity sector responds to the permit price by switching technologies, changing the utilisation of existing capacity, and replacing old plants with new more efficient plants. The modelling also includes changes in overall electricity usage projected in VURM's modelling of demand.

One of the most notable features of the numbers coming from the VURM/TIMES system is the increase in electricity usage even with deep decarbonisation action. This increase reflects changes in the relative price of energy products. In response to the CO_2-e price, electricity supply quickly adjusts by replacing fossil fuel generation with renewable generation. This allows the price of electricity to fall relative to the price of coal, gas and petroleum products. As electricity becomes relatively cheaper, end-users of energy, especially in the industrial, commercial and transport sectors, shift their demand away from coal, gas and petroleum products and towards electricity.

In TIMES, less CO_2-e intensive technologies for generating electricity from coal are adopted when the price on emissions makes it economical to do so. Steadily, the use of coal falls away as the price of emissions rise. Renewable generation takes nearly coal's entire share.

14.4.5 Road transport inputs from CSIRO

CSIRO provides data for growth in fuel use and emissions for road transport (private vehicles and commercial freight and passenger) by region. Projections for the use of each fuel type are accommodated in VURM by endogenous shifts in fuel-usage coefficients in the production functions of industries.

The CSIRO data show electric-powered vehicles taking significant market share away from vehicles relying on internal combustion technologies. The share of electric vehicles at the start of the period is negligible, but rises rapidly. This is a major factor explaining the increase in electricity usage overall, discussed in Section 14.4.4.

14.4.6 Land inputs from CSIRO

CSIRO's estimates of land used in forestry is accommodated in the VURM modelling via a combination of increased forestry production and endogenous shifts in sequestration per unit of forestry output. Corresponding changes in land under forestry are also imposed. When total land availability by region is fixed, land available for agriculture falls.

14.4.7 Trade variables based on information from GTAP-ANO

Projections for changes in the positions of foreign export-demand schedules for Australia are sourced from the GTAP-ANO modelling.

14.4.8 Assumptions for autonomous energy efficiency, electrification, etc.

VURM has a range of variables that allow for exogenous changes in overall energy usage and fuel shares by industry. For the ANO simulations, inputs from CSIRO were used to impose changes in:

- improvement of autonomous rates of energy efficiency in mining and manufacturing and in residential and commercial building
- rates of electrification of non-transport industry technologies – commercial, residential and industrial[6]
- rates of uptake of new forms of energy (notably, bioenergy).

The assumptions differ across time, energy source and industry for each scenario. Broadly, relative to business-as-usual, there are enhanced rates of improvement of autonomous energy, increased rates of electrification and faster uptake of bioenergy.

Two factors encourage industries to further substitute fossil fuels for electricity in their production processes. First, due to the price of CO_2, the price of electricity relative to the prices of natural gas and petroleum products drops. This puts in place an endogenous shift towards electricity by all users of energy. But more profound are exogenous changes to technologies directly imposed using CSIRO inputs. For example, two different processes can be used to produce steel: blast furnace (coke, oven-coal), using iron ore, and electric arc furnace (electricity), using scrap iron and steel. The second process consumes two to three times less energy than the first one. Based on information provided by CSIRO, the Australian steel making industry will shift from coal-based blast furnace operation to electric arc-furnace technologies and be fully electrified by 2040.

Electrification involves a cost – the cost of investing in the new technologies. In VURM the investment costs per unit of output are imposed as an all-input using technological deterioration in the production functions of the investing industries.

14.4.9 Aspects of the labour market and labour-saving technological change

Population changes over time and throughout a region are provided by CSIRO, and are consistent with the medium demographic projections of the Australian Bureau of Statistics. VURM has a fully

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[6] Electrification means the replacement of fossil-fuel energy with electricity energy, especially for process heat. In many applications, 1 Pj of electricity is equivalent to around 2 Pj from fossil fuel.

integrated demographic module that is able to trace numbers of persons (by gender) across age cohorts. Inputs to this module include birth and death rates, and levels of net foreign migration.

For the ANO modelling, VURM's demographic module is turned off, and population levels are exogenously determined in line with the CSIRO data.

It is assumed that the ratios of working-age population to population, and labour force to working-age population (the participation rate) do not change through the projection period. Thus, with population given, growth in the labour force is tied down. For each scenario, CSIRO provides data for the national unemployment rate. With the labour force determined, the employment rate can also be determined.

In addition to national employment (and indirectly employment by region), CSIRO provides inputs for labour-saving technological change by broad occupation category and region. This is a naturally exogenous variable, so there is no need to change the model's configuration to accept these numbers.

14.4.10 Change in urban transport efficiencies

Travel time costs, improvements in urban freight efficiency, agglomeration benefits and costs are key elements to several ANO scenarios. Information from CSIRO on these urban features is incorporated into the VURM modelling – generally through changes in labour-saving technological progress. For example, information from CSIRO suggests that people working in certain occupations in certain regions are spending progressively more or less time travelling to work. In the VURM modelling, the changes in travel time are translated into changes in labour productivity and the appropriate productivity variables, which are naturally exogenous to the model, are shocked.

14.4.11 Assumptions for the macroeconomy

The following assumptions were made for key aspects of the macroeconomy when progressively modelling the various scenarios.

Regional labour markets

At the regional level, labour is assumed mobile between state economies. Labour is assumed to move between regions to maintain inter-state unemployment-rate differentials. Accordingly, regions that are relatively favourably affected by exogenous changes across each of the alternative scenarios will experience increases (relative to business-as-usual trends) in their labour forces as well as in employment, at the expense of regions that are relatively less favourably affected.

Private consumption and investment

Private consumption expenditure is determined *via* a consumption function that links nominal consumption to household disposable income (HDI). HDI includes the lump-sum return of income raised by the permit price, which is part of the carbon-price scheme being modelled. For the ANO projections, the average propensity to consume (APC) is an endogenous variable that moves to ensure that the balance on current account in the balance of payments remains unchanged through the projection period. Thus, any change from business-as-usual trends in aggregate investment is accommodated by a change in domestic saving, leaving Australia’s call on foreign savings unchanged.

Government consumption and fiscal balances

VURM contains no theory to explain changes in real public consumption. In the projection, public consumption is simply indexed to nominal GDP. The fiscal balances of each jurisdiction (federal, state and territory) as a share of nominal GDP are fixed at their values in 2012. Endogenous movements in lump-sum payments to households accommodate budget-balance constraints.

Production technologies and household tastes

VURM contains many variables to allow for shifts in technology and household preferences. In the ANO scenarios, most of these variables are exogenous. The exceptions are technology variables that are made endogenous to allow for:

- changes in the fuel intensity of electricity generation, based on data from TIMES
- the new production technology required to achieve the reductions in emissions intensity implied required by the model’s emissions response functions.

14.5 References

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15 AUS-TIMES and ESM

Author: Luke Reedman

Model at a glance

	AUS-TIMES	ESM
Model summary	AUS-TIMES (Australian version of The Integrated MARKAL-EFOM System) is a partial equilibrium model of the Australian energy sector	ESM (Energy Sector Model) is a partial equilibrium model of the Australian energy sector
Key drivers model is sensitive to	• Passenger and freight demand growth • Global fuel prices • Projections of CO_2 prices • Cost and availability of low emission fuels	• Electricity demand • Global fuel prices • Projections of CO_2 prices • Cost and availability of electricity generation technologies
Key inputs	• Cost and performance characteristics of new vehicle technologies • Cost and availability of low emission fuels • Transport specific policies • Discount rate (currently assumed at 7% real based on The Office of Best Practice Regulation)	• Annual maximum (peak) electricity demand and electricity consumption • Cost and performance characteristics of electricity generation technologies • Cost and availability of fuels for electricity generation plant • Australian renewable energy policy (e.g. LRET, QRET, VRET) • Renewable resource supply (cost-quantity) curves • Discount rate (currently assumed at 7% real based on The Office of Best Practice Regulation)

15.1 Introduction

TIMES (The Integrated MARKAL-EFOM system) is a linear optimization energy model generator developed by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). The model satisfies energy services demand at the minimum total system cost, subject to physical, technological, and policy constraints. Accordingly, the model makes simultaneous decisions regarding technology investment, primary energy supply and energy trade. Extensive documentation of the TIMES model generator is available in Loulou et al. (2016).

CSIRO has created an Australian version of the TIMES model (AUS-TIMES). For the national outlook project, the energy sector modelling has used the AUS-TIMES model for the transport sector, and the Energy Sector Model (ESM) for the electricity sector.

The Energy Sector Model (ESM) is a partial equilibrium model of the Australian energy sector that has been developed by CSIRO over many years. The model satisfies energy services demand at the minimum total system cost, subject to physical, technological, and policy constraints. Accordingly, the model makes simultaneous decisions regarding technology investment, primary energy supply and energy trade.

For the national outlook project, the energy sector modelling has used the Energy Sector Model (ESM) for the electricity sector, and the AUS-TIMES model for transport.

15.2 Model description

15.2.1 AUS-TIMES

The transport module of the AUS-TIMES model has the following structural features:

- Coverage of all states and territories (ACT, NSW, NT, QLD, SA, TAS, VIC, WA)
- Ten road transport modes: motorcycles, small, medium and large passenger cars; small, medium and large light commercial vehicles; rigid trucks; articulated trucks and buses
- Five engine types: internal combustion engine; hybrid electric/internal combustion engine; hybrid plug-in electric/internal combustion engine; fully electric, and fuel cell
- Fourteen road transport fuels: petrol; diesel; liquefied petroleum gas (LPG); natural gas (compressed (CNG) or liquefied (LNG)); petrol with 10% ethanol blend (E10); diesel with 20% biodiesel blend (B20); ethanol and biodiesel at high concentrations; gas to liquids diesel; coal to liquids diesel with upstream CO_2 capture; shale to liquids diesel with upstream CO_2 capture, hydrogen (from renewables) and electricity
- All vehicles are assigned a vintage based on when they were first purchased or installed in annual increments
- Non-road transport is segmented into aviation, rail and shipping
- Time is represented in annual frequency (2015-2020) and then five-year time steps (2020, 2025, …, 2060).

15.2.2 ESM

The electricity module of ESM has the following structural features:

- Coverage of all states and territories (the Australian Capital Territory is modelled as part of NSW)
- 22 centralised generation (CG) electricity plant types: black coal pulverised fuel; black coal integrated gasification combined cycle (IGCC); black coal with CO_2 capture and sequestration (CCS) (90 per cent capture rate); brown coal pulverised fuel; brown coal IGCC; brown coal direct injection coal engine; brown coal with CCS (90 per cent capture rate); natural gas combined cycle; natural gas peaking plant; natural gas with CCS (90 per cent capture rate); biomass; hydro; onshore wind; offshore wind; large-scale photovoltaic (PV); solar thermal; solar thermal with 6 hours storage; integrated solar and gas; hot fractured rocks (geothermal), wave, ocean current and nuclear
- 17 distributed generation (DG) electricity plant types: internal combustion diesel; gas reciprocating engine; gas turbine; gas micro turbine; gas combined heat and power (CHP); gas micro turbine CHP; gas micro turbine with combined cooling, heat and power (CCHP); gas reciprocating engine CCHP; gas reciprocating engine CHP; solar photovoltaic; bagasse CHP; biomass steam; biogas reciprocating engine; landfill gas reciprocating engine; wind; natural gas fuel cell CHP and hydrogen fuel cell CHP

- Trade in electricity between National Electricity Market (NEM) regions
- Four electricity end-use sectors: industrial; commercial & services; rural and residential
- All centralised electricity generation plants are assigned a vintage based on when they were first purchased or installed in annual increments; and
- Time is represented in annual frequency (2015, 2016, …, 2060).

15.3 Method

15.3.1 AUS-TIMES

The TIMES model generator is a partial equilibrium model of the energy sector. In the energy domain, partial equilibrium models, sometimes referred to as 'bottom-up' models, were initially developed in the 1970s and 1980s (e.g. Manne, 1976; Hoffman and Jorgenson, 1977; Fishbone and Abilock, 1981). Partial equilibrium models are used because the analysis of energy and environmental policy requires technological explicitness; the same end-use service (e.g. space heating, lighting) or end-use fuel (e.g., electricity, transport fuel) can often be provided by one of several different technologies that use different primary energy resources and entail different emission intensities, yet may be similar in cost (Greening and Bataille, 2009).

Partial equilibrium modelling incorporates various technologies associated with each supply option and allows a market equilibrium to be calculated. It allows for competing technologies to be evaluated simultaneously, without any prior assumptions about which technology, or how much of each, will be used. Some technologies may not be taken up at all. This allows flexibility in the analysis: detailed demand characteristics, supply technologies, and additional constraints can be included to capture the impact of resource availability, industry scale-up, saturation effects and policy constraints on the operation of the market.

15.3.1.1 Model inputs

AUS-TIMES has been calibrated to a base year of 2015 based on the latest available energy balance (OCE 2016), national inventory of greenhouse gas emissions (DoEE, 2017b) and stock estimates of vehicles in the transport sector (ABS, 2016). Cost and performance data on future technologies are mainly sourced from Reedman and Graham (2016) and Graham et al. (2018).

For given time paths of the exogenous (or input) variables that define the economic environment, AUS-TIMES determines the time paths of the endogenous (output) variables. Table 15.1 summarises the key input variables and data sources for the base year calibration of AUS-TIMES.

Table 15.1 Key model inputs and data sources for base year calibration of AUS-TIMES

Model input	Data sources
Energy balance	*Australian Energy Statistics 2017* (DoEE, 2017a)
Vehicle stock, scrapping rate	*ABS Catalogue No. 9309.0 - Motor Vehicle Census, Australia, 31 Jan 2016* (ABS, 2016)
Average vehicle kilometres travelled	*ABS Catalogue No. 9208.0 - Survey of Motor Vehicle Use, Australia, 12 months ended 30 June 2016* (ABS, 2017)
Activity growth in passenger and freight	Victoria University Regional Model (VURM)
GHG emission factors	*National Greenhouse Accounts Factors* (DoEE, 2017b)
Vehicle costs (capital, maintenance)	ABMARC (2016); NRMA; Graham et al. (2014); EIA (2016); ATAP (2016); RACQ (2018)
Registration, insurance costs	State/territory government websites
Vehicle fuel efficiency	ABMARC (2016)
Retail fuel price components	Australian Institute of Petroleum
Fuel excise rates	Australian Taxation Office
Biofuel mandates	NSW - *Biofuel (Ethanol Content) Act 2007*, historical take-up of ethanol and biodiesel is from the *Office of Fair Trading*. QLD - The *Liquid Fuel Supply (Ethanol and Other Biofuels Mandate) Amendment Act 2015*
Biofuel availability	Land-use trade-off (LUTO) model

15.3.1.2 Objective function

Using the inputs described above, the ultimate objective of the AUS-TIMES model is the satisfaction of the demand for transport services at minimum cost. For this, AUS-TIMES is simultaneously making decisions on equipment investment and operation; primary energy supply; and energy trade between regions, according to the following equation:

$$NPV = \sum_{r=1}^{R} \sum_{y \in years} (1 + d_y)\, REFYR - y.\, ANNCOST(r, y)$$

$$NPV = \sum_{r=1, y=REFYR}^{R,2060} \frac{ANNCOST_{r,y}}{(1 + d)^{(y-REFYR)}}$$

Where:

NPV: net present value of the total costs

ANNCOST: Total annual cost incorporating investment, operation and trade (where relevant relevant)

d: general discount rate

REFYR: reference year for discounting

YEARS: set of years for which there are costs

R: region

The choice by the model of the vehicle technology (type and fuel) is based on the analysis of the characteristics of alternative vehicle technologies, on the economics of the energy supply, and on environmental criteria. For non-road transport segments, engine technologies are not defined but rather fuel choices are made on the basis of relative fuel costs, the transport markets served (passenger or freight) and expected changes in fuel efficiency over time.

AUS-TIMES is thus a vertically integrated model of the entire extended energy system.

15.3.1.3 Model outputs

Key output variables include:

- Activity (vehicle kilometres travelled) by road transport mode
- Investment and vehicle stock by road transport mode
- Fuel mix and engine technology uptake
- Fuel consumption
- Price of domestic fuels after local and imported inputs and taxes
- GHG emissions (carbon dioxide, methane and nitrous oxides).

Example model outputs at the national resolution for transport are shown below.

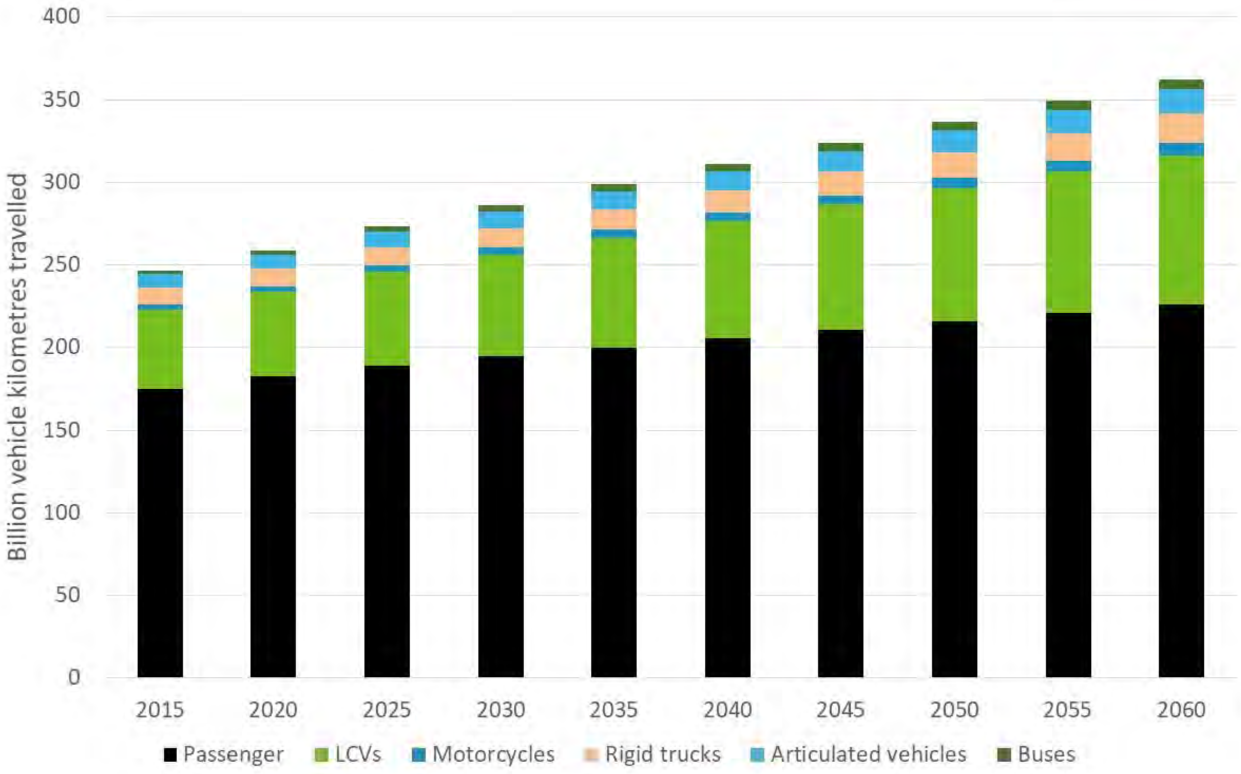


Figure 15.1 Activity by road vehicle class, selected years, *Slow Decline*

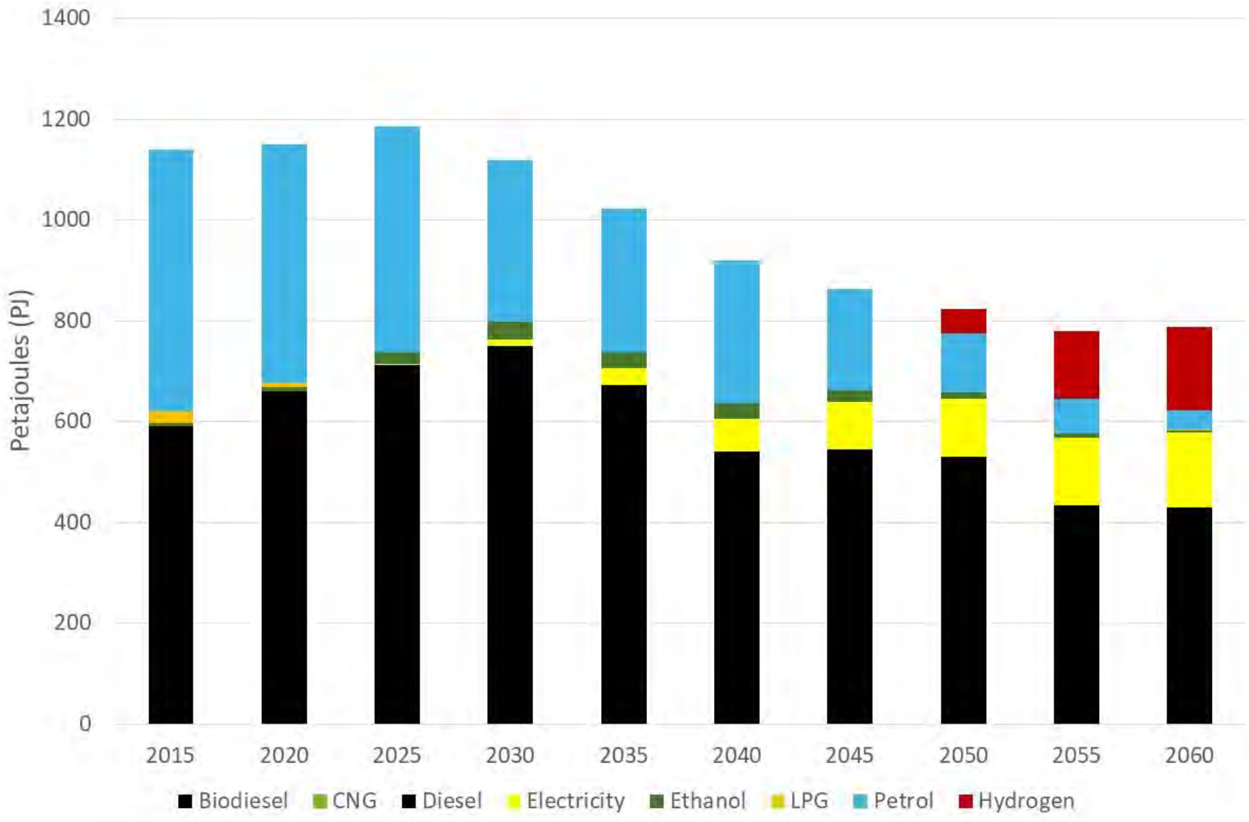


Figure 15.2 Fuel use by road transport, selected years, *Slow Decline*

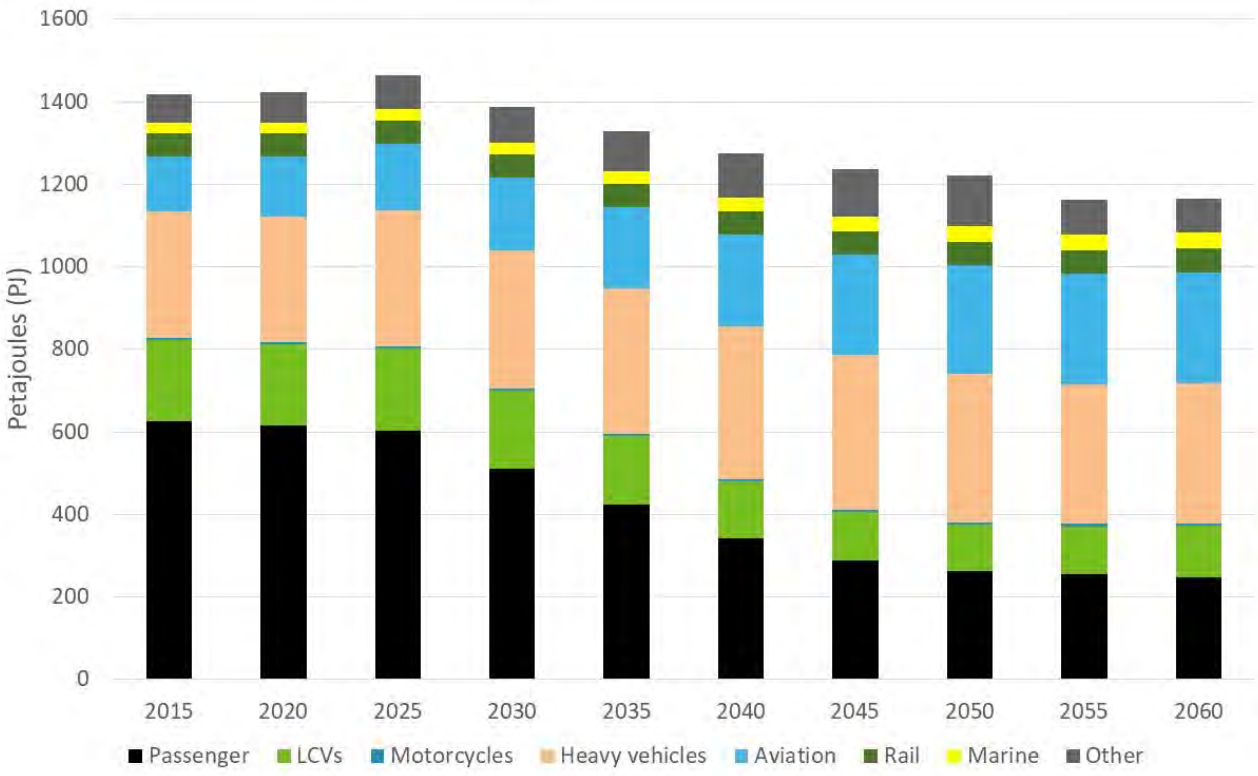


Figure 15.3 Domestic fuel use by transport mode, selected years, *Slow Decline*

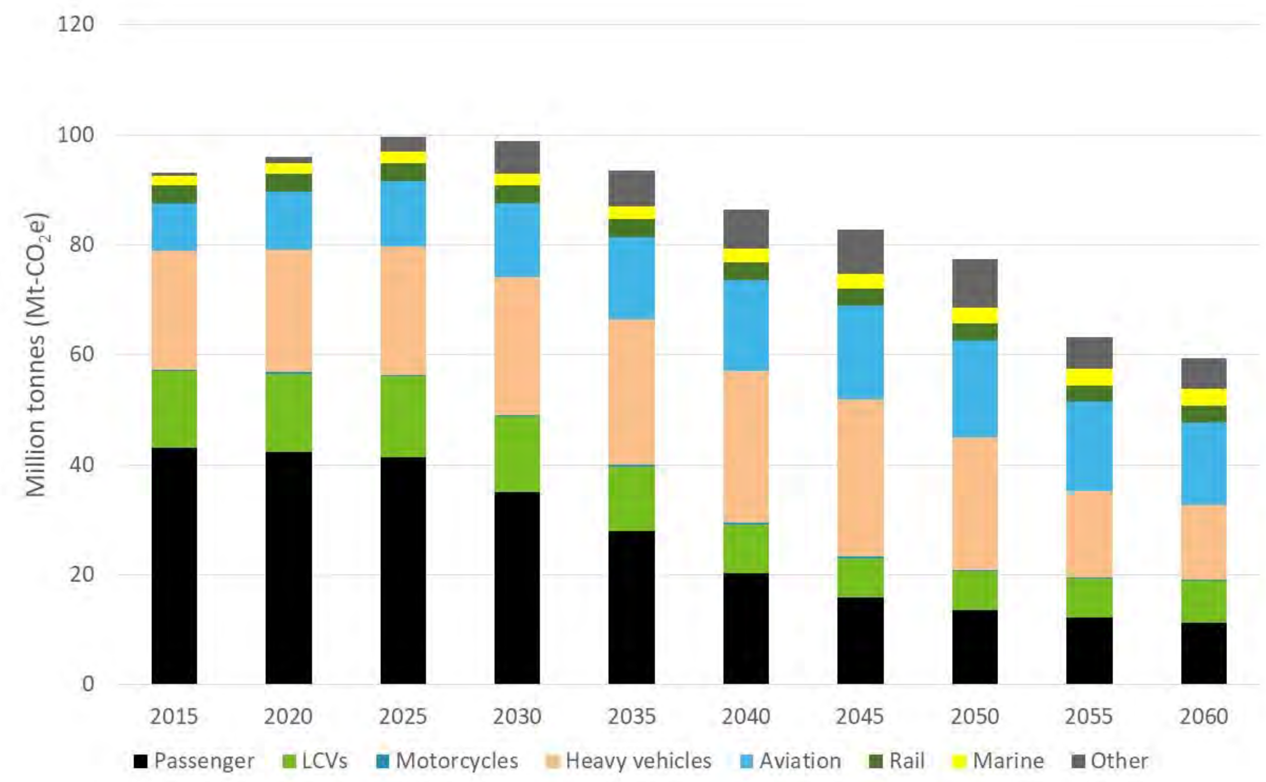


Figure 15.4 Domestic GHG emissions by transport mode, selected years, *Slow Decline*

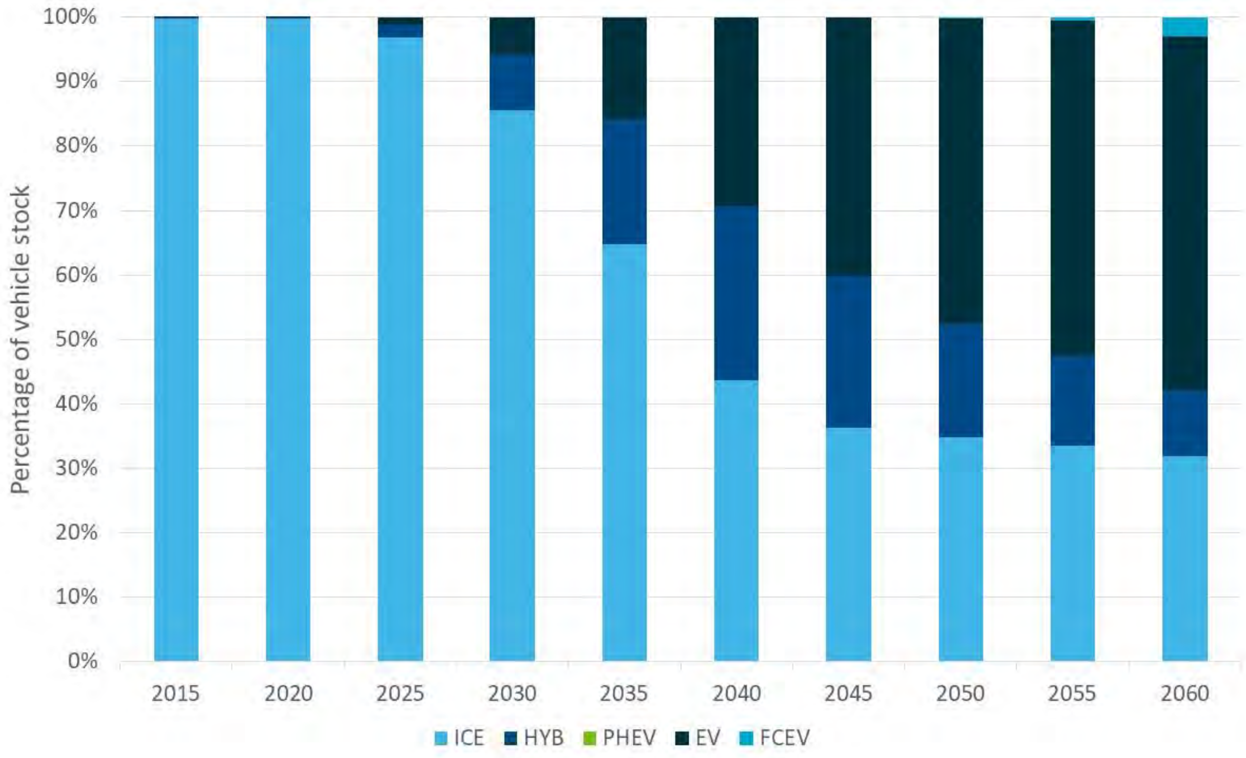


Figure 15.5 Vehicle investment by engine type, selected years, *Slow Decline*

15.3.1.4 Limitations

As a partial equilibrium model, AUS-TIMES does not model the economic interactions outside of the energy sector. However, the macro-economic feedback between the economy and energy systems is considered through soft-linking with VURM (see Chapter 14). Moreover, it does not consider in detail the mathematical formulation underlying demand curves functioning and non-rational aspects that condition investment in new and more efficient technologies. Such issues have to be dealt with via exogenous constraints to represent non-rational decisions.

The most powerful aspect of AUS-TIMES is that it is able to provide economically consistent projections of road sector fuel and vehicle choices (and non-road transport fuel choices) across a range of given scenarios. Projections can be logically understood as economic choices within a set of physical constraints. As with all models, the approach has some limitations which are discussed below.

The first is that it includes many assumptions for parameters that are in reality uncertain and in some cases evolving rapidly. Parameters with the greatest uncertainty include possible breakthroughs in so-called “second or advanced generation” biofuel production technologies and the unknown quality and cost of future offerings of fully and partially electrified vehicles and fuel cell vehicles.

A second limitation places a strong emphasis on cost in determining technology and fuel uptake. Too much emphasis on cost can overlook the behaviour of so-called “fast adopters” who take up new technology before it has reached a competitive price point. For example, most consumers of hybrid and electric vehicles today could be considered “fast adopters.” Their purchase cannot be justified on economic grounds since the additional cost of such vehicles is not offset by fuel savings in a reasonable period of time (relative to the cost of borrowing). Nevertheless, hybrid and electric vehicles are purchased and such purchasers may be motivated by a variety of factors including a strong interest in new technology, the desire to reduce emissions or status. As a result of this limitation, AUS-TIMES’s projections of the starting point for shifts in preferences for new technologies could be considered conservative.

Another factor which AUS-TIMES can overlook due to its strong emphasis on cost is community acceptance. This limitation might lead AUS-TIMES to overestimate the rate of uptake of some fuels and technologies. For example, greater use of gaseous fuels such as natural gas and the introduction of electricity as a transport fuel might be resisted by the Australian community which has predominantly used liquid fuels for transport over the past century.

These two examples indicate the potential for AUS-TIMES to both under or overestimate technology uptake by overlooking some factors while emphasising cost effectiveness. These limitations can be, and often are, partially corrected by adding further user defined assumptions and constraints. For example, in a recent project, we projected the uptake of electric vehicles via an alternative method using a payback calculation and consumer adoption curve (see Graham et al., 2018). For the national outlook, we have compared these results and the differences are not large overall and depend on the stage of adoption and type of vehicle.

15.3.2 ESM

ESM is a partial equilibrium model of the energy sector. In the energy domain, partial equilibrium models, sometimes referred to as 'bottom-up' models, were initially developed in the 1970s and 1980s (e.g., Manne, 1976; Hoffman and Jorgenson, 1977; Fishbone and Abilock, 1981). Partial equilibrium models are used because the analysis of energy and environmental policy requires technological explicitness; the same end-use service (e.g. space heating, lighting) or end-use fuel (e.g., electricity, transport fuel) can often be provided by one of several different technologies that use different primary energy resources and entail different emission intensities, yet may be similar in cost (Greening and Bataille, 2009).

Partial equilibrium modelling incorporates various technologies associated with each supply option and allows a market equilibrium to be calculated. It allows for competing technologies to be evaluated simultaneously, without any prior assumptions about which technology, or how much of each, will be used. Some technologies may not be taken up at all. This allows flexibility in the analysis: detailed demand characteristics, supply technologies, and additional constraints can be included to capture the impact of resource availability, industry scale-up, saturation effects and policy constraints on the operation of the market.

All technologies are assessed on the basis of their relative costs subject to constraints such as the turnover of capital stock, existing or new policies such as subsidies and taxes. The model aims to mirror real world investment decisions by simultaneously taking into account:

- The requirement to earn a reasonable return on investment over the life of a plant
- That the actions of one investor or user affects the financial viability of all other investors or users simultaneously and dynamically
- That the consumption of energy resources by one user affects the price and availability of that resource for other users, and the overall cost of energy services, and
- Energy market policies and regulations.

The model projects uptake on the basis of cost competitiveness but at the same time takes into account constraints on the operation of energy markets, current pricing structures, GHG emission limits, existing plant stock in each State, and lead times in the availability of new plant. It does not take into account issues such as community acceptance of technologies but these can be controlled by imposing various scenario assumptions which constrain the solution to user provided limits.

15.3.2.1 Model inputs

ESM has been calibrated to a base year of 2015 based on the latest available energy balance (OCE, 2016), national inventory of greenhouse gas emissions (DoEE, 2017b), data on the existing power generation fleet (ACIL Allen, 2014a; 2014b; AEMO, 2015; ESAA, 2016) and installed capacity of distributed generation (CER 2018, AEMO 2018). Cost and performance data on future technologies are mainly sourced from GALLM.

For given time paths of the exogenous (or input) variables that define the economic environment, ESM determines the time paths of the endogenous (output) variables. Table 15.1 summarises the key input variables and data sources for the base year calibration of ESM.

Table 15.2 Key model inputs and data sources for base year calibration of ESM

MODEL INPUT	DATA SOURCES
Energy balance	Australian Energy Statistics 2017 (DoEE, 2017a)
Annual electricity consumption	Victoria University Regional Model (VURM)
Nameplate capacity of existing generators	NEM Registration and Exemption List (AEMO, 2018)
Cost and performance data on existing power stations	ACIL Allen (2014a, 2014b), AEMO (2015,2016a), ESAA (2016)
Installed capacity of distributed generation	NEM Registration and Exemption List (AEMO, 2018); Postcode data for small-scale installations (CER, 2018)
GHG emission factors	National Greenhouse Accounts Factors (DoEE, 2017b)
Future electricity generation technology costs (capital, maintenance)	Global And Local Learning Model (GALLM)
Performance characteristics on new electricity generation technologies	BREE (2013), CO2CRC (2015), Brinsmead et al. (2015), AEMO (2016a), Global And Local Learning Model (GALLM)
Wholesale electricity prices by region	AEMO (2016b)
Retail price structures	AEMC (2016; 2017), ACCC (2018)
Renewable resource availability	AEMO (2012)
Renewable policies (national)	Renewable Energy Target (RET) consisting of: large-scale RET (LRET): 33,000 GWh of large-scale renewables, so that 23.5% of Australia's electricity in 2020 will be generated from renewables (33,000 GWh maintained until 2030). Small-scale renewable energy scheme (SRES): incentives for home-owners and small businesses to install eligible small-scale renewable energy systems and solar water-heating systems.
Renewable policies (state)	Queensland Renewable Energy Target (QRET): 50% renewable electricity generation by 2030 Victoria Renewable Energy Target (VRET): 25% renewable electricity generation by 2020; 40% renewable electricity generation by 2025.

15.3.2.2 Objective function

Using the inputs described above, the ultimate objective of ESM is the satisfaction of the demand for electricity at minimum cost. For this, ESM is simultaneously making decisions on equipment investment and operation; primary energy supply; and energy trade between regions, according to the following equation:

$$NPV = \sum_{r=1}^{R} \sum_{y \in years} (1+d)\, REFYR - y.\, ANNCOST(r,y)$$

Where:

NPV: net present value of the total costs

ANNCOST: Total annual cost

d: general discount rate

REFYR: reference year for discounting

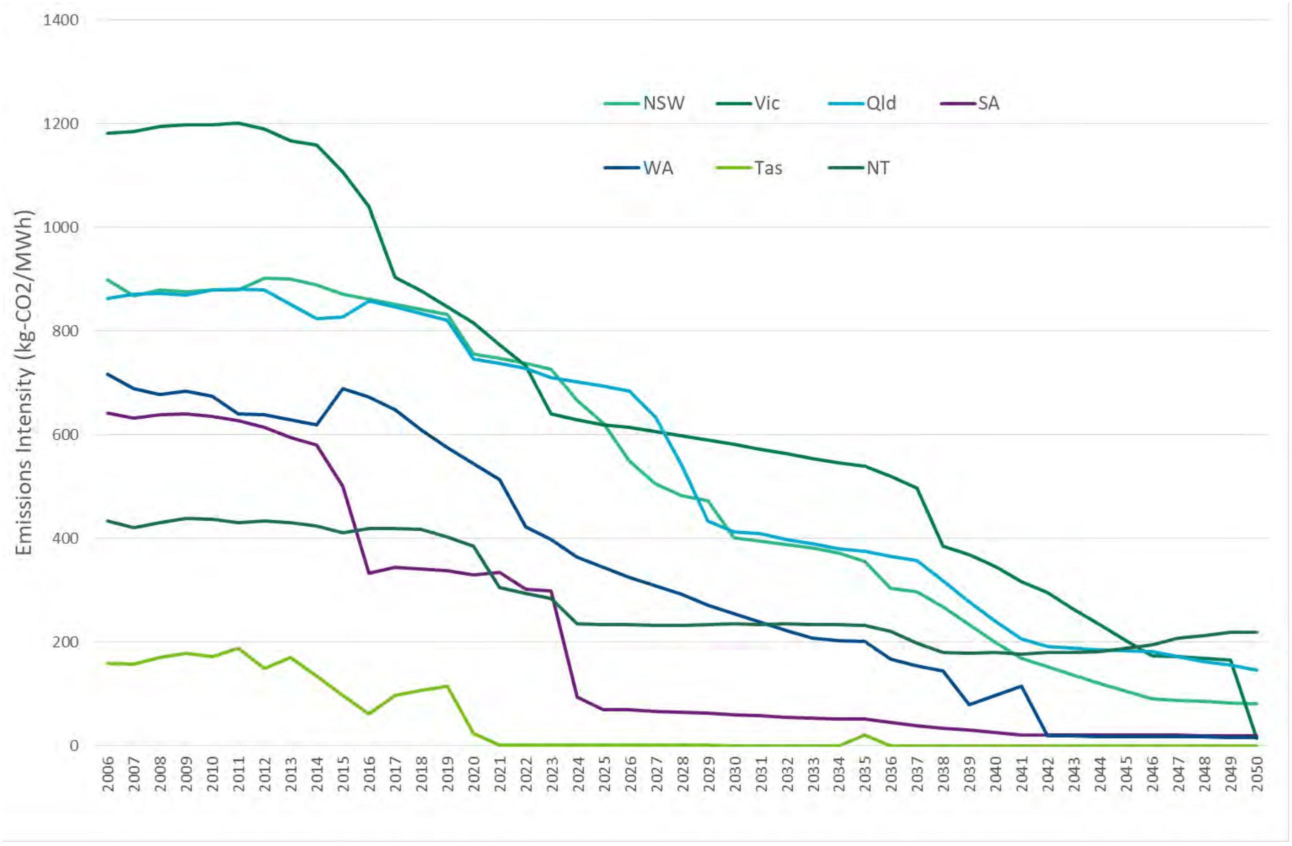
YEARS: set of years for which there are costs

R: region

The choice by the model of the electricity generation technology (type and fuel) is based on the analysis of the characteristics of alternative electricity generation technologies, on the economics of the energy supply, renewable policies, and on environmental criteria.

Key output variables include:

- Electricity supply by technology, by state/ territory. (see Figure 15.9)
- Electricity consumption by state/territory by end-user grouping (industrial; commercial & services; rural and residential) by year
- Maximum electricity demand by state/territory by year
- Investment and stock of electricity generation plant by technology by state/territory by year
- Fuel consumption in electricity generation
- Average cost of wholesale electricity by year (see Figure 15.8)
- Retail electricity cost by year
- GHG emissions (carbon dioxide-equivalent, Figure 15.6 and



- Figure 15.7)

Example model outputs at the national scale for electricity are shown below.

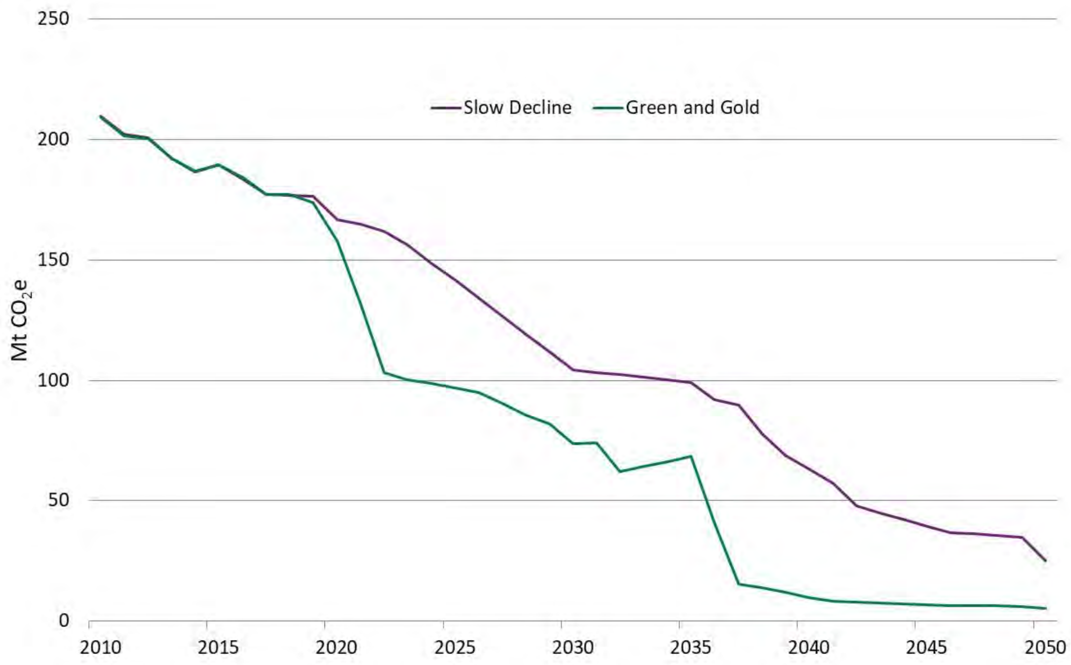


Figure 15.6 Greenhouse emissions projections from the electricity sector ESM (typical output)

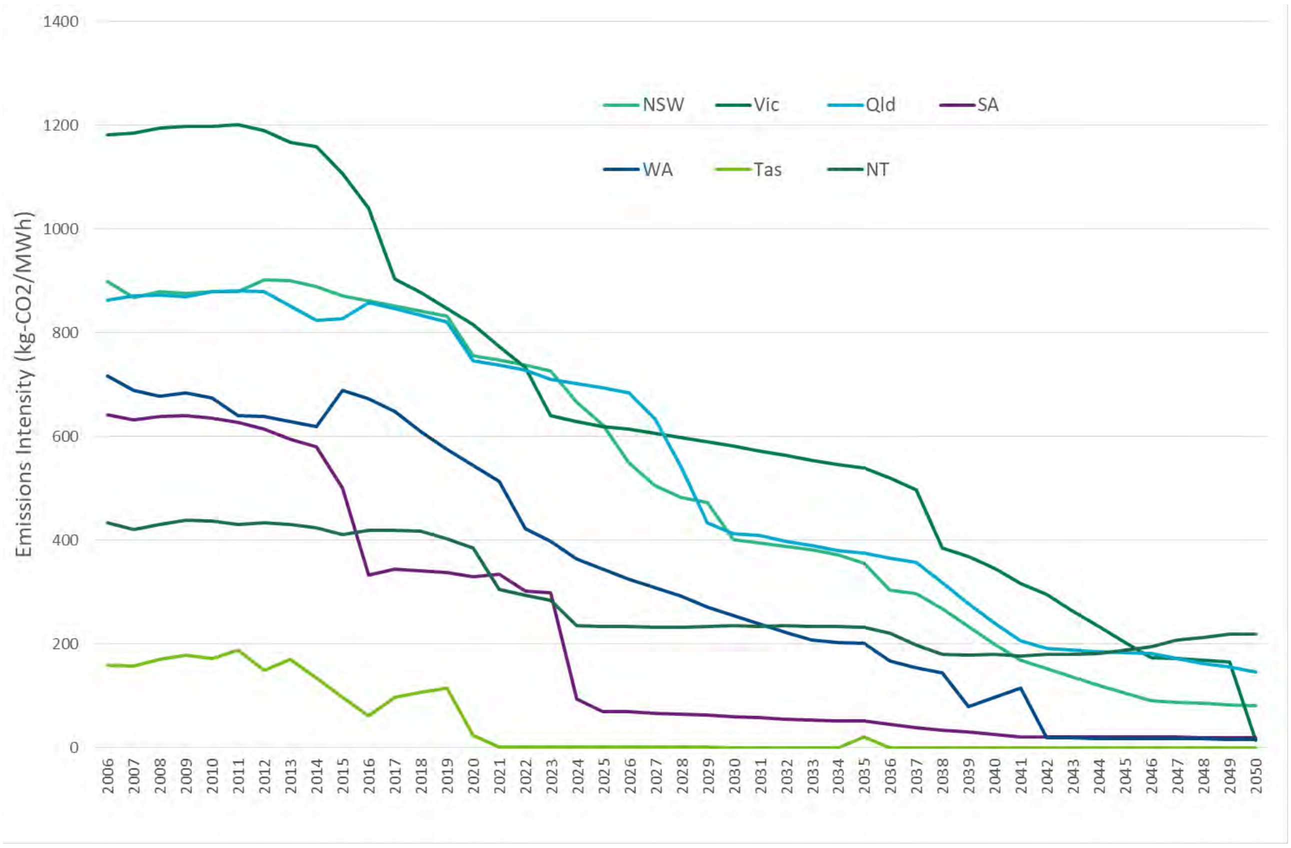


Figure 15.7 Greenhouse emissions intensity from the electricity sector by state ESM (typical output)

Figure 15.8 Five yearly average levelised cost of electricity generation ESM (typical output)

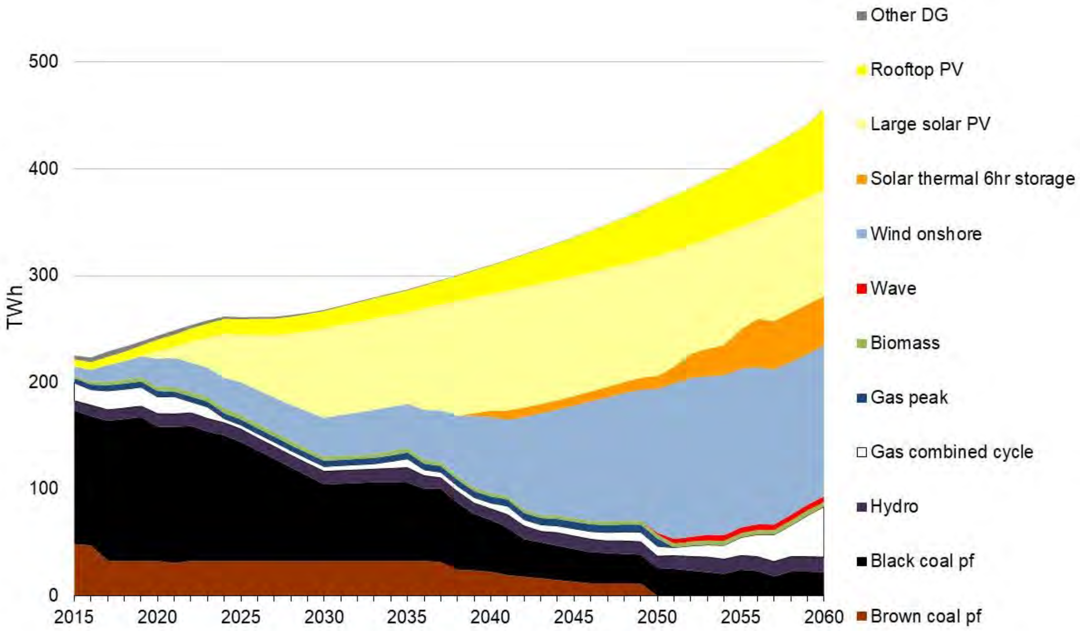


Figure 15.9 Technology mix electricity generation ESM (*Slow Decline* – above, Outlook Vision - below)

15.3.2.3 Additional price calculations using DiSCoM

ESM produces wholesale electricity cost estimates. However, we are often interested in retail price estimates since it is the retail price which is faced by end-users and it represents the cost of the system as a whole (generation, transmission, distribution, and retail). To determine retail electricity prices we employ CSIRO's Distribution System Costing Model (DiSCoM). DiSCoM is a model which measures over time the change in the capacity of approximately 1800 zone substations and calculates the necessary augmentation and replacement investments to meet the growth in demand and maintain the necessary headroom for reliability purposes. Based on the existing financial asset base of each network region and its future expenditure DiSCoM projects the future distribution price. Additional detail on DiSCoM formulation and assumptions are available in Graham et al. (2013) and Graham et al. (2015).

When distribution system costs are combined with the wholesale price, some additional assumptions about transmission charges and retailer margin, the sum of these costs represents an estimate of the retail price. Retail prices differ by customers and by tariff and we use historical conventions to share these costs between customers and tariff types. Note that, the costs faced by a customer might also depend on their exposure to the grid which might be reduced by the presence of on-site generation such as rooftop solar.

15.3.2.4 Limitations

As a partial equilibrium model, ESM does not model the economic interactions outside of the energy sector. However, the macro-economic feedback between the economy and energy systems is considered through soft-linking with VURM (see Chapter 14). Moreover, it does not consider in detail the mathematical formulation underlying demand curves functioning and non-rational aspects that condition investment in new and more efficient technologies. Such issues have to be dealt with via exogenous constraints to represent non-rational decisions.

The most powerful aspect of ESM is that it is able to provide economically consistent projections of electricity generation technology choices (and by implication fuel choices) across a range of given scenarios. Projections can be logically understood as economic choices within a set of physical constraints. As with all models, the approach has some limitations which are discussed below.

The first is that it includes many assumptions for parameters that are in reality uncertain and in some cases evolving rapidly. Parameters with the greatest uncertainty include the future cost of low emission electricity generation technologies. These are an input assumption from GALLME.

Another factor which ESM can overlook due to its strong emphasis on cost is community acceptance. This limitation might lead ESM to overestimate the rate of uptake of some technologies. For example, the deployment of nuclear generation is possible in the model solution although nuclear power is currently prohibited by legislation.

These two examples indicate the potential for ESM to under- or overestimate technology uptake by overlooking some factors while emphasising cost effectiveness. These limitations can be, and often are, partially corrected by adding further user defined assumptions and constraints. These include constraints on technology availability or deployment rate. An example is that the rate of adoption of rooftop solar can be imposed as an assumption rather than a model output given investment in rooftop solar is driven by a number of non-cost factors.

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16 LUTO

Author: Martin Nolan

Model at a glance

Model summary	LUTO (Land Use Trade-Offs) is a spatially detailed model that calculates the relative profitability of a wide range of potential Australian rural land uses. For more details see Bryan et al. (2014).
Key ANO scenario drivers	• projection of CO_2 prices (source: IPCC and CSIRO) • prices for agricultural (crop and livestock) commodities and energy (from GLOBIOM and emulator, VURM, AUSTIMES and ESM) • demand for biofuels (from AUSTIMES) • climate projections (temperature and rainfall) downscaled from an ensemble of four general circulation models • biodiversity levy and biodiversity priorities.
Key inputs and assumptions	• spatially explicit production and profitability data of observed land uses in a baseline year • agricultural yield productivity projections based on historical trajectories • modelled tree CO_2 sequestration rates, establishment costs and water interceptions • agricultural sector financial discount rate • productivity (agricultural output).

16.1 Introduction

This chapter provides a brief model overview before focusing on modifications implemented for the Australian National Outlook 2019. For a detailed description of the Land Use Trade-Offs (LUTO) model see Connor et al. (2015) and Bryan et al. (2014).

16.2 Model description

LUTO is a spatially detailed rural land use change model for Australia. It combines data on agricultural land use, production functions, prices, costs and physical variables to estimate the profitability of a range of existing and potential land uses (Table 16.1). At each location in the study area, for each year, a decision is made to change to the most profitable land use or stay with the current land use. These decisions are subject to capacity constraints, permanence requirements and uptake lags. The impacts of these land use decisions on economic returns to land, food-fibre-fodder production, greenhouse gas (GHG) emissions, carbon sequestration, energy production, water use and biodiversity are then quantified and reported.

Table 16.1 New land use choices

Potential land use	Description
Carbon plantings	Monoculture species receive payments for carbon sequestration and have a 100-year permanence period
Environmental plantings	Mixed species receive payments for carbon sequestration or carbon sequestration plus biodiversity and have a 100-year permanence period
Wheat biofuels	Wheat grain processed to produce ethanol using standard first generation fermentation processes and crop residue processed to produce ethanol using second-generation biochemical conversion processes
Wheat food/biofuels	Wheat grain sold into the food market, residue used to produce ethanol using second-generation biochemical conversion processes
Wheat food/bioenergy	Wheat grain sold into the food market, residue burned to produce renewable electricity via biomass steam generation processes
Woody perennials biofuels	Biomass from short-rotation Eucalyptus species used to produce ethanol using second-generation biochemical conversion processes
Woody perennials bioelectricity	Biomass from short-rotation Eucalyptus species burned to produce renewable electricity via biomass steam generation processes

16.3 Method

Rural land use decisions are modelled in LUTO using optimisation algorithms. For ANO 2019, LUTO runs as a constrained profit maximisation algorithm, with variables used in profit calculations, such as price paths for agricultural commodities, energy and carbon, provided by other ANO 2019 model components. These exogenous variables define alternative futures under each ANO 2019 scenario. Constraints on overall biofuel and bioelectricity production capacity, available biodiversity funds, social lags in uptake and constraints on water use impact the extent and timing of land use change.

16.3.1 Model inputs

In addition to the scenario-specific exogenous variables, the LUTO model inputs consist of spatial datasets and non-spatial parameters used in the calculation of land use profitability and for impact assessment. LUTO takes at its starting point a subset of the national land use mapping of agricultural profitability (Marinoni et al., 2012), which was modified to provide an estimate of average profitability over the period 1996–2006. The subset being the 85 Mha of cleared land, as defined by the National Vegetation Information System (ESCAVI, 2003), in the south-west, south and eastern states of Australia. The spatial resolution is approximately 1.1 km.

Other key input spatial datasets provide estimates of:

- monoculture and mixed species plantings rates of growth
- grain and stubble yields for biofuel and bioelectricity
- woody perennials biomass for biofuel and bioelectricity
- plantation establishment costs
- tree water interceptions
- biodiversity priority.

Figure 16.1 provides examples of some of the 56 spatial layers used in LUTO.

16.3.2 Productivity assumptions

The productivity paths used in the Australian National Outlook (ANO) 2015 (CSIRO, 2015) were also relied upon for the ANO 2019. The recent trend path assumes a simple 1.25% increase per annum in agricultural output and the above trend path assumes a simple 3.0% increase per annum in agricultural output.

The ANO 2015 assumptions about the potential for increases in carbon plantings productivity were also made for ANO 2019, with a simple 0.467% increase per annum in maximum growth achieved for the recent trend and 1.0% for the above trend. These increases were implemented at the year of planting for carbon monocultures only, and reflect a potential for genetic advances.

The recent and above trend productivity paths provide a lower and upper bound for which the future is expected to be positioned.

16.3.3 Climate impact modelling

Future climate impacts on agricultural production and tree growth were assessed using four global circulation model (GCM) projections corresponding to two representative concentration pathways (RCP 2.6 and 6.0) (van Vuuren et al., 2011). The RCP 2.6 is used in ANO 2019 for the 2 °C world temperature increase scenarios and the RCP 6.0 for the 4 °C increase scenarios.

The four GCMs are in the collection of eight GCMs used by *Climate Change in Australia* for application-ready data (CSIRO and Bureau of Meteorology, 2015; Whetton et al., 2012) and were chosen as they have outputs for both RCP 2.6 and RCP 6.0. These GCMs are CESM1-CAM5, GFDL-ESM2M, MIROC5 and NorESM1-M (see CSIRO (2017)).

GCM climate futures

Raw GCM annual outputs, which provide annual changes in surface temperature and precipitation with respect to 1986–2005 averages, were processed as follows. The 20-year mean for each location and adjacent locations, for each year, was calculated to provide an average change. Figure 16.2 provides an example and plots these values of absolute change in temperature and percentage change in precipitation for ten locations across Australia. A spline interpolation was then performed and these resulting surfaces (Figure 16.3 and Figure 16.4) were used as input to the climate impacts modelling for the period 2017–2060.

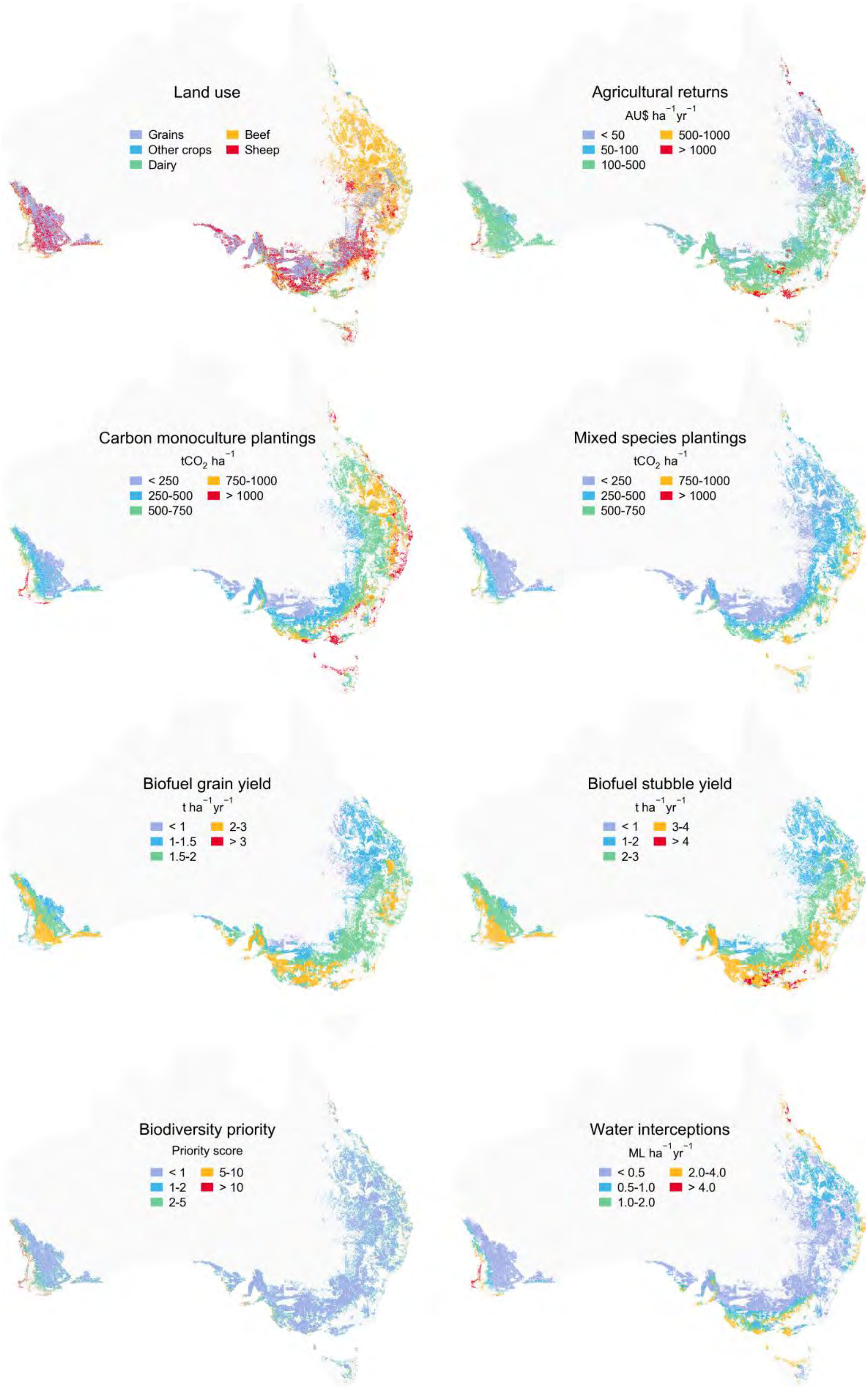


Figure 16.1 Example of spatial layers

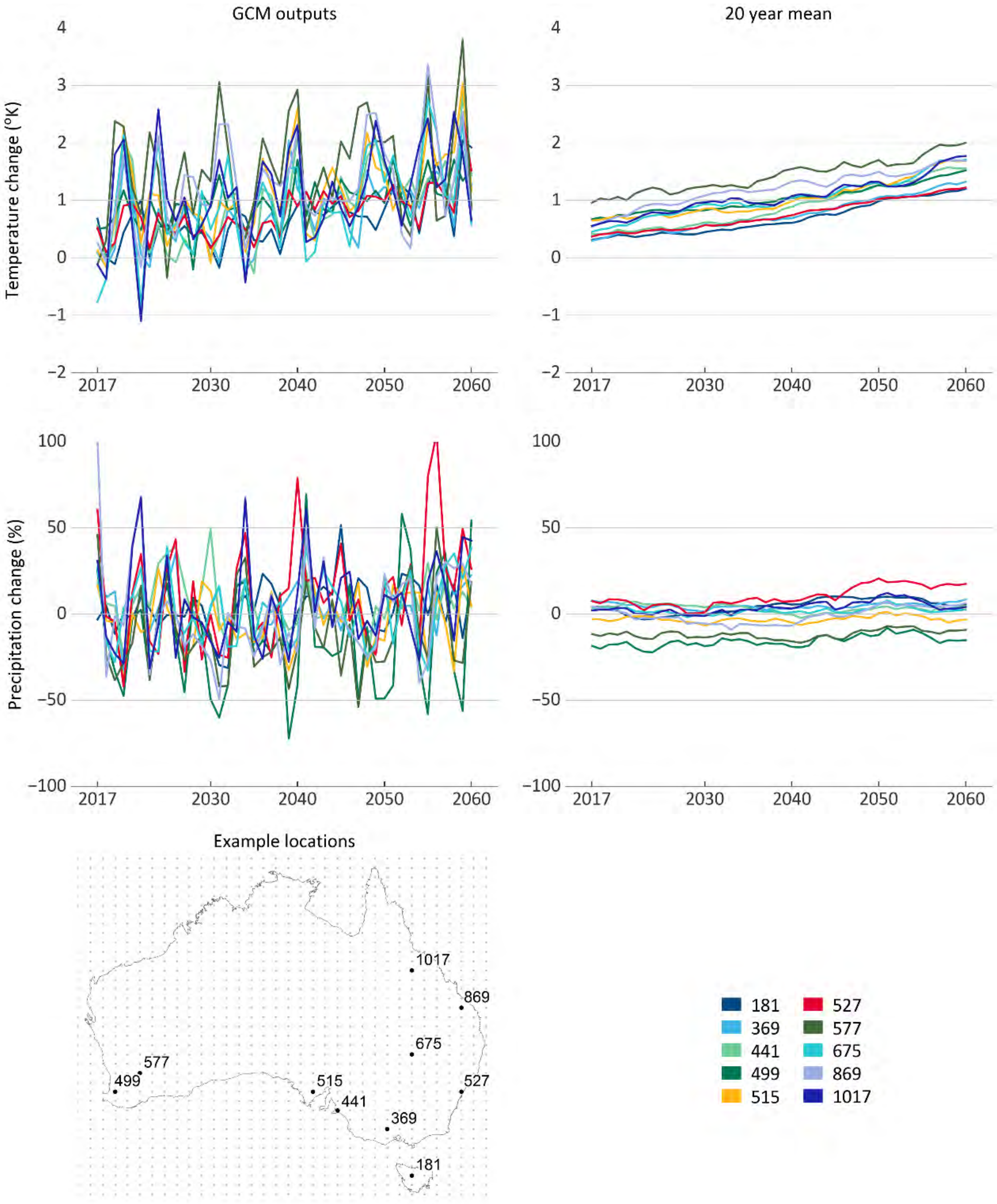


Figure 16.2 Processing of selected points for CESM1-CAM5 RCP 6.0

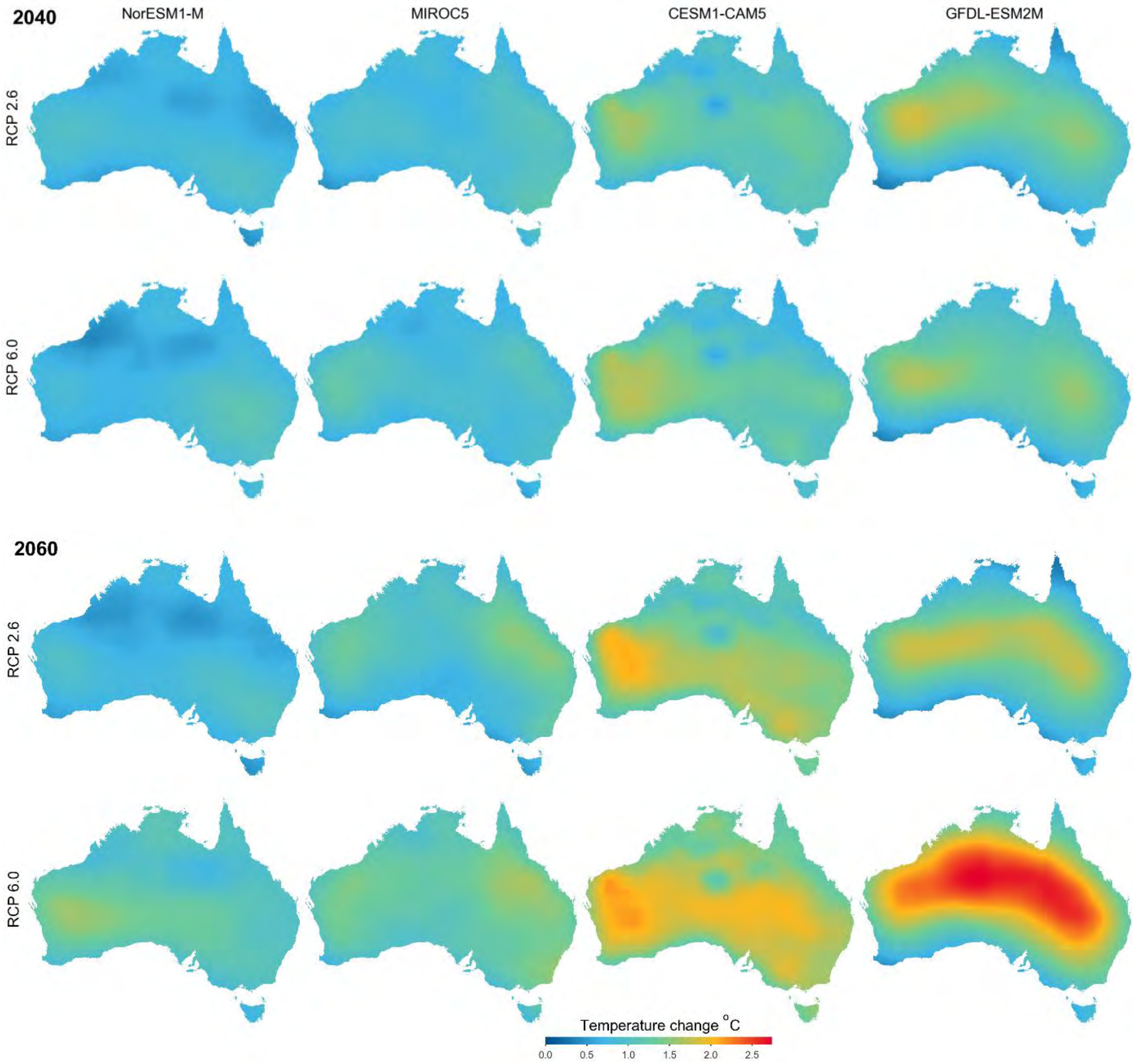


Figure 16.3 Example of splined 20-year mean temperature change surfaces for 2040 and 2060

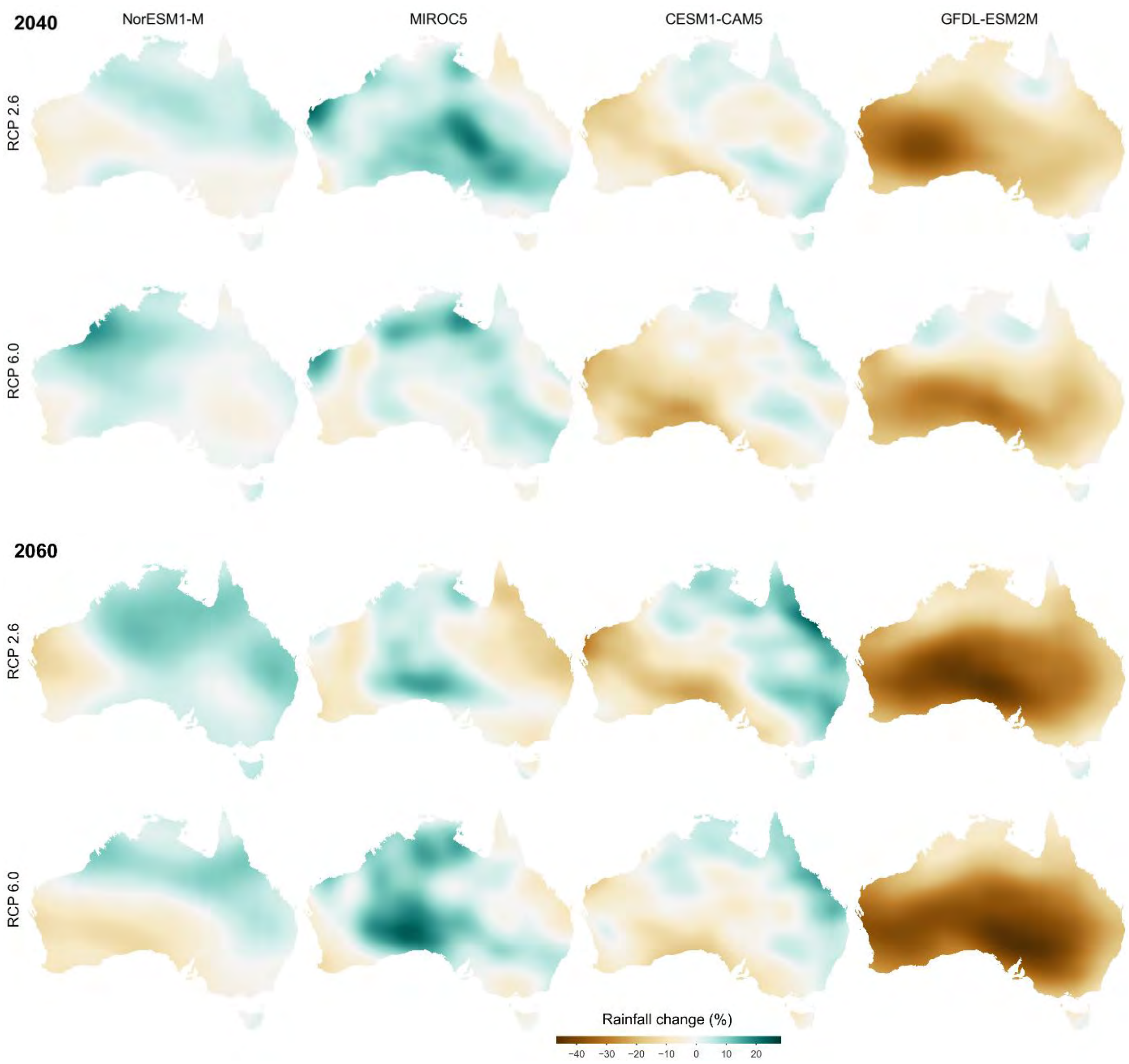


Figure 16.4 Example of splined 20-year mean precipitation change surfaces for 2040 and 2060

Climate impacts modelling

Agriculture

A generalised additive model (GAM) of APSIM (Keating, 2003) modelled wheat yield to historical average annual rainfall and temperature was run in R with the *mgcv* library (Wood, 2011) for a random sample of 50,000 locations:

$$GAMmod = gam\big(yield \sim s(rain) + s(temp)\big)$$

This GAM was used to calculate yield given historical average annual rainfall and temperature:

$$Yield \ = \ predict(GAMmod, data.frame(rain \ = \ rainHIST, temp \ = \ tempHIST))$$

and for each year to calculate yield under rainfall and temperature change as per the GCM outputs:

$$YieldGCM \ = predict(GAMmod, data.frame(rain \ = rainGCM, temp \ = tempGCM))$$

The ratio of future to current yield was then calculated:

$$Yield\Delta = \ YieldGCM \ / \ Yield$$

to provide a climate impact factor used in LUTO to adjust annual yield for all agricultural commodities for each grid cell. The range of climate impacts across Australia vary from positive to negative with adverse impacts generally occurring further inland and positive impacts in current high rainfall areas (Figure 16.5).

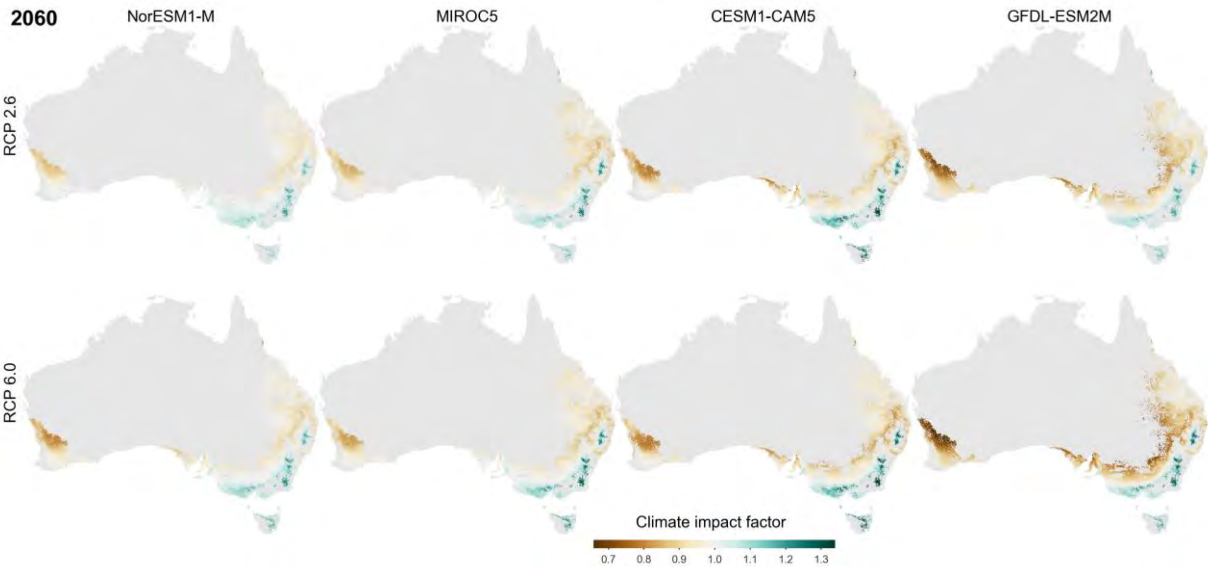


Figure 16.5 Modelled agricultural impacts across GCMs and RCPs for 2060

Impacts of climate on agricultural production were assessed for all dryland crops (e.g. cereals, oilseeds, legumes etc.), dryland horticulture and dryland livestock by multiplying the quantity produced or livestock numbers by the climate impact factor for each cell over time.

A breakdown of modelled production components is presented in Figure 16.6 for dryland agriculture (crop and horticulture). Results are presented for each GCM under two productivity assumptions (above trend and recent trend) and two RCPs (RCP 2.6 and RCP 6.0), and assumed no land use change. These results show that productivity assumptions are the major factors of change in production over the period. Climate impacts have an overall negative effect for the RCP 6.0, with the GFDL-ESM2M GCM having the greatest negative impact.

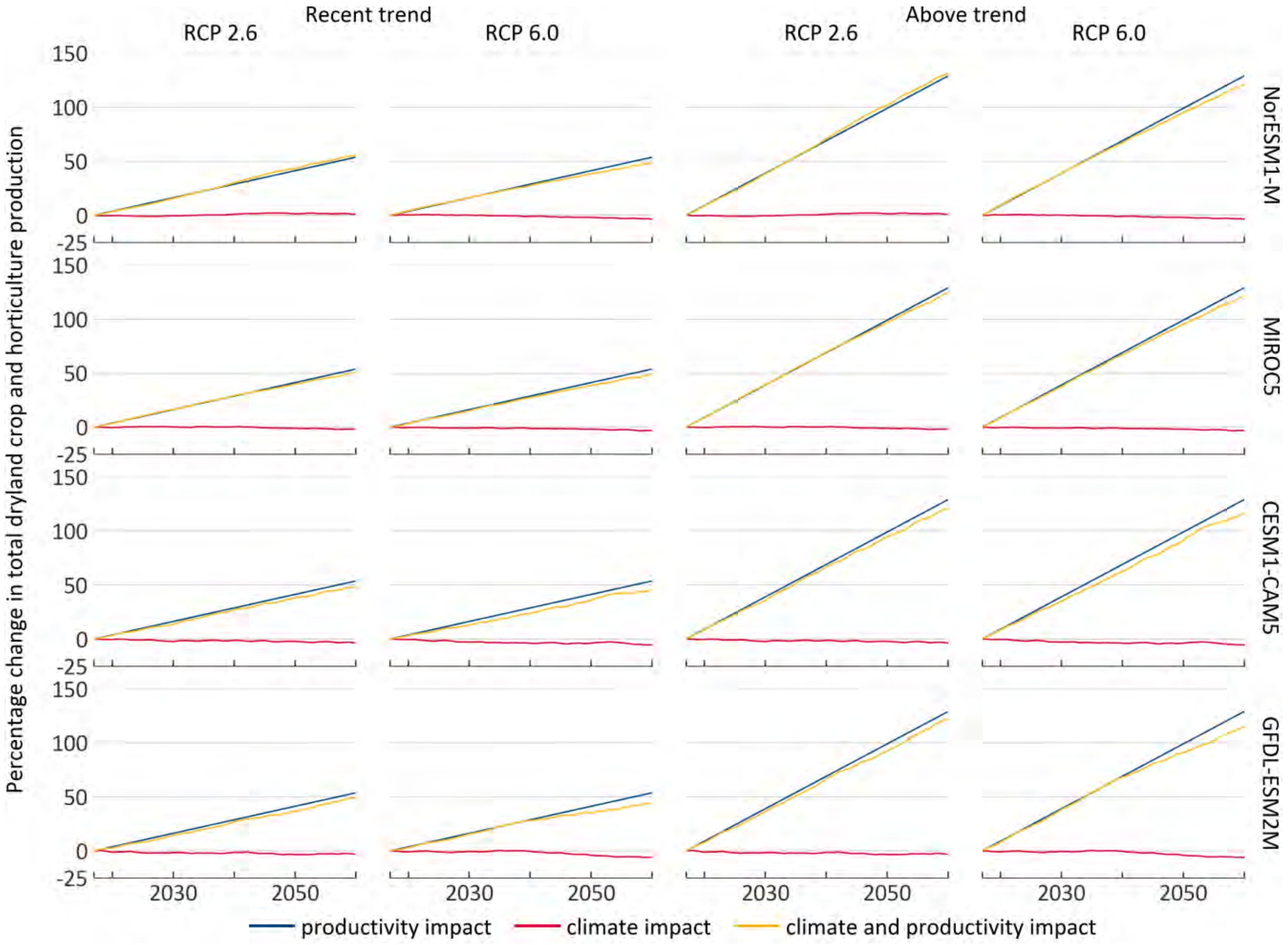


Figure 16.6 Percentage change in total dryland agricultural production for four GCMs, each comprising a productivity assumption (above trend and recent trend) and an RCP (RCP 2.6 and RCP 6.0)

Monoculture, mixed species and biomass plantings

A linear model regressing historical average annual rainfall and temperature with tree growth modelled using 3-PG2 for carbon monocultures, mixed environmental plantings and biomass plantings (Polglase et al., 2008) was constructed using a bootstrap sampling method. This linear model was used to calculate tree growth for each grid cell in the LUTO study area given historical average annual rainfall and temperature and GCM derived rainfall and temperature for each year.

For modelled regression coefficients, *bRain* and *bTemp* and *intercept*:

$$maxGrowth = intercept + bRain * rainHIST + bTemp * tempHIST$$

$$maxGrowthGCM = intercept + bRain * rainGCM + bTemp * tempGCM$$

The ratio of future to current growth was then calculated:

$$maxGrowth\Delta = maxGrowthGCM \,/\, maxGrowth$$

to provide a climate impact factor used in LUTO to adjust maximum growth for each grid cell by modelled impact for each year planted (Figure 16.7).

Figure 16.7 Modelled mixed environmental plantings and carbon monoculture plantings climate impacts across GCMs for 2060

A breakdown of modelled sequestration components is presented in Figure 16.8 for carbon monoculture plantings. The potential sequestration shown is the sum of maximum growth achieved for all cells for each year of planting. Results are presented for each GCM and under two productivity assumptions (above trend and recent trend) and two RCPs (RCP 2.6 and RCP 6.0). These results are similar to agriculture in that productivity assumptions are the major factor of change in production over the period and the GFDL-ESM2M GCM has largely negative overall climate impacts. By contrast, the NorESM2M and CESM1-CAM5 GCMs have overall positive impacts.

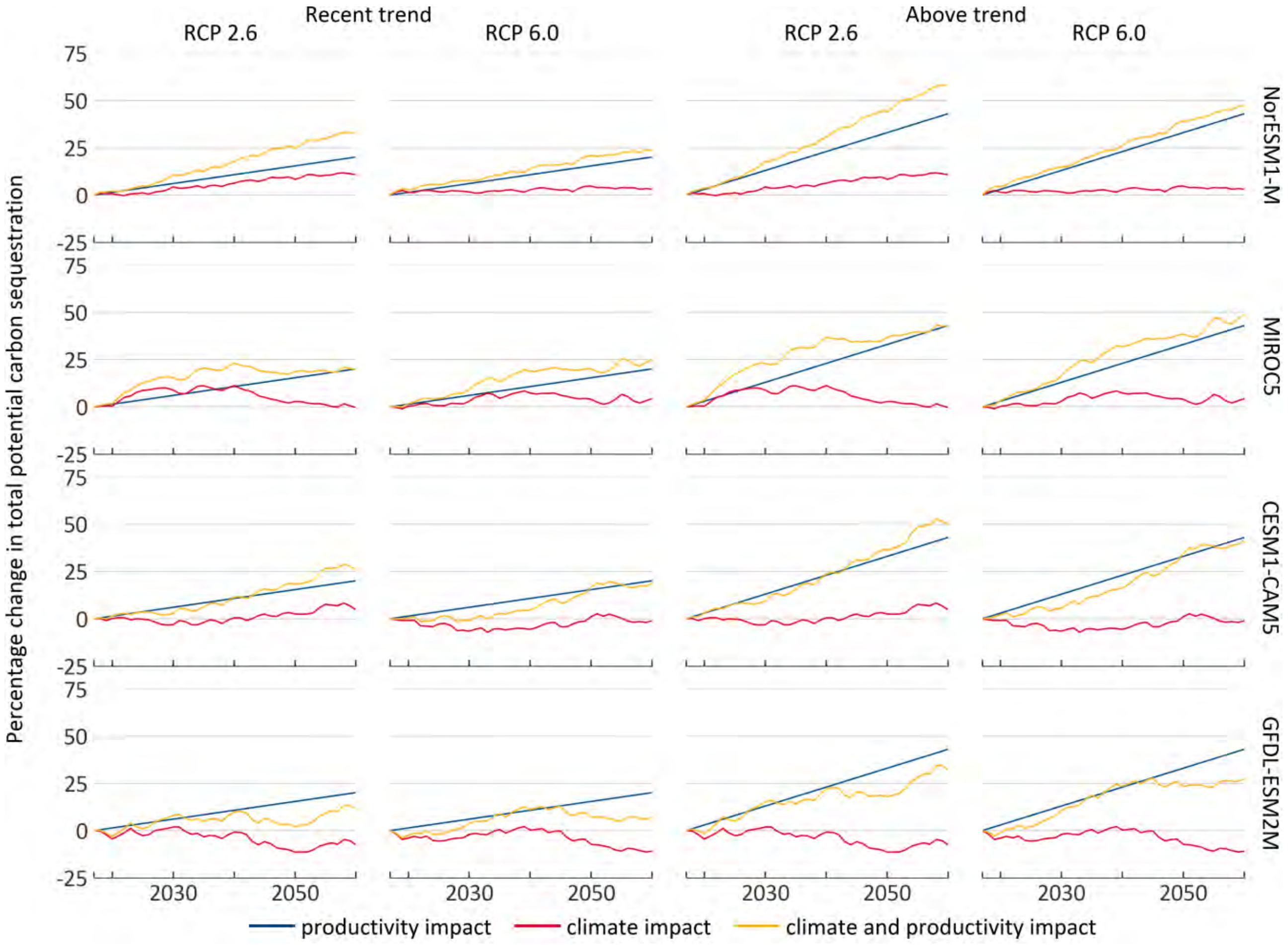


Figure 16.8 Percentage change in potential total carbon monoculture plantings sequestration for four GCMs, each comprising a productivity assumption (above trend and recent trend) and an RCP (RCP 2.6 and RCP 6.0)

This analysis is presented to demonstrate possible climate impacts on agricultural production and total sequestration potential in ANO 2019.

Applying climate impacts from APSIM modelled wheat growth to all commodities provides a simple method of climate impact modelling and could be improved using modelled, or historical, yield and climate relationships for the range of commodities and pastures. Another limitation of this approach is that it assumes no climate impacts on irrigated production and no influence of the carbon dioxide fertilisation effect on production.

Tree growth is influenced by many factors (Polglase et al., 2008) and, as with agriculture in this investigation, regressing growth to annual average temperature and annual rainfall provides a simple method of climate impact modelling. Ideally the 3-PG2 model would be run with future climate realisations in order to improve measures of climate impacts. Also, the modelled 3-PG2 growth data for environmental plantings are considered to be generalisations and further calibration and validation in northern areas are needed (Polglase et al., 2008).

The use of four GCMs in the LUTO modelling of the ANO 2019 scenarios provides a range of possible climate impacts to future agricultural production and total sequestration potential. Both agricultural production and tree growth are strongly influenced by available water and, given the uncertainty in the modelling of precipitation in GCMs (Woldemeskel, 2016), the corresponding results should be interpreted as possible futures rather than as predictions of net impacts.

There were twelve national scenarios run in the LUTO model: *Slow Decline*, *Thriving Australia*, and *Green and Gold* under the four GCM climate futures.

16.3.4 Social lag

In order to accommodate for delays in the uptake of land use change a 'social lag' was implemented within the LUTO decision process. Landholders may be reluctant to change despite a new land use becoming more profitable especially given the 100-year permanence assumption for carbon plantings. This lag in uptake was implemented each year for those cells that became profitable for monoculture and mixed species carbon plantings by staggering their transition to the new land use from most to least profitable so that land use change is assumed to occur along a symmetric non-linear sigmoid curve, with 50% of the change achieved after 8 years and 100% achieved after 16 years.

The actual spatial patterns of uptake are likely to be complex and capturing such complexity is beyond the scope of this project. Assuming that the most profitable land changes occurs first is a practical solution implemented for ANO 2019, however, more research is needed to improve the modelling of this component.

16.3.5 Biodiversity levy

To realise biodiversity co-benefits from action on climate change, carbon levies on both monocultures and mixed species plantings are hypothecated to a biodiversity fund. A 33.33% levy on annual carbon sequestration revenue is applied to monoculture plantings when the carbon price is over AUD \$30 tCO_2-e and to mixed species plantings over AUS \$60 tCO_2-e. The carbon price at the year of plantings is taken as the price for which the levy is raised. These funds are allocated to deliver the maximum biodiversity benefits per dollar based on targeting land use change in areas of high biodiversity priority (Ferrier et al., 2007). The levy fund is used to cover the gap between the most profitable land use and carbon price funded mixed species plantings and is paid to landholders as the net present value of the gap over the 100-year period.

16.3.6 Water-stressed catchments

Water use by irrigated agriculture (Marinoni et al, 2012) and interceptions by plantations (van Dijk and Renzullo, 2011) are both considered in LUTO. In ANO 2015 there was no limit on total rural water use – agricultural water use was capped at current use with additional water use from tree interceptions being 'taken' from the environment. For ANO 2019 a cap and trade mechanism similar to Connor et al. (2016) has been implemented to cap total water use in water-stressed catchments.

The cap on water use was applied to Class C and D catchments as identified by the National Water Commission (2012), defined in Table 16.2 and mapped in Figure 16.9. The cap operates as follows:

1. Current total agricultural water use for a stressed catchment is calculated and set as the cap for that catchment.
2. Plantations and agriculture within a catchment then compete for this water. A location will only switch to carbon plantings if carbon plantings is more profitable at that location and an

equivalent amount of water is displaced from less profitable irrigated agriculture at the same or other locations within the catchment.

3. If those conditions hold then land use will switch from agriculture to carbon plantings at the location and the irrigated agriculture will change to non-irrigated agriculture, being dryland sheep.

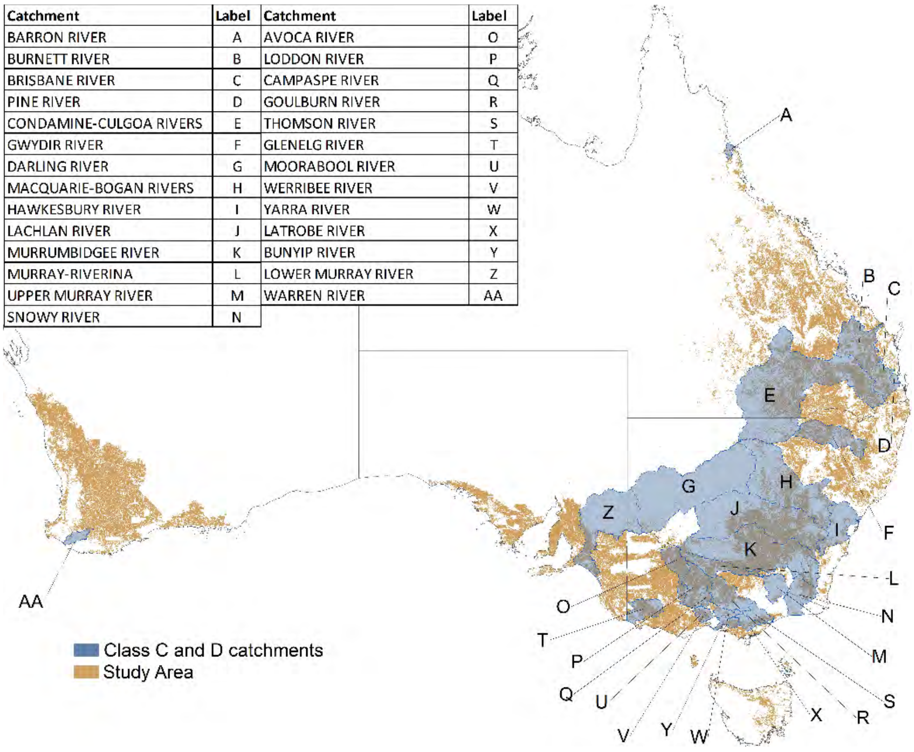
For ANO 2019, under the 'landscape repair' setting used in the *Green and Gold* scenario, irrigated agriculture in water-limited catchments improves water use efficiency by 20% over 10 years from 2020, with half saving returned to environment. The other 10% savings are available for interception by plantations.

Also, under the 'landscape repair' setting for the *Green and Gold* scenario, only mixed species (environmental) plantings are allowed in these water-stressed catchments.

Table 16.2 Characteristics of the categories of water stress from the National Water Commission

Category	Classification	Characteristics
C	Highly water stressed relative to other systems	• Likely high level of development and/or water regime change • Likely moderate risk of overuse/overallocation • Likely moderate to high risk of compromising environmental assets, ecosystem functions or the long term sustainability of the resource
D	Most water stressed	• Likely very high level of development and/or water regime change • Likely high risk of overuse/overallocation • Likely high risk of compromising environmental assets, ecosystem functions or the long term sustainability of the resource

Source: National Water Commission (2012, p. xiii)



Catchment	Label	Catchment	Label
BARRON RIVER	A	AVOCA RIVER	O
BURNETT RIVER	B	LODDON RIVER	P
BRISBANE RIVER	C	CAMPASPE RIVER	Q
PINE RIVER	D	GOULBURN RIVER	R
CONDAMINE-CULGOA RIVERS	E	THOMSON RIVER	S
GWYDIR RIVER	F	GLENELG RIVER	T
DARLING RIVER	G	MOORABOOL RIVER	U
MACQUARIE-BOGAN RIVERS	H	WERRIBEE RIVER	V
HAWKESBURY RIVER	I	YARRA RIVER	W
LACHLAN RIVER	J	LATROBE RIVER	X
MURRUMBIDGEE RIVER	K	BUNYIP RIVER	Y
MURRAY-RIVERINA	L	LOWER MURRAY RIVER	Z
UPPER MURRAY RIVER	M	WARREN RIVER	AA
SNOWY RIVER	N		

Figure 16.9 Water-stressed catchments

16.3.7 Favour food production and landscape repair

Under the ‘favour food production’ setting in the *Slow Decline* and *Thriving Australia* scenarios, policy uncertainty means take-up of carbon plantings is 50% of potential. This was achieved by applying a ‘hurdle rate’ of 2x for *Slow Decline* and 1.7x for *Thriving Australia*. For example, with a hurdle rate of 2x, change would occur as soon as carbon plantings became twice as profitable as the existing agricultural land use. These hurdle rates were determined by running the scenarios with various hurdle rates until approximately 50% of carbon plantings area was achieved. Under the ‘landscape repair’ setting only the social lag impacts monoculture and mixed species plantings take-up and, as mentioned previously, the mixed species plantings are allowed in water-restricted catchments and water use efficiency assumptions apply in these catchments.

16.3.8 Agricultural GHG tax and emissions efficiency

Another modification made for ANO 2019 is a carbon tax cost to agriculture. A map of agricultural GHG emissions (Navarro Garcia et al., 2013) was modified to align with the National Greenhouse Gas Inventory. This map of CO_2 equivalent emissions per hectare, when multiplied by the carbon price in a given year, provides an estimate of the cost to landholders of emissions. Current research, such as reducing livestock emissions, is likely to see this impact fall over time. In order to simulate this, a 1% per annum reduction in emissions intensity for agriculture was implemented for *Slow Decline* and *Thriving Australia* with a 2.5% per annum reduction for *Green and Gold*.

16.3.9 Drought simulation

The modelling of average conditions in LUTO does not consider the impact of extreme events such as drought. In order to explore the impact of such conditions a simulation based on the Millennium Drought in Australia from 1996–2009 was undertaken.

The modelling of climate impacts in LUTO for the four GCM based climate futures uses changes in rainfall and temperature to estimate changes in production. The same methodology was applied using historical annual rainfall and temperature of the Millennium Drought produced by the Bureau of Meteorology for the Australian Water Availability Project (BAWAP) (Jones et al., 2007). The coarser spatial resolution BAWAP data of minimum and maximum monthly temperature were processed to produce annual mean temperatures for each location in the LUTO study area. Similarly, the BAWAP monthly rainfall was summed to produce annual rainfall for each location in the LUTO study area.

As with the climate impact modelling described in Section 16.3.3 the ratio of production under drought to production under average conditions is calculated to provide a drought impact factor which is then used in LUTO to adjust year-on-year agricultural production. The drought simulation was inserted between 2036 and 2049 and rates of productivity adjusted to 0.24 % during this period to approximate those observed in the Millennium Drought (Hughes et al., 2011). The results presented are for the winter cereals commodity class without land use change and in terms of the relationship between cost and revenue.

16.4 References

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Appendix A

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A.1 Automation framework

Although timing and resource constraints prevented ANO 2019 modelling team from significantly automating the model interlinkages transformations and model executions for the three national models, the global modelling suite was fully automated, allowing the full global workflow to be performed by a single operator. One of the key advantages of automation is that it permits scenario exploration and assumption sensitivities to be explored relatively rapidly. As some of the global models take several hours to execute, delays (and effort) required by manual processing of inter-model results and initiation of the next model execution in the workflow is significantly reduced. It also makes it significantly more convenient to implement feedback iteration between models. One of the key advantages of automation is that is forces explicitness of assumptions on model parameters scenario dependence, and interlinkage dependence. It forces explicit description of inter-model data transformation, highlighting the myriad of assumptions behind interpolation, extrapolation and other adjustments that are necessary to prepare the datasets required for any substantial quantitative modelling analysis. The following section describes the general structure of the automated scenario and model workflow management process, followed by some more detailed technical documentation on a library of functions designed to read and write data files compatible with the various model software comprising the GNOME.3 suite.

The automation of model integration includes two essential components, the processing of scenario data and model output results data into data that is suitable for use by downstream models, and the automated initiation of a model execution. There are two different perspectives for describing the process, a (global) workflow perspective, and a local model execution perspective.

From the global workflows perspective the integration processes start with global scenario inputs being translated and collated, models are then executed according to the required workflow ordering, and output data is translated and provided from upstream to downstream models as input data in a sequential manner. For each model interaction, results of the upstream model are post-processed, collated, combined with suite-exogenous scenario assumptions and transformed into data suitable for a downstream model, and pre-processed. Pre- and post- processing steps are the responsibility of the model owner, implemented in software that may be distinct from the primary modelling software. The integration software is responsible only for initiating the execution of those steps and managing the results. Data transformation and inter-model communication are the responsibility of the integration software.

From the perspective of each individual model, results from upstream models and scenario assumptions are transformed and collated by the integration software. Upstream model results can then be pre-processed by calculations that the model owner has control over, before the model execution is initiated. Model results are post-processed and provided to downstream models or reporting.

The next section describes some of the data interoperability requirements for integration that are best understood from the global workflow perspective (the process of transforming data outputs of an upstream model to be suitable as an input for, and communicating to the downstream model). Section A.2 describes the integration software structure and process from a model orientation.

A.1.1 Data interoperability- ConCERO: automation software

Introduction

The terms *'economic models'*, *'computer models'* and simply *'models'* are used interchangeably in this section. The ANO project required the application of many different computer models for forecasting the possible future states of the global and Australian economy and physical environment. The computer models range in computational complexity – some of the models feature fully-fledged graphical user interfaces (GUIs), and engines that have been developed over decades, whilst other models were python scripts that are executed using a terminal/command line interface (Python is a cross-platform open-source programming language, Python Software Foundation, https://www.python.org). The computer models used a variety of data input and output formats, and the formats themselves ranged in complexity – many models rely on files containing comma-separated values (CSV) and/or spreadsheets (XLSX), whilst others use specialised and proprietary formats – for example, HAR and GDX files (which are associated with the programs *RunDynam* and *GAMS* respectively).

Often, it was necessary to integrate the models – that is, the forecast of one of the models provided input data to another. However, the different data formats often required an associated *manual* process to change the data format. This manual process was often laborious, difficult to repeat consistently, and prone to human error. Furthermore, many errors in the setup or execution of the models were only identifiable after the model had been executed – a process often taking several hours.

To maximise: (a), the running time of the models; and (b), the time available for modellers to improve their models - and by extension, their projections - the ANO 2019 project decided to automate this process by developing software to handle both the data format conversion and model execution. An element of the resultant product is ConCERO, which is designed to achieve these objectives by providing simple and easy-to-learn interfaces for (a), specifying file structures in configuration files - thereby simplifying data format conversion - and (b), the execution of models.

Given simple and easy-to-write configuration files, ConCERO can import data from a variety of sources and formats, then manipulate/mutate that data, and then export that data into a variety of file formats (suitable for use as input files for a model). After data format conversion, models can be directed to execute using the newly-created files, and the forecast generated by the model used as inputs (after data format conversion) for further model executions.

To help academics/economists outside of the ANO project automate the same (or similar) processes, the source code of ConCERO has been released publicly under a GNU General Public

License (GPL - Version 3) on the 13th of June 2018. The source code for ConCERO can be found at: https://github.com/charlie0389/ConCERO

ConCERO design objectives

ConCERO was developed with a significant number of design features/objectives:

- Simple interface – file format conversion can be achieved by defining import/export configuration files (see the Example section below), or by using a python interface.
- Simple automation – any computer program that can be executed from a terminal/command line interface can be automated by ConCERO.
- Portable – a lack of ANO-specific code means that this program can be used in future projects and in different contexts. The only constraint on data format conversion is that the data must be time-referenced. The only constraint on model execution is that the model must have a terminal/command line interface.
- Easily extensible – the execution of models developed in the future can be automated (assuming the model has a command line interface) without modifying the codebase. Currently unsupported file formats can be integrated without altering the *structure* of the existing codebase.
- Distributed nature – ConCERO is designed such that:
    1. the person responsible for managing the execution of models; and the person responsible for (a), programming/managing a model and (b), handling the model's data input/output; *can* be two different people, *and*:
    2. neither person has the capability to modify a ConCERO-related configuration files owned by the other (person), *and*
    3. both people can (a), execute a model, or (b), convert data between formats, either independently or as part of a suite of models, without impact on the other person.
- Documented – ConCERO comes with documentation covering the complete codebase, alongside examples and guides.
- Tested – ConCERO has a suite of tests to ensure code quality and backwards-compatibility is maintained.
- Open-source – ConCERO has been released publicly, on the website *GitHub*, under a GPL v3 license, which ensures that users from around the world can use ConCERO and contribute to its codebase, allowing for ongoing and continued development and improvements.

Example

The interface of ConCERO is very simple by nature. For an example of data format conversion, consider the csv file `import_data.csv` with the content:

```
EnergyUse,2018,2019,2020
Gas,5,10,15
Coal,20,10,5
Oil,15,12,9.5
```

This file can be converted to an xlsx file by:

(a) Creating the file `import_data.yaml`, with the content:

```
files: - file: import_data.csv
```

(b) Creating the file `export_data.yaml`, with the content:

```
procedures:
  - file: export_data.xlsx
```

(c) And from the command line execute:

```
concero convert import_data.yaml export_data.yaml
```

Please note that ConCERO documentation has examples of much greater complexity (that also exhibit the model execution features).

A.2 Integration Code Process description

In addition to the ConCERO library designed to support generic ease of data format conversion, additional automation code was required to perform other integration functions. This included configuration management for individual global models within the suite as well as configuration management of the ANO 2019 specific workflow. Other functions required included management of data including scenario input data, as well as individual model results data for storage, inspection, and reporting.

The following provides a brief description of the general process for executing an integrated scenario using **runiam{str}.py** code, with an emphasis on describing the functions performed by commonly used methods. The following section describes the structure of the integration code.

The integrated scenario python code is intended to be executed from the computation node. The overall process is that first a *scenario* object, and a corresponding folder on the computation node, are created, and linkage and model folders created in that scenario folder. Finally, various models are each executed in sequence, with results transferred among models within the scenario folder, or to the integrated scenario outputs folder, as appropriate. See Apx Figure A for an overview.

A.2.1 Scenario and model setup

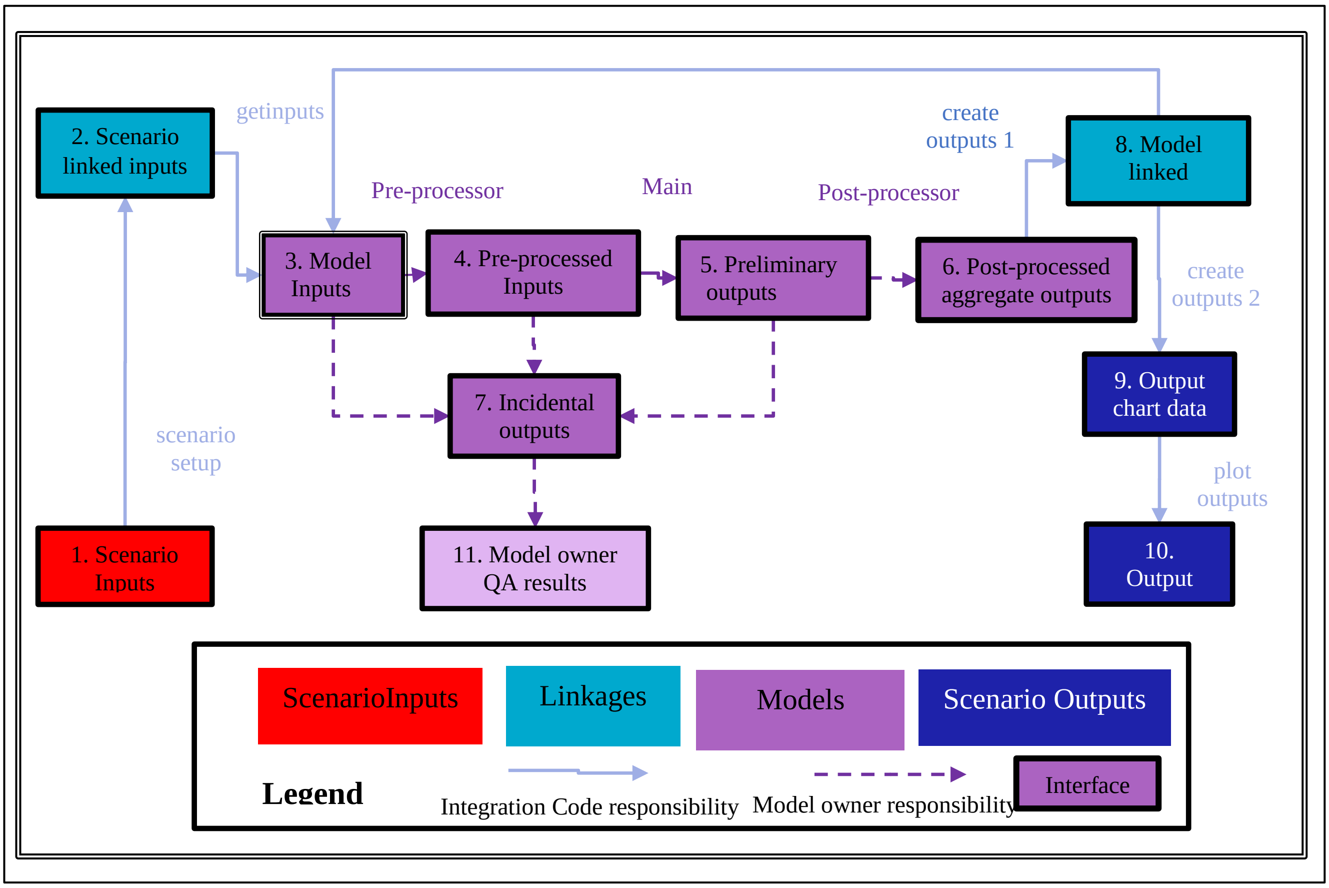
The scenario to be executed defines a particular suite of models to be executed within that scenario and a single set of particular values of input parameters that are exogenous to that suite. The integration code does not yet support the execution of several model specific scenarios (sub-scenarios) within the execution of a single integrated scenario (‘super-scenario’). Setting up a scenario involves creating the folder on the computation node consistent with the structure described in Section A.3 (including the creation of a linkage subfolder), and loading scenario attribute values into the relevant scenario object. Next, model folders are created in the scenario folder to provide locations for model specific inputs, outputs, scenario independent data, model structure information etc.

Scenario setup includes the process of accessing scenario specific data that is exogenous to the suite of models involved from the scenario inputs repository and copying those data (check this)

These functions are defined in **glonat_modelclasses.py**.

A.2.2 Model execution

The management of model execution by the integration code includes not only the spawning of a computational process that replicates the manual execution of a model that a model owner would usually be responsible for operating. It also includes the sundry acquisition of scenario (and model iteration) specific input data and the appropriate disposal of specific results data within the execution of the overall integrated scenario. These data transfer (and translation) processes are described below. Such communication of data by the integration code can be as straightforward as transfer: copying a file from one location to another, or doing so and renaming the file. Translation as well as transfer may involve simply reformatting to a different file format, or to a different data structure, and/or filtering to retain only a useful portion of the data, and/or more sophisticated processing that essentially creates new datasets. The spirit of the integration process, however, is that any of the more sophisticated translations ought to be carried out by computational processes that are represented as individual models in their own right.



Apx Figure A Information flow diagram, integrated assessment code

1) (Integrated) Scenario inputs
2) (Integrated) Scenario linked inputs
3) (Individual) Model inputs
4) (Individual) Model pre-processed inputs
5) (Individual) Model preliminary outputs
6) (Individual) Model post-processed aggregated outputs

7) (Individual) Model incidental outputs
8) (Individual) Model linked outputs
9) (Individual) Model output chart data
10) (Individual) Model output charts
11) (Individual) Model owner QA

From	To	Method
1	2	Scenario setup
2	3/4	Model getinputs
8	3/4	Model getinputs, modlink
3	4	Model preprocessor (by model owner) – optional
4	5	Model execution (model by owner)
5	6	Model postprocessor (by model owner) – optional
3/4/5/6	7	Preprocessor/ model/ postprocessor (optional, by model owner)
6	8	Model._createoutputs 1
8	9	Model._createoutputs 2
9	10	Scenario.plotmutiline
7	11	Create Model QA (optional, by model owner)

Accessing model inputs

Model inputs are transferred (and potentially translated) from the scenario linking folder to the location in the folder for the individual model **{ScenarioName_Num}/{modelname}/model/…** where the execution of the individual model would expect to find the input, with the name expected by the individual model. This is undertaken by the **model.getinputs({arg})** method, where the argument of the method specifies which particular input should be sought. At present there is no guaranteed generic support in the integration code for placing such model input data in particular subfolders.

This method applies both to scenario inputs that are scenario dependent, but exogenous to all models in the integrated suite, as well as model inputs that are the results of the calculation of other models in the suite. Recall that the scenario setup is the process responsible for ensuring that the appropriate scenario input files can be located in the linking folder. The responsibility for ensuring that the needed results of other models are available in the linking folder belongs to the donor models (see below).

Although not yet supported by the integration code functionality, in principle it would be possible for a similar method to get inputs directly from the results folder of another model in the integrated modelling suite, as a bilateral transfer initiated by the recipient model, without placing the results in the linking folder to be made available for other models as well. This would also permit a bilaterally specific translation to take place.

Model execution

Model execution is invoked with a **model.run()** method. It is in this method that model software specific execution commands are defined and referred to, including the location of any needed installed applications on the computation node, and any command arguments that are necessary for the proper calling of the model execution. At present, the integration code does not support the provision of scenario specific, individual model specific or model iteration specific command arguments. The model execution command is specific only to the model's software class defined in **glonat_modelclasses.py.**

In addition to the 'main' execution of an individual model as defined by the model owner, the integration code permits the execution of an optional additional preprocessor and an optional additional postprocessor. It is intended that the management of the preprocessor and postprocessor, if any, is the responsibility of the model owner. The integration code merely invokes these 'models' at an appropriate point in the processing sequence.

The model owner is responsible for ensuring that a (post-processed) aggregated set of outputs is created by the model execution, which contains all and any model outputs that might be used downstream. This is in addition to any 'incidental' (to the scenario integration) outputs that might also be created by the model execution. This aggregated output must be provided in an expected location, in an expected format. At the present time, the integration code supports an aggregated output as a single file, and located only in the **{ScenarioName_Num}/{modelname}/model** folder, rather than any child subfolders. Commonly supported formats such as csv or sql compatible databases are recommended.

In order to save time when checking only the data management aspects of the integration code without having to actually execute an individual model, the **model.run()**, method has a parameter **skiprun** option that when set to **True**, should ensure that there is a copy of a file representing a (post-processed) aggregated set of outputs of the appropriate format and name and in the appropriate location, without executing the model. In general, this 'dummy' output file is referred to as a 'testoutput' file.

Managing model outputs

After the execution of an individual model, including any optional post processing, such that the aggregated output is available in the computation node model folder, the aggregated outputs are made available to the rest of the integrated scenario by being transferred to the linking folder. There is scope in the integration code for optional data translation, specific to the individual model, to be realised during this process. This is achieved by the **model._createoutputs()** method.

After transfer to the linking folder, selected model outputs are converted into a set of model specific standard charts. The first step in this process is for the model's aggregated outputs in the linking folder to be converted into a scenario, model and iteration independent data format, and copied into the scenario output location **ScenarioOutputs/{ScenarioName_Num}/{modelname}/Iter_{Num}**. This is also part of the **model._createoutputs()** method. The process of translating the model's aggregated output that has been copied into the linking folder into a standard data format is specific to the model's application software, and has aspects that are specific to the individual model. The parameters that are to be extracted from the data in the linking folder and whose values are to be written, in standard format, in the scenario output location, are defined, by individual model, in **plotdefs.py**.

Finally a plotmultiline (scenario) method creates standard charts from standard format chart data, also archiving the resulting charts in

ScenarioOutputs/{ScenarioName_Num}/{modelname}/Iter_{Num}, by scenario, model and iteration count. More than one standard chart may be produced from a given file representing chart data.

In a future version, there might be more distinctive separation among the subfunctions within create outputs: export to linkage, extraction of chart data, creation of charts.

At the present time, there are two alternative routes for translating linked model results to standard data format results and then to standard charts. One pair of functions has been written with primarily the global models in mind, and the other with the national models in mind. In principle, however, they perform the same generic function. In the future, they may be combined and/or current versions deprecated.

The intention of the functions that translate linked results to charts, for the global models, is that each data file represents no more than a single parameter, with at least one time index, no more than three indices in total, and if there are more than two indices, at least one should also be a region index. The standard format for this data is csv in ‘coordinate format’, with values for up to three indices in up to three columns and parameter values in exactly one column. The charting function allows more than one chart per parameter value data file only by permitting filtering on no more than one non-time index per chart.

The functions that translate linked results to charts, for the national models, is slightly different. The standard format for this data has one time index in one column, an optional region index in an additional column, and a (multi?) index in rows, with data values in matrix-like tabular format.

Although not yet supported by the integration code functionality, in principle it would be possible for a similar method to place results directly into the input folder of another model in the integrated modelling suite, as a bilateral transfer initiated by the donor model, without placing the results in the linking folder to be made available for other models as well. This would also permit a bilaterally specific translation to take place.

A.2.3 Restarting the execution of an integrated scenario after interruption

See the scenario class method in **glonat_modelclasses.py** for details.

Archiving inputs, intermediate results and execution logs for debugging and recording provenance

- Note that model data and intermediate results that appear on the computation node are not guaranteed to be archived indefinitely, as this is a flush drive on the computation node.
- The *integration code* for a given scenario is not (yet) archived within each scenario execution. It may only be reconstructed on the basis of the version management for the integration code.
- *Inputs exogenous to the scenario* are not (yet) archived within each scenario execution. They may be reconstructed based on the scenario definition and the data in the scenario input archive, assuming that the scenario input archive is static. They are also recorded in the linkage folder of the integrated scenario folder on the computation node.
- *Inputs exogenous to individual models* but not exogenous to the integrated scenario are results derived from direct outputs of other models in the integrated scenario. Those

inputs are not archived systematically – only the most recent version of the input will be recorded on the computation node, as a model input for that individual model.

- *Intermediate results from individual model runs* are not systematically archived, but those from the most recent iteration may be found in both the model output folder and linking folder on the computation node.
- *Some of the results for individual models* are archived in ScenarioOutputs. But these are only those results that are necessary for plotting the standard charts, and the standard charts themselves. A systematic archive for each model and each iteration within the integration scenario is recorded.

A.3 Structural description

A.3.1 Integration code structure

The code for ANO2 model integration comprises several python scripts, controlled by main integration scripts typically named **runiam{str}.py**. The primary sets of objects that the code operates on are *models* and also *scenarios*. The classes for these objects are defined in

glonat_modelclasses.py, **glomodelclasses.py**, **natmodelclasses.py**

The utility file **iamutils.py** defines a library of various small 'helper' functions that are regularly and repeatedly called upon by object methods, functions such as path definitions and the reorganisation of data into commonly used formats for communication interchange among objects. Another utility file, **harutils.py** contains helper files relevant to the 'har' file format, a data file format commonly used by a software specific class of model. The linking function files **glomodlink.py** and **natmodlink.py** contain model specific implementation details of bilateral data transfer between individual models. In a future implementation, the functions in **iamutils.py** that are specific to the communication of model outputs, including charts, may be split off into a standalone function.

Definition files **scendefs.py**, **plotdefs.py**, **glomodeldefs.py** and **natmodeldefs.py** define attribute values for specific individual scenarios and models, saving them to a data structure that can be used to initialise attribute values for individual scenario and model object instances used by the integrated execution software suite. **Scendefs.py** defines attribute values particular to individual scenarios, **glomodeldefs.py** and **natmodeldefs.py** define attribute values particular to individual models (global scale and national scale respectively) and **plotdefs.py** define values particular to individual models that characterise how to plot charts of results from individual models for quality assurance checking.

Class definitions

Of the class definition files, **glonat_modelclasses.py** defines classes that are parents to classes in each of **glomodelclasses.py** and **natmodelclasses.py**. The classes defined in **glonat_modelclasses.py** are relevant to operating on both global scale and national scale individual models in the ISAM suite, whereas **glomodelclasses.py** and **natmodelclasses.py** define classes relevant to specific individual models. The primary reason for splitting class definitions for managing the operation of global and national scale individual models into different files is because different individual developers have been responsible for managing the global scenario model integration and the national scenario model integration, and no individual models are common to both. For ANO2, the suite of global models are automated to interact among each other with bidirectional communication, but only to interact with the suite of national models by providing results data once. The suite of national models are automated to interact among each other, but only to receive data once from the global scenario results.

Parent classes defined in the file **glonat_modelclasses.py** include the *Scenario* class, which includes methods specific to a single scenario – a realisation of a set of parameter values exogenous to the suite of models to be executed. They also include the *model* class, which defines methods applicable to the management of generic model input, execution and output. The *model* class is specialised further in **glonat_modelclasses.py** dependent on the specific software used to execute the model. In **glomodelclasses.py** and **natmodelclasses.py** these subclasses are specialised still further to specific individual models that may be found within the **iam** folder structure as characterised below.

A.3.2 Model integration data structure

The integration scripting python source code itself is to be found in the folder **iam\integration\model**. There is a subfolder **iam\integration\model\Pickles** that is used to contain pickle files corresponding to the state of execution of the integration code itself, as opposed to the execution of individual models controlled by the integration code.

The information required to execute each individual model, that is, model structural definition data and parameter value data, but not including the executable software required to be installed on an operating system in order to execute one or more models, is to be found in a folder named for the model under the **iam\{modelname}** folder. A subfolder **iam\{modelname}\model** contains all the information (except possibly the software executable) required to run each individual model. The contents of the **iam\{modelname}\model** subfolder is copied in its entirety to a computation node where a specific calculation scenario is executed.

Data inputs that are exogenous to an integrated modelling suite are to be found in the folder **ScenarioInputs**. Subfolders corresponding to the domain of these exogenous inputs structure this folder in more detail. At present there are two alternatives for permitting inputs that are exogenous to each scenario to be incorporated into an integrated scenario execution. The less explicit manner is for parameters of low dimensionality to be defined in **scendefs.py**. A preferred manner that is more explicit is for their values to be defined in files located in subfolders of **ScenarioInputs**, the filenames and paths of which are defined in **scendefs.py**.

Result outputs from an integrated scenario execution must each correspond to specific results outputs (numerical data and/or charts) from a (particular iteration of a) particular individual model execution within the integrated scenario. These results are written to **ScenarioOutputs**. In **ScenarioOutputs** there is a subfolder for each integrated scenario (including the scenario iteration number), and within the integrated scenario folder there is a subfolder for each model, and within each of these subfolders, there is a further set of child folders corresponding to each iteration of the parent model within the given integrated scenario including its iteration number. That is **ScenarioOutputs/{ScenarioName_Num}/{modelname}/Iter_{Num}**.

When the integration code is run, the first task performed is for a scenario folder to be created on a processor computation node. The scenario must have a name that is recognised as a key in the data structure created by **scendefs.py**. The scenario folder has a name corresponding to the scenario name, but also includes a scenario iteration number that increments each time a scenario bearing the same name is executed.

Several subfolders are created within the scenario folder for a scenario execution. There is a subfolder corresponding to each model to be integrated, that is

{ScenarioName_Num}/{modelname}/model, and a linking subfolder **{ScenarioName_Num}/linking** which is a container for data to be communicated between models. Direct outputs from models must be written to each model subfolder, and all model data inputs must be read from each model subfolder, though there may be some model specific flexibility regarding further subfolder hierarchies within the model subfolder for locating inputs and outputs. (The integration code does not support this especially well as present.) Model owners are strongly encouraged to ensure that there exists at least one (model direct output) file that contains all the data to be communicated by each individual model. If a given model is executed more than once during a scenario, the direct model results output data file(s) may be overwritten on subsequent iterations, as may data files in the linking folder. Log files corresponding to the execution of individual models are saved to each individual model subfolder, including an iteration count number appended to the file name.

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