ACIL ALLEN

15 May 2023

Report to Geoscience Australia

Economic impact of the National Positioning Infrastructure Capability program

About ACIL Allen

ACIL Allen is a leading independent economics, policy and strategy advisory firm, dedicated to helping clients solve complex issues.

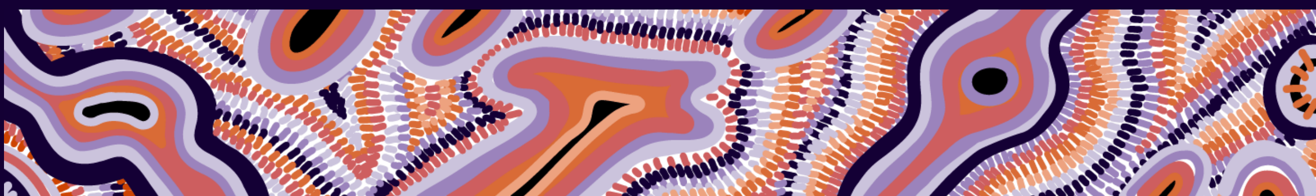
Our purpose is to help clients make informed decisions about complex economic and public policy issues.

Our vision is to be Australia's most trusted economics, policy and strategy advisory firm. We are committed and passionate about providing rigorous independent advice that contributes to a better world.

Suggested citation for this report

ACIL Allen (2023). The economic impact of the National Positioning Infrastructure Program, Geoscience Australia.

ACIL Allen acknowledges Aboriginal and Torres Strait Islander peoples as the Traditional Custodians of the land and its waters. We pay our respects to Elders, past and present, and to the youth, for the future. We extend this to all Aboriginal and Torres Strait Islander peoples reading this report.



Goomup, by Jarni McGuire

Contents

ACIL ALLEN

Contents

Contents

Figures

Contents

Contents

Boxes

Glossary

AV	Autonomous vehicle
BCR	Benefit-Cost Ratio
BeiDou	Chinese satellite positioning system
CAS	Collision avoidance system
CGE Model	Computable General Equilibrium Model
CORS	Continuously Operating Reference Station
CRCSI	Cooperative Research Centre for Spatial Information
CTF	Controlled traffic farming which refers to the use of autonomous self-steering farm machinery in farm operations.
DGPS	Differential Global Positioning System – an augmented Global Navigational Satellite System
DFMC	Dual Frequency Multiple Channel
DIAS	Data information and access services
Digital Twin	A digital twin is a virtual representation that serves as the real-time digital counterpart of a physical object or process.
Discount rate	The social opportunity cost of money.
DR	Discount rate
Integrity	The measure of trust that can be placed in the correctness of the information supplied by a GNSS
EGNOS	European Geostationary Navigation Overlay Service
FTE	Full time equivalent employment

FrontierSI	A not for profit company established following the conclusion of the operations of the CRCSI. The company delivers services to government, industry and the community using their deep expertise in spatial mapping, infrastructures, positioning, geodesy, analytics and standards.
GA	Geoscience Australia
Galileo	European GNSS service
GDA94	The Geocentric Datum of Australia 1994 is a coordinate reference system whose origin coincides with a determination of the centre of mass of the earth. It is a plate fixed or static coordinate datum.
GDA2020	The Geocentric Datum of Australia 2020 is Australia's new national datum which replaces GDA 1994
GDP	Gross Domestic Product
ESA	European Space Agency
FY	Financial year (for example FY 2019 is financial year 2018-19)
Ginan	Geoscience Australia's Global Navigation Satellite System analysis centre software
GLONASS	Global Navigation Satellite System (Russian satellite navigation system)
GNSS	Global Navigational Satellite System
GPS	Global Positioning System (US Navstar GNSS)
GRP	Gross regional product
GSP	Gross State Product
GTAP	Global Trade Analysis Project
IMU	Inertial Measurement Units
IRNSS	Indian Regional Navigation Satellite System
LiDAR	Light Detection and Ranging. A remote sensing method used to examine the surface of the Earth.
L1	Frequency Band used for standard SBAS services
L5	An additional frequency for DFMC SBAS services
MFP	Multifactor productivity. A measure of economic performance that compares the amount of output to the amount of combined inputs used to produce that output.
MGA94	Map Grid of Australia 1994. A transverse Mercator projection that conforms to the internationally accepted Universal Transverse Mercator Grid system (metric rectangular grid coordinate system).

MGA2020	Map Grid of Australia 2020 is the latest Map Grid of Australia.
NCRIS	National Collaborative Research Infrastructure Strategy
NDVI	Normalised Difference Vegetation Index (measures plant health)
Network RTK	Uses GNSS data from several widely spaced permanent stations to determine the differences between expected and actual observations
NPIC	National Positioning Infrastructure Capability
NPV	Net Present Value of benefits and costs over time.
OBPR	Office of Best Practice Regulation
PDS	Proximity Detection Systems
PPP	Precise Point Positioning
PPP-RTK	Precise Point Positioning Real-Time Kinematic (combines the two techniques)
QZSS	Quasi Zenith Satellite System (Japanese satellite positioning system)
Reliability	The reliability of a GNSS navigation system is concerned with the overall consistency of a measure. It encompasses concepts of service continuity, satellite availability, accuracy and repeatability.
RTK	Real-Time Kinematic
SBAS	Satellite Based Augmentation System
SIBA/GITA	The Spatial Industry Business Association and the Geospatial Information and Technology Association
Single-base RTK	Single base RTK is a relative positioning technique that uses a base station with known coordinates and a rover. The base station transmits a correction to the rover to improve the accuracy of the position that the rover records.
SouthPAN	Southern Positioning Augmentation Network
SSSI	Surveying and Spatial Sciences Institute
Third-party service provider	A company that offers GNSS data to end users via a paid subscription. Also known as a Value-Added Reseller.
Value added	Value added of an enterprise is the difference between the revenue generated less the costs of inputs. Gross valued for an economy is the main component of Gross Domestic Product.
Vicmap Position	A DGPS network architecture deployed in Victoria which provides real-time data stream via the Internet and Global System for Mobile communication (GSM)/General Packet Radio Services (GPRS) radios

VRA	Variable rate application (usually relates to application of fertiliser in agriculture)
VRT	Variable rate technologies (variable rate applications in agriculture).
WAAS	Wide Area Augmentation System (US)

National Positioning Infrastructure Capability Economic Benefits

FINANCIAL YEARS 2019 TO 2038

NATIONAL POSITIONING INFRASTRUCTURE (NPIC) ECONOMIC BENEFITS FINANCIAL YEAR (FY) 2018-19 TO 2037-38

NPIC is expected to generate national economic benefits of **$545 million** in present value terms (7% discount rate)

$365 million of direct benefits in present value terms to the agriculture, mining, construction and surveying and mapping sectors

$163 million for the agriculture sector

$91 million for the mining sector

$68 million for the construction sector

$43 million for the surveying and and mapping sector

NATIONAL POSITIONING INFRASTRUCTURE (NPIC) COST BENEFIT (DIRECT EFFECTS) [a]

NPIC expected to return **$2.58 for every dollar** of Australian Government funding at 7% discount rate (FY 2019 to FY 2038)

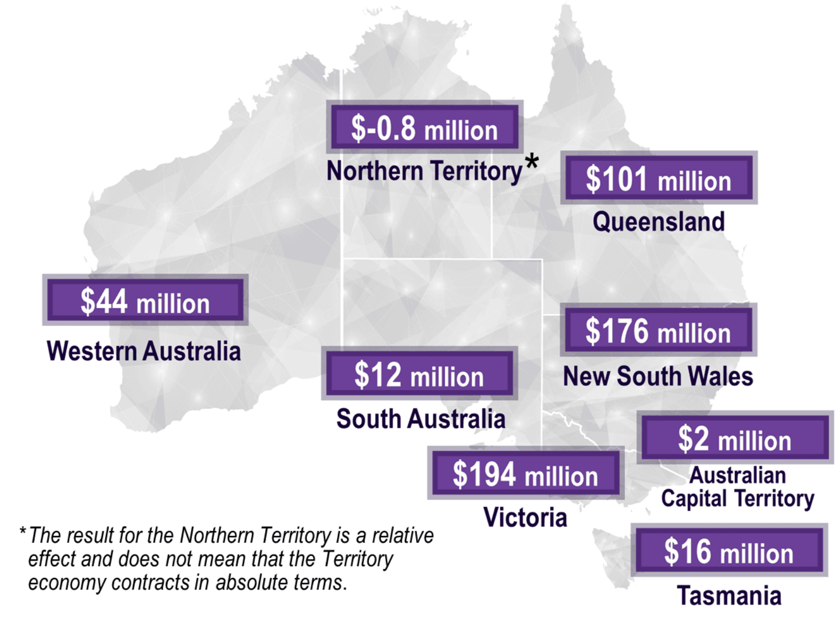
Discounted at	NPIC costs (FY 2022 prices)	NPIC measurable benefits (FY 2022 prices)	Benefit Cost Ratio
3%	$171 m	$494 m	2.89
7%	$141 m	$365 m	2.58
10%	$126 m	$301 m	2.28

[a] Benefits to agriculture, mining, construction and the surveying and mapping sectors

NATIONAL POSITIONING INFRASTRUCTURE NATIONAL ECONOMIC IMPACTS BY STATE FY 2019 TO FY 2038 DISCOUNTED AT 7%

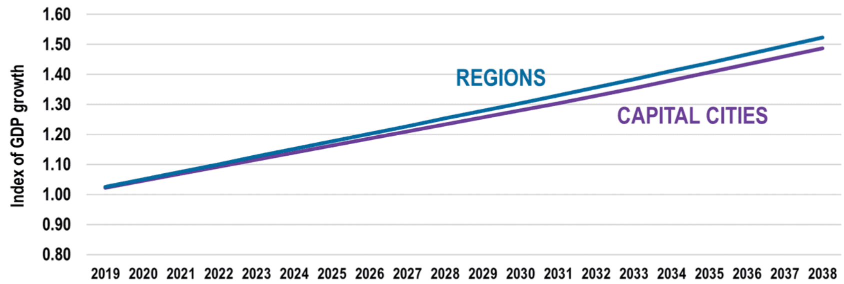
NPIC is expected to generate national economic benefits of **$545 million** in present value terms.

$141 million committed by the Australian Government present value terms.



**The result for the Northern Territory is a relative effect and does not mean that the Territory economy contracts in absolute terms.*

The relative growth rate is **higher for regional areas** relative to capital cities regions as a result of NPIC.



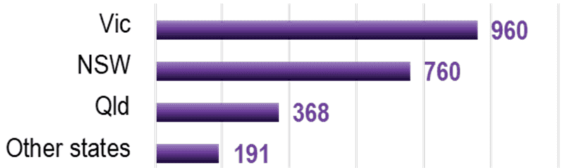
ADDITIONAL EMPLOYMENT GENERATED FROM NATIONAL POSITION INFRASTRUCTURE (NPIC) FY 2019 TO FY 2038

2,316 additional full-time equivalent (FTE)

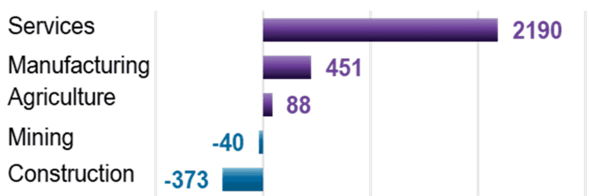
Average increase in employment **116 FTE per annum**

The largest impact on employment is in **Victoria, New South Wales and Queensland.**

ADDITIONAL FTE BY STATE FY 2019 TO FY 2038



ADDITIONAL FTE BY SECTOR FY 2019 TO FY 2038



The largest increase in employment from NPIC is in the **services sector** and the **manufacturing sector.**

Precise positioning from NPIC delivers improvements in labour productivity to end users. This is why employment is expected to fall in **mining** and **construction**.

Executive summary

The purpose of this report is to estimate the economic benefits that have been generated by Geoscience Australia's National Positioning Infrastructure Capability (NPIC) program since 1 July 2018 and that are expected to be realised by 30 June 2038. The economic benefits are considered in two parts: the direct economic benefits to four sectors of the economy; and the overall impact on economic growth and employment that can be attributed to the NPIC program.

The National Positioning Infrastructure Capability (NPIC) provides a unified approach to the management of the nation's positioning infrastructure. This ensures that consistent, fit-for-purpose precise positioning data and services are available to government, business, and academia.

Through a unified national network:

— consumers have access to high-quality positioning data from certified reference stations,
— coverage of positioning services is increased and consistent between providers,
— service costs can be lowered due to free and open positioning data,
— service providers have increased flexibility to tailor offerings to different industry sectors.

By establishing a unified national network, NPIC is enabling the delivery of positioning services with accuracies better than 5 cm across Australia in areas of mobile phone coverage.

The Australian Government invested around $64 million into better positioning to support Australian businesses between 1 July 2018 and 30 June 2022 and around $12 million annually from 1 July 2023 to maintain the NPIC program. Of this around $44 million and $10 million respectively has been directly invested in the NPIC network. The research undertaken for this report indicates that this expenditure can be expected to deliver benefits to the Australian economy that exceed the Australian Government costs of the program.

These findings are based on quantification of the impact of the NPIC program on four selected sectors of the economy (surveying and mapping, agriculture, construction, and mining). This research also found other sectors, including research and innovation, infrastructure planning, manufacturing and transport and logistics would also be expected to benefit over time. These sectors have not been included in the estimates of the direct economic benefits of NPIC but have been captured as indirect benefits in the economy wide modelling.

Economic benefit of the NPIC on selected sectors

Direct benefits

This economic analysis found that NPIC is expected to deliver either productivity improvements or increases in revenue to the surveying and mapping, agriculture, construction, and mining sectors of the economy. Table ES 1 summarises the benefits for these four sectors.

NPIC is estimated to deliver $365 million in direct benefits to the surveying and mapping, agriculture, construction, and mining sectors between financial year FY 2019 and FY 2038 in present value terms (FY 2022 prices). Of this, $51 million (14 per cent of the total) is estimated to have already been realised between FY 2019 and FY 2022.

Table ES 1 Economic benefits of NPIC on selected sectors, FY 2019 to FY 2038

Sector	FY 2019 – FY 2022	FY 2023 – FY 2038	FY 2019 – FY 2038
	$million (FY 2022 prices)	$million (FY 2022 prices)	$ million (FY 2022 prices)
Surveying and mapping	8.8	34.2	43.0
Agriculture	25.1	138.0	163.1
Construction	7.7	60.1	67.8
Mining	9.5	81.1	90.7
Total	**51.1**	**313.4**	**364.6**

Note: Benefits in terms of present value as at FY 2022 calculated with a discount rate of 7 per cent.
Benefits are net of user costs but are not net of any GA NPIC costs.
Source: ACIL Allen

Benefit-cost ratio of the NPIC program

The NPIC program is generating more value for the surveying and mapping, agriculture, construction, and mining sectors than it costs, with an expected return of $2.58 for every dollar of Australian Government funding.

The benefit-cost ratio of the NPIC (discounted at 7 per cent) is 2.58.

To assess this, the cash flows of benefits and costs were discounted at three discount rates (3 per cent, 7 per cent and 10 per cent). The results are summarised in Table ES 2 below. The table shows that these findings are not sensitive to the discount rate.

Table ES 2 Costs, benefits and benefit-cost ratio for the NPIC program for FY 2019 to FY 2038

Discounted at	NPIC costs	NPIC direct benefits	Benefit-Cost Ratio
	$million (FY 2022 prices)	$million (FY 2022 prices)	Ratio
3%	171	494	2.89
7%	**141**	**365**	**2.58**
10%	126	301	2.38

Note: Benefits in terms of present value as at FY 2022 calculated with a discount rate of 7 per cent. The NPIC costs are Australian Government costs only but include payments to service providers for access to private CORS data.
Source: ACIL Allen

Wider benefits of the NPIC to the Australian economy

Economic impacts by state and territory

Broader impacts on the Australian economy from NPIC will accrue as the wider economy responds to the increased efficiency of precise positioning, particularly in the four sectors assessed: surveying and mapping, agriculture, construction, and mining.

The economic impacts of NPIC by state and territory are summarised in Table ES 3. The table shows that the highest benefits accrue to Victoria, New South Wales and Queensland. This reflects the size of their economies, more extensive mobile phone coverage, and the maturity, dependence and sustained update of positioning infrastructure and services.

Table ES 3 Direct and indirect economic benefits of NPIC, FY 2019 to FY 2038

State	Direct and indirect net economic benefit
	$million (FY 2022 prices)
New South Wales	176
Victoria	194
Queensland	101
South Australia	12
Western Australia	44
Tasmania	16
Northern Territory	-0.8
Australian Capital Territory	2
Australia	**545**

Note: Net economic benefit has been calculated as a present value as of FY 2022, using a 7 per cent discount rate.
Source: ACIL Allen

The present value of the total (direct and indirect) net economic benefit of the NPIC program to Australia is estimated at $545 million (discounted at 7 per cent). All jurisdictions, apart from the Northern Territory, benefit from the NPIC program. The Northern Territory experiences a relative negative result due to limited mobile phone coverage outside of the main population centres restricting the ability to deliver precise positioning services over the internet. This is a relative effect and does not mean that the Northern Territory economy contracts in absolute terms.

Regional impacts of the NPIC

There is larger relative increase in output in the regions compared to the output of the capital cities as a result of NPIC. This is the result of capital and labour mobility.

This means the regional areas grow faster than capital cities and reflects in part the fact that the agricultural and mining sectors are largely located in regional areas. A significant component of heavy engineering is also located in regional areas.

The indices of growth in Gross Regional Product (GRP) for Australian capital cities and regional areas are summarised in Figure ES 1.

Figure ES 1 NPIC Gross Regional Product (GRP) impact, Index of capital and non-capital city regions GRP impact (FY 2018 to FY 2038)

Note: FY 2018=1

Source: ACIL Allen modelling based on the direct impact estimates

Employment impacts of the NPIC

Full-time equivalent (FTE) employment as a result of the NPIC program is expected to increase as shown in Table ES 4.

Total employment as result of NPIC is projected to increase. The average annual increase is 116 full-time equivalent employment (FTE) with a total increase of 2,316 FTE years over the period from FY 2019 to FY 2038.

The largest impact on employment is expected to occur in Victoria, New South Wales and Queensland.

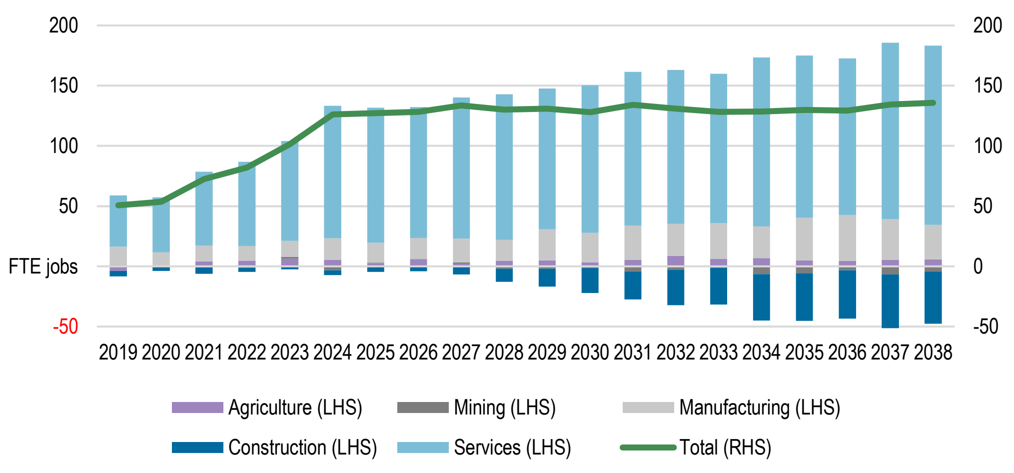
Table ES 4 Increase in full-time equivalent (FTE) employment due to NPIC, FY 2019 to FY 2038.

Regions	Annual average	Employment in FY 2038	Total (FY 2019 –FY 2038)
	FTE	FTE	FTE
New South Wales	38	40	760
Victoria	50	47	996
Queensland	18	31	368
South Australia	2	3	31
Western Australia	2	6	35
Tasmania	5	6	90
Northern Territory	1	1	15
Australian Capital Territory	1	1	21
Australia	**116**	**136**	**2,316**

Note: Columns do not add to total due to rounding errors.
Source: ACIL Allen modelling

The relative impact of NPIC on employment across the economy is shown in Figure ES 2. Employment growth due to NPIC is forecast in the services, manufacturing and agricultural sectors. The increase in output from the four sectors modelled (surveying and mapping, agriculture, mining and construction) will result in the purchase of more goods and services by these sectors. These goods and services will increase employment in the services and manufacturing sectors. Employment is forecast to fall in the mining and construction sectors as improvements in productivity reduce the demand for workers in those sectors. This is a relative fall and does not imply employment falls in absolute terms in these sectors. The absolute level of employment will depend on the rate of growth in the economy.

Figure ES 2 Employment impacts of NPIC by broad sectors, Full-time Equivalent (FTE) jobs, financial years FY 2019 to FY2038



Note: The services sector includes surveying and mapping.
Source: ACIL Allen

1 Introduction

1.1 This assignment

This report has been prepared for Geoscience Australia (GA) to estimate the net economic benefits that have accrued from the National Positioning Infrastructure Capability (NPIC) program since 1 July 2018 and forecast benefits that are expected to accrue out to 30 June 2038.

The scope of work for this assignment comprises two parts.

— The first is an assessment of the direct impact of the NPIC program on the surveying and mapping, agriculture, construction and mining sectors plus the impact on the research and innovation sectors.

— The second part is an assessment of the national and regional economic benefits of the program.

While the focus of this assignment has been on the NPIC program, the methodology has been developed in a way that could be extended to the assessment of other activities in Geoscience Australia's Positioning Australia program.

1.2 Positioning Australia program

In the 2018-19 Federal Budget, the Australian Government announced an investment of an average of $83.6 million a year to enhance Australia's satellite positioning capability and provide world-leading positioning services. This capability is delivered by GA under the 2018-19 Budget measures, *Better GPS for regional Australia and Better GPS for Australian business*.[1]

The program is supporting innovation in positioning services and delivering productivity improvements across many industries important to Australia's future economic prosperity. It aims to improve positioning accuracy using the Global Navigation Satellite System (GNSS) to within 3 to 5 cm in areas with mobile phone or internet coverage, and from as little as ten centimetres everywhere else in Australia including the maritime zone.[2] The program is delivering this through:

— National Positioning Infrastructure Capability (NPIC). The NPIC program provides a unified approach to the management of the nation's positioning infrastructure.

— Ginan - a suite of open-source tools that are used to analyse GNSS data in real-time and generate products that support precise positioning solutions.

---

[1] Australian Space Agency (2018). *State of Space Report 2018-19,* accessed online 6 June 2022 at: https://www.industry.gov.au/sites/default/files/2020-05/state-of-space-report-2018-19.pdf

[2] Geoscience Australia (n.d.). Positioning Australia: About the Program, accessed online 6 June 2022 at https://www.ga.gov.au/scientific-topics/positioning-navigation/positioning-australia/about-the-program

— Southern Positioning Augmentation Network (SouthPAN). SouthPAN provides augmented and corrected satellite navigation signals directly from satellites based on Satellite Based Augmentation System (SBAS) technology. SouthPAN offers as little as 10 centimetre level accuracy across Australia, New Zealand and its maritime zones, overcoming gaps in mobile, internet and radio communications.

The Government invested around $64 million between 1 July 2018 and 30 June 2022 and around $12 million annually from 1 July 2023 to develop and maintain the NPIC and Ginan. Of this around $44 million has been directly invested in the NPIC infrastructure to 30 June 2022.

The economic benefits estimated in this report do not include the potential value of Ginan as a standalone tool but does include the value of Ginan as applied to NPIC. A production release of Ginan occurred in July 2022 and it is too early to understand and estimate the full value of the tools.

1.3 NPIC

Precise positioning technologies are embedded across many industry sectors. In Australia these technologies are being used to grow our food, build our roads, and keep our communities safe.

To obtain a precise position, observations from navigation satellite systems need to be corrected for a range of errors. These corrections are derived from networks of ground-based positioning infrastructure with precisely known coordinates.

The National Positioning Infrastructure Capability (NPIC) provides a unified approach to the management of the nation's positioning infrastructure. This ensures that consistent, fit-for-purpose precise positioning data and services are available to government, business, and academia.

Through a unified national network:

— consumers have access to high-quality data from certified reference stations,
— coverage of positioning services is increased and consistent between providers,
— service costs can be lowered due to free and open data,
— service providers have increased flexibility to tailor offerings to different industry sectors.

NPIC underpins Australia's geospatial fabric, supports research and innovation and is growing the positioning sector in Australia.

By establishing a unified national network, NPIC is enabling the delivery of positioning services with accuracies better than 5 cm across Australia in areas of mobile phone coverage.

To achieve this, Geoscience Australia has:

— modernised and expanded Australia's fundamental geodetic GNSS network (200 stations) to improve resilience and enable the tracking of the modern GNSS constellations and signals – ensuring a more accurate reference frame and improving the performance of positioning services within Australia,
— formalised agreements with government and commercial network operators, opening up access to the data streams from over 500 stations and supporting the uplift of these stations to meet national standards, and
— established secure digital platforms to collect, validate and disseminate the data.

Figure 1.1 National Positioning Infrastructure Capability

Source: Geoscience Australia

How it works

Through NPIC, Geoscience Australia offers two correction services derived from the unified network – a single base real-time kinematic (RTK) service which enables centimetre level positioning to registered users with the correct equipment near a reference station (< 50 km) and a Precise Point Positioning (PPP) service. Both of these services are offered free of charge – as a public good – but users are not provided with support or system integration.

All of the NPIC data streams are equally available to commercial services providers who offer value added services such as network RTK, system integration, support, and equipment sales.

Box 1.1 Techniques for improving accuracy of satellite data

Real-Time Kinematic positioning

The most common and most accurate technique is Real-Time Kinematic (RTK) positioning. RTK is based on the theory that the reference station and user are located close together (closer than 50 km) and therefore subject to the same errors. RTK offers high-accuracy positioning with near instantaneous convergence.

Precise Point Positioning

An alternate to RTK positioning is Precise Point Positioning (PPP). PPP depends on satellite clock and orbit corrections, generated from a network of fixed reference stations. Once these corrections are generated, they can be applied by the user regardless of how close they are to the reference stations. PPP does have some limitations on accuracy and performance.

Hybrid of PPP and RTK

More recently, a hybrid approach has been developed which combines the accuracy and performance of RTK with the flexibility of PPP. This technique, known as PPP-RTK, requires a denser reference station network than PPP (~ 150 to 200 km spacing) with stations used to generate corrections for the satellite clocks, orbits and atmospheric errors.

1.4 Ginan and NPIC

Ginan is a suite of open-source tools that are used to analyse GNSS data in real-time and generate products that support precise positioning solutions (e.g., precise orbits, clocks and atmospheric models). Ginan is developed and maintained by Geoscience Australia and uses state-of-the-art algorithms and models.

Within the NPIC system, Ginan is being used to validate and verify the quality of the data coming from the network, ensuring customers are only accessing data that is accurate and reliable and providing feedback to the station operators.

Ginan is also being used to generate models of the errors sources in real-time that are broadcast to customers over the internet as a PPP service with accuracies better than 5 cm.

1.5 SouthPAN

SouthPAN is a Satellite Based Augmentation Service (SBAS) that will provide from as little as 10 cm positioning accuracy across Australia and New Zealand including maritime zones.

SouthPAN early Open Services went live on 26 September 2022.

SouthPAN will provide safety of life services as well as positioning for users that purchase compatible receivers. It is possible that some current users of CORS based positioning services will switch to SouthPAN where accuracy of 10 cm is sufficient for their needs. Some such applications include vegetation mapping and autonomous vehicles where other sensors are available for safety and collision avoidance.

EY and FrontierSI estimated the economic benefits of an SBAS at $6.2 billion to the Australian economy over 30 years. The potential for switching between NPIC and SouthPAN services has been considered in this assessment of the benefits of NPIC.

1.6 This report

This report is structured as follows:

- Chapter 1 introduces the project
- Chapter 2 outlines our methodology and approach
- Chapter 3 discusses the impact of NPIC on the surveying and mapping sector
- Chapter 4 discusses the impact of NPIC on agriculture sector
- Chapter 5 discusses the impact of NPIC on the construction sector
- Chapter 6 discusses the impact of NPIC on the mining sector
- Chapter 7 discusses the impact of NPIC for research and innovation
- Chapter 8 discusses impact of NPIC in other sectors of the economy
- Chapter 9 summarises the economic impacts of NPIC

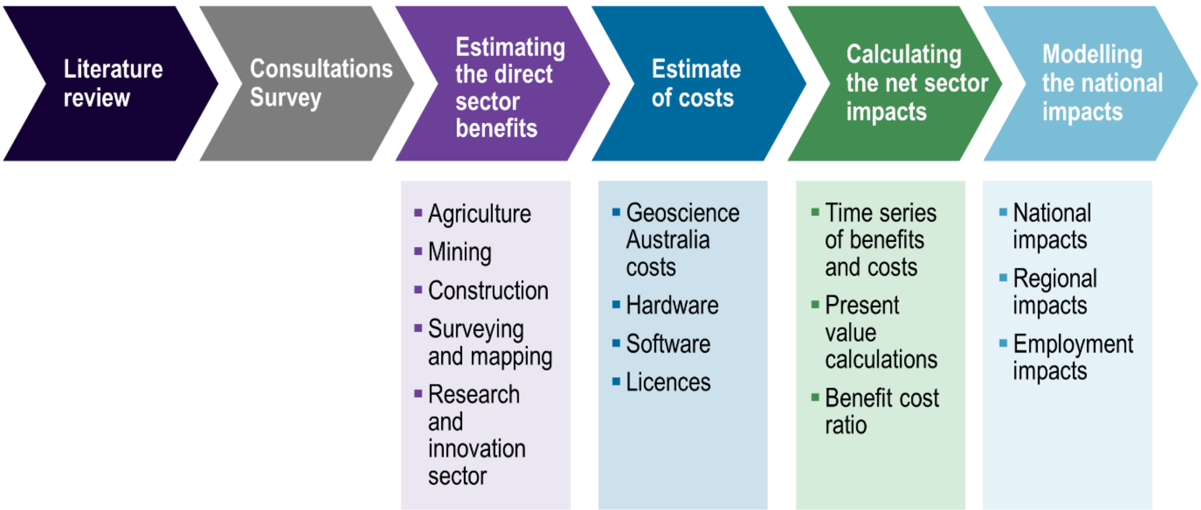
Approach and methodology 2

This Chapter sets out the approach adopted for this assignment. Chapter 3 sets out a detailed methodology for estimating the benefits.

2.1 Overview of the work program

An overview of the work program undertaken to generate this assessment is provided in **Figure 2.1** below.

Figure 2.1 Work program



Source: ACIL Allen

2.2 Literature review

ACIL Allen identified and reviewed 25 reports on the impact of precise positioning as part of this study. A full list of references is provided on page 82.

GA recommended the following reports for review:

- EY (2019), SBAS Test-bed Demonstrator Trial, Economic Benefits Report, FrontierSI
- ACIL Allen (2017), Economic value of spatial information in NSW, CRC SI
- US RTI International (2019), Economic Benefits to the Global Positioning System
- EU (2021), Special Report, EU space programs, Galileo and Copernicus
- ACIL Allen (2008), The value of spatial information in Australia, CRC SI.

These reports included relatively recent information on the economic benefits of positioning services as well as older information that provided context to the findings of recent reports. Not all the examples cited in these reports examined positioning services with 3 to 5 cm accuracy that is a characteristic of the NPIC. However, they provide a comprehensive review of the precise positioning applications in various sectors of the economy.

Earlier reports that focused on CORS network services in Australia were also reviewed. While some of these reports are dated, they included detailed analysis of applications that is still relevant today. The main changes that have occurred since those reports were published are greater integration of other technologies with precise positioning services, including sensors, control systems data analytics and machine learning. Adoption levels are now higher in most cases, than reported in earlier documents.

Relevant earlier reports include:

- Three reports prepared by the Allen Consulting Group between 2008 and 2011 for the then Victorian Department of Land, Water, Environment and Planning, prior to the Victorian Government's decision to invest in a network of CORS stations in Victoria. These reports canvased the potential benefits of positioning from a CORS network for agriculture, mining, and construction.
- 2013 analysis by ACIL Allen on the value of precise positioning in Australia, including nine separate reports on specific sectors including agriculture, mining, construction and surveying and mapping.
- An ACIL Allen (2017) report on the economic benefit of 3D digital models of the built environment in Queensland.
- Four reports by the Grains Research and Development Corporation (GRDC) on
  - The economics of precision agriculture (2017)
  - Variable rate technologies for Western Australian grain producers (2017)
  - A profit-first approach to precision agriculture (2019).
- Reports on applications in agriculture including:
  - Australian Farm Institute (2018), Precision to Decision
  - Revell GB et al (2020). Economic potential of autonomous tractor technology in Australia cotton production systems, Australian Farm Business Journal.

ACIL Allen reviewed these reports for evidence on economic benefits and levels of adoption of precision positioning services and used this evidence to complement the findings of the consultations and surveys.

2.3 Consultations

ACIL Allen consulted with a total of 37 organisations between March 2022 and June 2022. These organisations included those from:

- equipment manufacturers
- providers of positioning services
- surveying and mapping organisations
- agriculture
- mining
- construction
- research and innovation
- transport infrastructure.

A full list of the organisations consulted is provided at Appendix A**.**

Organisations in the equipment manufacturing and service provider sector, the agriculture sector, and the surveying and mapping sector provided significant information on the application and adoption of precise positioning services in Australia. Representatives of the Victorian, Queensland and Tasmanian governments were also consulted to better understand current and future government use of positioning technology.

Consultations with the construction and mining sectors were not as comprehensive, owing to lack of willingness to engage or share information on the technologies they use to support their activities. In this case, ACIL Allen relied on information from service providers augmented with internal information accumulated over many years of analysing the economics of geospatial systems in these two sectors.

2.4 Survey

ACIL Allen's economic assessment was also informed by a web-based survey examining the impact of precise positioning technology in Australia. The survey was launched on 25 April 2022 and closed on 28 June 2022.

The survey targeted three groups:

— component manufacturers/service providers/system integrators
— research and innovation organisations
— end users including surveyors.

Each group was provided with a different sequence of questions, exploring the benefits, costs and adoption of precise positioning, and the source of the positioning data. The questions were tailored to the target group to ensure they were relevant to that group. Stakeholders were asked to distinguish between likely applications and impacts over three time periods: FY 2018 to FY 2022, FY 2023 to FY 2028 and FY 2029 to FY 2038.

ACIL Allen contacted 17 stakeholder groups to support the distribution of the survey. The list of these organisations is included in Appendix B.

The survey received 19 draft responses and 10 submitted responses. ACIL Allen summarised 16 responses (10 submitted responses and 6 draft responses that were substantially completed) for use in the study. These 16 responses included the construction, geospatial, forestry and R&D sectors.

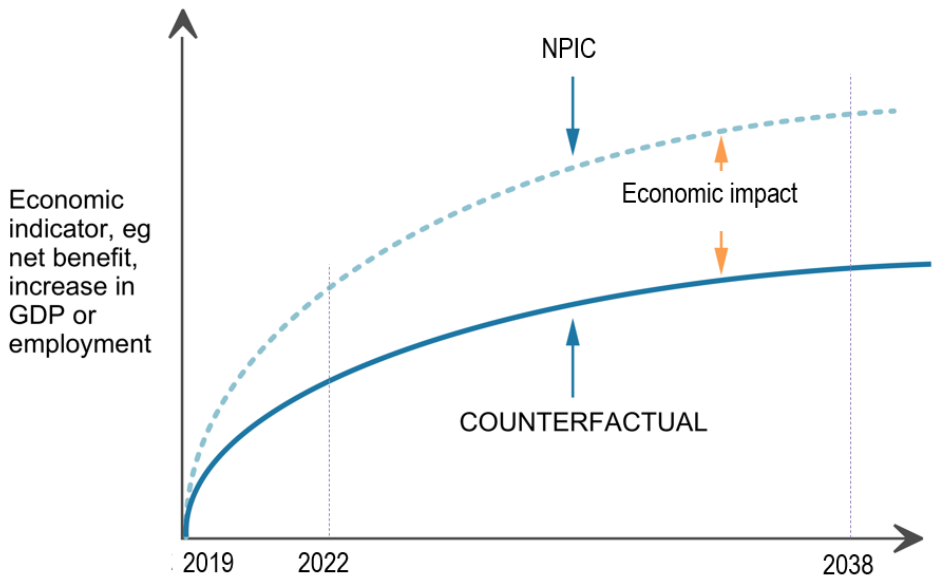
2.5 Establishing the evaluation and the counterfactual scenarios

Two scenarios were established to estimate the economic impact of the NPIC program:

— An "NPIC Scenario" that includes NPIC
— a Counterfactual Scenario that excludes NPIC.

The difference in economic outcomes between the NPIC Scenario and the Counterfactual Scenario represents the net benefit that NPIC delivers (see Figure **2.2).**

Figure 2.2 Economic impact



Source: ACIL Allen

2.5.1 The NPIC Scenario

As discussed in Chapter 1, NPIC provides a unified approach to the management of the nation's positioning infrastructure. This ensures that consistent, fit-for-purpose data and services are available to government, business, and academia.

Commercial service providers across Australia rely on the data streams from the NPIC network to deliver value added services such as RTK correction services, system integration, support and sales.

The following assumptions apply to the NPIC Scenario:

1. The GA's CORS network that existed at the end of FY2018 is expanded in line with historical trends (FY2019 to FY2021) and as projected from FY2022 to FY2038.
2. Capital, operating and maintenance expenditure for NPIC from FY2018 to FY2021 as incurred.
3. Capital, operating and maintenance costs from FY2022 to FY2042 were based on projected budget figures provided by GA.
4. There continues to be a unified approach to the management of the nation's positioning infrastructure.
5. Further innovation in receiver technology and control systems continues. An assessment was made on the rate of innovation from consultations and be used as an input into projections of future growth in the geospatial market.
6. SouthPAN went live in September 2022.
7. Mobile phone coverage was as indicated in the November 2022 Positioning Australia Monitoring and Evaluation report.[3]

[3] GA compares CORS stations against mobile phone coverage. Mobile phone coverage in this report has been based on reporting by Telstra and can be found at https://www.telstra.com.au/coverage-networks/our-coverage /

8. Private sector and state-run CORS services continue as at December 2021 with some expansion of the commercial network in some areas.
9. New open service offerings from NPIC using the Ginan software are commissioned by the end of 2022 to enable accuracies better than 5 cm without the need for a direct connection to local CORS. This will result in increased coverage of NPIC services up to 95% in areas in mobile phone reach.
10. Introduction of the new service offerings enabling services such as PPP-RTK delivered through industry, will provide real time corrections to less than 5 cm across larger regions without the need for a direct connection to local CORS. This will result in increased coverage of centimetre services by industry up to 95% in areas in mobile phone reach.

Counterfactual Scenario

The following assumptions apply to the Counterfactual Scenario.

1. The GA CORS network as existed at the end of financial year 2018 continues to operate with no further capital investment in reference stations or in processing software by GA.
2. Operations and maintenance expenditure continue consistent with the number of reference stations in the network.
3. Investment by GA in the NPIC program does not occur.
4. There is no unified approach to the management of the nation's positioning infrastructure.
5. SouthPAN comes into existence in December 2022.
6. Mobile phone coverage is as assumed in the November 2022 Positioning Australia monitoring and evaluation report.
7. Private sector and state-run CORS services continue as at December 2021 with expansion of commercial networks in some areas.
8. Additional availability and reliability due to redundancy in stations and unification of the CORS network is not realised.

2.6 Estimating the direct economic benefits

The direct economic benefits represent those immediate benefits that accrue to a sector. Precise positioning has applications in many sectors of the economy. This report focusses on the direct economic impacts of NPIC on four sectors that have been early adopters of precise positioning services:

— surveying and mapping
— agriculture
— construction
— mining.

The report also reviews the impact of NPIC on research and innovation, which is important to future adoption of precise positioning services. This was used to support estimates of likely future adoption of technologies that would draw on NPIC.

2.6.1 NPIC as a public good

The data and services derived from NPIC are provided by GA as a public good. This is consistent with policies for supply of location information under the Foundation Spatial Data Framework.[4] The characteristics of public goods are outlined in Box **2.1**.

This policy recognises that there are larger benefits achievable to society by providing these data free of charge. Under these circumstances there is no price on which an assessment of economic value can be based. Accordingly, it is necessary to estimate the value of a public good such as NPIC by examining the value that it creates for users of the service.

Box 2.1 The nature of a public good

A public good is defined as non-rival and non-excludable good.

— Non rival – that is, the consumption by one consumer does not diminish the availability of the good to other consumers. An example is national security or defence

— Non excludable – that is, one cannot exclude individuals from consuming it. An example of non-excludability is the environment or biosecurity.

A characteristic of a public good is that the marginal cost of supplying additional consumption is zero or close to zero. It follows that the price of a public good should be zero or close to zero if economic welfare is to be maximised.

Source: Productivity Commission (2001) Cost recovery by Government Agencies – Inquiry report

2.6.2 The value created by NPIC users

NPIC provides a unified approach to the management of the nation's positioning infrastructure. This ensures that consistent, fit-for-purpose data and services are available to the government, business, and academia.

The value that this delivers to users can be realised in several ways through:

1. increased productivity
2. cost savings
3. increased turnover
4. increase in innovation
5. increase in resources
6. increase in the efficiency of capital.

For this report, ACIL Allen explored the first four of these possible sources of value.

[4] The Foundations Spatial Data Framework comprises 10 spatial data themes (including positioning) that are provided as a public good. For more information visit: https://link.fsdf.org.au/

2.6.3 Estimating the direct impact of NPIC on a sector

To estimate the economic impact of NPIC on a sector, it was first necessary to estimate the percentage increase in productivity or output that could be attributed to NPIC. This percentage was then combined with the value added created by that sector to provide the estimate of the economic impact of NPIC. [5]

$$Economic\ impact\ for\ a\ sector\ = Pnpic * V$$

where

Pnpic = the percentage change in value added for a sector that can be attributable to NPIC

V = the baseline value added for the sector.

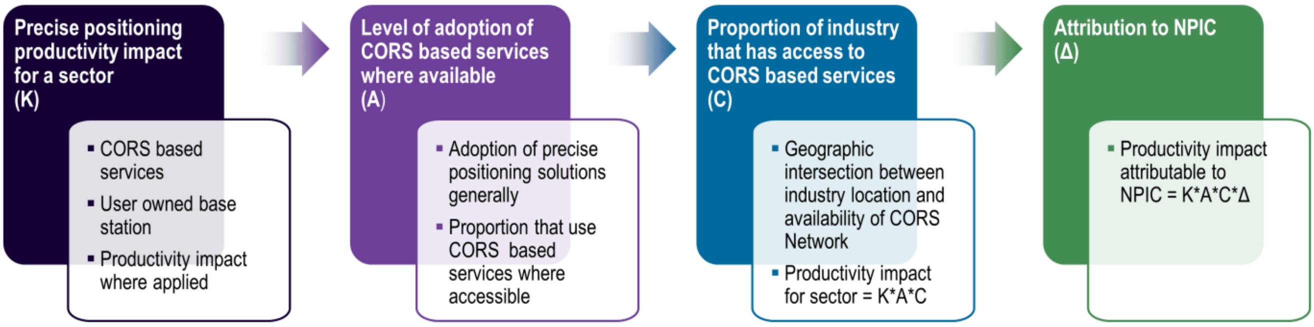
Value added for a firm or economic sector is the revenue it generates less the cost of inputs and is a broad measure of the economic contribution of a firm or sector. Total value added for an economy is the major component of Gross Domestic Product. Sectoral value added statistics are collected by the Australian Bureau of Statistics and provided in Input Output tables. ACIL Allen also maintains a data base of value added by sector as part of its Computable General Equilibrium (CGE) Model software.

The analysis considered the likely costs users would incur in using the NPIC data. This was a very broad assessment based on the findings of interviews and the survey.

2.6.4 Estimating the Pnpic

Estimating the percentage change in value added for a sector in this case involves four steps. An overview of the sequence of analysis that was undertaken to assess the direct benefit of NPIC is summarised in Figure **2.3** below.

Figure 2.3 Process for identifying the benefit of NPIC



Source: ACIL Allen

Step 1 – Assessing the benefit attributable to precise positioning (K)

The first step involved estimating the productivity benefit (K) of an application of precise positioning (3 to 5 cm) regardless of whether it was achieved through a CORS based service or via user owned base station.

These estimates were drawn from the review of research papers and reports, the findings of the survey where available and consultation with industry and users as outlined in Sections 2.2 to 2.4.

[5] Value added of an enterprise is the difference between the revenue generated less the costs of inputs. Gross value added across the economy is the main component of Gross Domestic Product.

The estimates of potential future productivity impacts also considered findings from consultations on research and innovation as discussed in Chapter 7.

Step 2 – Assessing adoption of precise positioning solutions that use the CORS Network (A)

The second step was to assess the level of adoption of a CORS based services to support the delivery of precise positioning. This required estimates of two adoption factors:

— the general level of adoption of precise positioning in the industry sector in question (Ap)

— the proportion of users that draw on the CORS networks as opposed to an alternative approach (Ac).

The level of adoption of a CORS based service can be calculated from the following formula

$$Adoption\ of\ CORS\ based\ services\ (A) = Ap * Ac$$

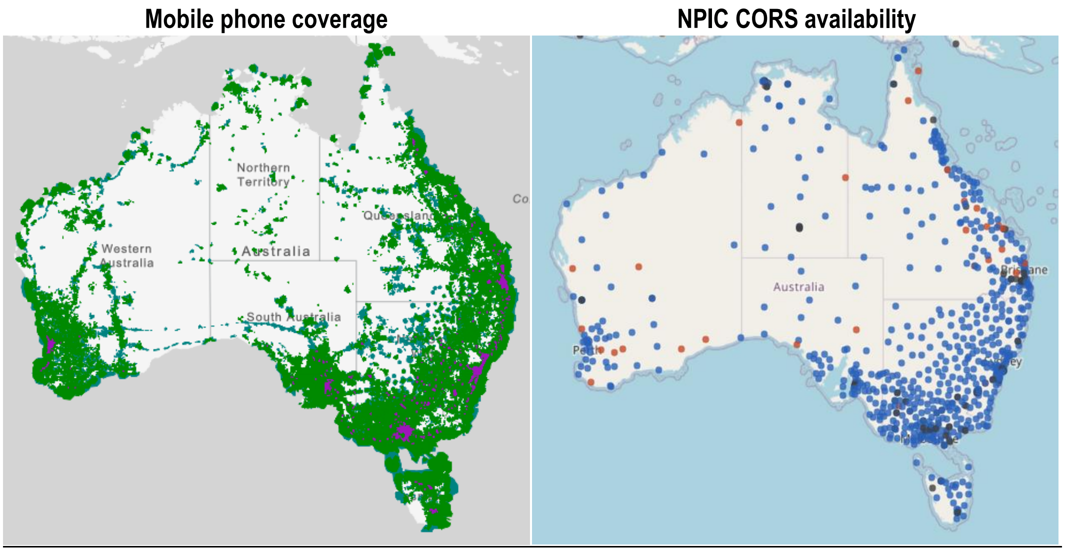
Information to inform this assessment was derived from literature and consultations.

Step 3 – Assessing the access of the industry to the CORS based services

The third step was to assess the industry's access to CORS based services. This is a function of mobile phone coverage, the availability of CORS within that coverage and the geographical intersection between the location of the NPIC CORS network and the location of the industry.

The extent of mobile phone coverage is estimated from data available on the Telstra network and the CORS coverage is derived from data provided by GA (**Figure 2.4**).

Figure 2.4 Mobile phone coverage



Source: https://www.telstra.com.au/coverage-networks/our-coverage / https://gnss.ga.gov.au/network as of March 2022.

The intersection between the NPIC CORS network and the mobile phone coverage is recorded spatially by GA. **Table 2.1** shows the percentage of mobile phone coverage in Australia where NPIC services are enabling centimetre level positioning services by direct connection to local CORS. The analysis assumes that services are available within 50 km of CORS where there is mobile phone coverage. This analysis is based on RTK technologies; with the launch of the Ginan PPP service, the availability of centimetre level positioning services will have increased beyond the goal of 95% coverage.

Table 2.1 Estimated percentage of area covered by the Telstra mobile phone network with access to RTK services supported by NPIC

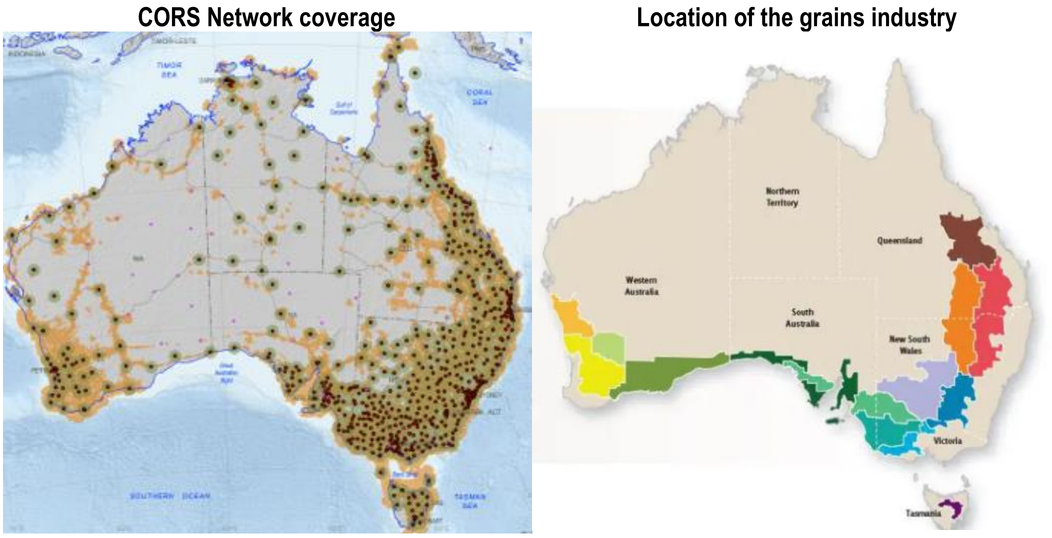
	July 2018	February 2021	April 2021	June 2021	October 2021
NPIC coverage	23%	49%	60%	60%	67%

Source: Geoscience Australia

As many commercial offerings integrate the NPIC network with private infrastructure to deliver services with wider coverage and improved performance, these figures represent a minimum level of contribution that can be reasonable attributed to the NPIC.

To translate this into industry benefits, the geographic intersection between the physical location of the industry sector being assessed and the modelled coverage of the CORS based services was used to identify the areas where an industry would be able to take advantage of the benefits available from NPIC. This was achieved by overlaying maps of industry location and the CORS network coverage. This is illustrated in **Figure 2.5** using the grains industry as an example. The figure shows that not all grains enterprises have access to the NPIC CORS network.

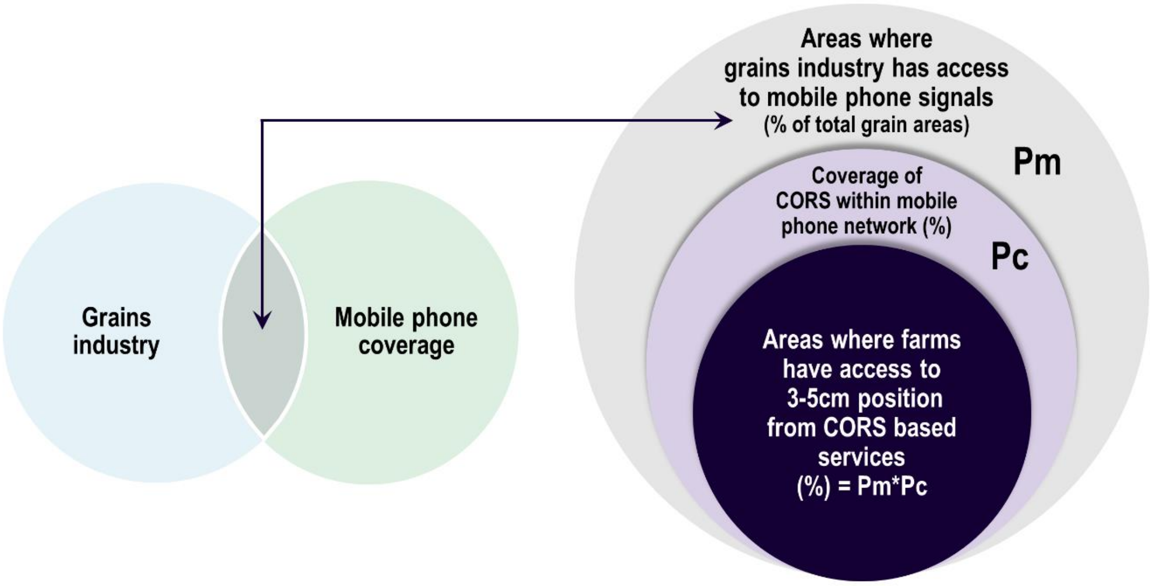
Figure 2.5 Overlaying CORS network over the grains industry



Source: Geoscience Australia and Grains Research and Development Corporation (GRDC). Accessed March 2022.

The process of developing the share of the productivity benefits that could be attributed to the NPIC CORS network solution is illustrated graphically in Figure **2.6**.

Figure 2.6 Assessing the area where grains industry has access to the CORS network



Source: ACIL Allen

As shown in the diagram, the areas where users have access to the NPIC CORS network is a function of the proportion of the grains industry that has access to mobile phone coverage and the availability of the NPIC CORS network within that coverage. This was estimated from the following formula:

$$C = Pc * Pm$$

where

C = The proportion of grain enterprises that have access to CORS based services

Pc = the coverage (%) of the NPIC CORS network within that mobile phone coverage.

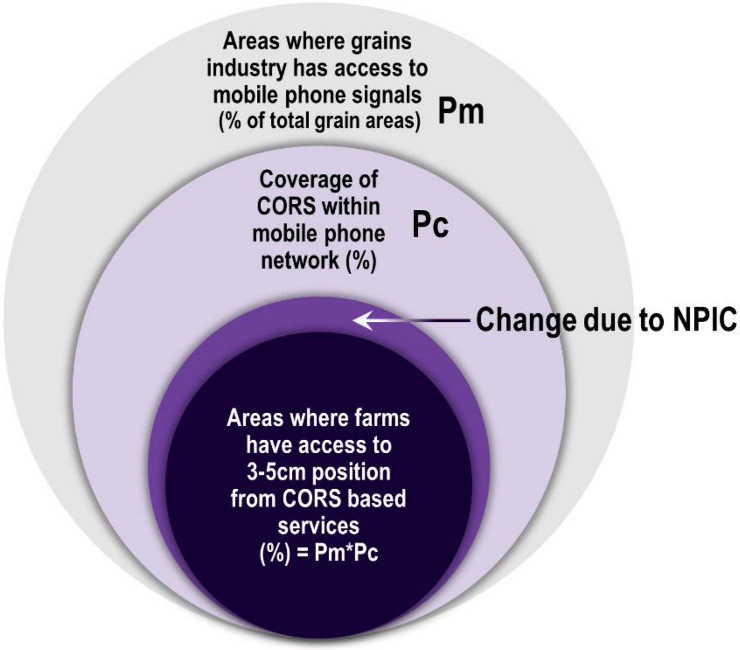
Pm = the proportion (%) of grains industry enterprises have access to mobile phone coverage

2.6.5 Percentage change in value added for a sector that can be attributed to NPIC

The final step is to estimate the proportionate productivity benefit that can be attributed to NPIC for each sector.

To simplify, it is assumed that the NPIC enables and improves access to 3 to 5 cm accurate positioning services and increases coverage as discussed in Section 2.5.1. This is illustrated in Figure **2.7**.

Figure 2.7 Increased access to CORS based services attributable to NPIC



Source: ACIL Allen

The increase in access to 3 to 5 cm accurate positioning services is then adopted as a proxy for the additional benefits from the use of precise positioning that can be attributed to NPIC. The increase in access to CORS based services is calculated from the following formula.

$$Increase\ in\ access\ to\ CORS\ based\ services = C * \Delta$$

Where Δ = the proportionate increase in the area where the 3 to 5 cm accurate positioning services is available because of NPIC.

The magnitude of Δ was assessed at around 2 per cent based on technical evidence provided by GA and the views of service providers and users on the incremental value of the service. This considered the:

- expansion of precise positioning services through the introduction of new positioning techniques, such as PPP/RTK that require less dense CORS networks.
- increased levels of reliability and redundancy with the support of NPIC providing confidence that the data and services are accurate and reliable.
- effect of strengthening the precise positioning sector providing a more robust industry with increased confidence on the part of users of its reliability leading to increased use of precise positioning in Australia generally.

2.6.6 Aggregating the impact

The final impact on the sector is calculated as follows:

$$Pnpic = K * A * C * \Delta$$

where

- Pnpic = sector impact as a percentage of sector value added
- K = productivity impact of the application of precise positioning at 3 to 5 cm accuracy

— A = level of adoption of solutions based on the NPIC CORS network.

The sector impact is then calculated as shown in Section 2.6.3**.**

$$Economic\ impact\ for\ a\ sector\ = Pnpic * V$$

Where V = industry value added

The impacts were calculated for each of the surveying and mapping, agriculture, construction and mining sectors and reported in Chapters 3, 4, 5 and 6 that follow.

2.7 Estimating the costs

There are two types of costs involved in implementing NPIC:

— user costs incurred by sectors when using NPIC

— GA's capital and operating costs for the NPIC program.

User costs include capital costs in purchasing receivers and other equipment to enable the user to receive the positioning services, operating costs associated with using the services, training and other costs required to establish the system. These costs were considered when estimating productivity impacts so that end user benefits were estimated net of these costs.

GA's program costs include two main elements:

— direct capital and operating costs incurred by GA

— licence fees paid by GA to third-party operators of CORS stations in exchange for access to their data.

The licence fees reflect a proportion of costs that other operators have incurred to establish their facilities that provide data to GA.

Table **2.2** below shows NPIC's budget by year, broken down by operating and capital expenses. Operating expenses include all employee expenses and scientific data licences.

Table 2.2 NPIC budget breakdown by financial year[6] ($ '000)

	2018-19	2019-20	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26
Operating Expenses	3,060	5,345	5,655	6,700	6,897	6,897	6,897	6,897
Capital Expenses	1,495	2,453	4,082	15,330	3,100	3,100	3,100	3,100

Source: Geoscience Australia

On advice from GA, ACIL Allen has assumed that the operational and capital expenses remain constant at 2025-26 levels until 2037-38.

As the use of the NPIC is non-rival, it is not meaningful to attribute NPIC costs to sectors. As a result, the economic benefits of the NPIC for each major sector presented in Chapters 3 to 6, are net of user costs in those sectors but are not net of GA's NPIC costs. The latter costs are considered in aggregate and factored into the overall cost-benefit analysis in Chapter 9.

[6] 2018-19 to 2020-21 represents expenditure, while 2021-22 onwards is the projected budget

2.8 Reporting direct impacts on the four sectors

The evaluation period involves the benefits since NPIC commenced in FY 2019 up to FY 2021 and estimates of future benefits that may emerge between FY 2022 to FY 2038. The results of the analysis were converted into economic costs and benefits, and the present value and a benefit-cost ratio was calculated using standard discounting techniques as outlined in Box **2.2.**

Box 2.2 Discounting economic costs and benefits

Discounting

The present value of a monetary value A(n) accruing in a future year n is discounted according to the following formula:

$$Present\ value\ of\ A(n) = \frac{A(n)}{(1+r)^{n-1}}$$

Where:

r= discount rate

Benefit-cost ratio

This can be calculated with the following formula:

$$Benfit\ cost\ ratio = \sum_1^n \frac{B(n)}{(1+r)^{n-1}} / \sum_1^n \frac{C(n)}{(1+r)^{n-1}}$$

Where:

B(n) = benefit in year n C(n) = cost in year n

Source: ACIL Allen

Economic costs and benefits were discounted at 3 per cent, 7 per cent and 10 per cent in line with the requirements of the Office of Impact Analysis.[7] Calculations were presented as a present value as at FY 2022.

2.9 Calculating the national and regional benefits

The impacts calculated for each sector are considered in economic analysis as the direct effects. There are also indirect effects that arise because of the changes induced in each sector. These arise when the performance improvement in one sector works its way through to the rest of the economy.

For example, an increase in productivity in the agricultural sector is likely to result in growth in agricultural output which, in turn, leads to an increase in demand for agricultural equipment which benefits the equipment manufacturing sector.

Increased productivity in the agriculture sector can also stimulate an increase in agricultural exports as Australian agricultural production becomes more competitive compared to competitors in other countries. These effects ultimately lead to additional economic benefits for the agricultural sector as well as the national economy.

[7] Office of Impact Analysis, Cost Benefit Analysis, accessed online on 27 March 2023. https://oia.pmc.gov.au/resources/guidance-assessing-impacts/cost-benefit-analysis

There may also be negative impacts on other sectors of the economy, as capital and labour are reallocated to the better performing sectors. The net effect on the national economy, however, will be positive because of an increase in efficiency of resource allocation in the economy generally.

We calculated these changes using our *Tasman Global* Computable General Equilibrium (CGE) model that draws on the Global Trade Analysis Project (GTAP) data base developed at Purdue University.[8] ACIL Allen has tuned this model specifically for the Australian economy, drawing on our extensive experience in modelling the Australian economy at a national and regional level.

To calculate the national and regional impacts of the NPIC program, ACIL Allen applied the economic benefits calculated for the four sectors analysed above to the CGE model. The CGE model adjusts for resource reallocation throughout the economy and calculates a new equilibrium for the national economy.

The changes in economic aggregates between this NPIC scenario and the counterfactual scenario then represent the change in national and regional impact of NPIC. National changes are then reported as changes in Gross Domestic Product and regional changes are reported as changes in Gross State Product or Gross Regional Product.

The brief for this project requires reporting the results for the jurisdictions and for capital cities and regional areas.

A key issue when estimating the impact of NPIC is determining how the labour market will respond to capital and operational expenses of NPIC.[9] An increase in the demand for labour can be met by three mechanisms:

- increased migration from the rest of Australia
- increased participation rates and/or average hours worked
- reduced unemployment rate.

In the model framework, the first two mechanisms are driven by changes in the real wages paid to workers in the region of benefit. The third is a function of the additional labour demand relative to the Counterfactual Scenario.

Given the moderate unemployment rate assumed throughout the projection period, changes in employment and participation rates account for most of the additional employment from the NPIC Scenario relative to the Counterfactual Scenario. This analysis does not assume any change in net foreign migration. Interstate migration rates, and the birth and mortality rate trends, are assumed to follow current demographic trends.

Details of ACIL Allen's Tasman Global model are provided at Appendix C.

---

[8] The Global Trade Analysis Project is based at Purdue University, see https://www.gtap.agecon.purdue.edu/about/center.aspx

[9] As with other CGE models, the standard assumption within *Tasman Global* is that all markets clear (i.e., demand equals supply) at the start and end of each period, including the labour market. CGE models place explicit limits on the availability of factors and the nature of the constraints can greatly change the magnitude and nature of the results. In contrast, most other tools used to assess economic impacts, including I-O multiplier analysis, do not place constraints on the availability of factors. Consequently, these tools tend to overestimate the impacts of a project or policy.

Impact on surveying and mapping 3

3.1 Overview of the surveying and mapping sector

The surveying and mapping sector provides professional services spanning a range of markets and disciplines. This includes cadastral surveying, engineering surveying, construction surveying, mining, geophysical and integrated surveying, mapping and geospatial image acquisition and processing.

The services provided by surveyors are drawn on by developers, architects and engineers and form the underlying data on which conceptual and detailed design are based. Surveying also supports the construction phase of projects and plays a role in the creation and formatting of spatially accurate and reliable 'as constructed' asset management records.

The surveying and mapping sector generated around $3.5 billion in revenue and $2 billion in value add in FY 2022. The industry is estimated to employ around 16,300 people.[10]

Most small-scale surveying firms generally generate revenue through provision of traditional cadastral boundary surveying services, while larger firms also derive revenue from integrated surveying, mapping and planning services for property development, construction, mining and energy projects.

The sector output also includes creation of geographic information services that support a wide range of activities in both the public and private sectors.

3.2 Overview of precise positioning use in surveying and mapping sector

Precise positioning is used widely in the surveying sector. From a gradual take up of Global Navigational Satellite Services (GNSS) during the 1990s, mainly by larger firms undertaking project control network surveys, most surveying firms now use satellite based precise positioning in their work. Our consultations confirmed that adoption is now close to 100 per cent in this sector.

The cadastre has been developed since federation and it contains inherent inaccuracies of spatial definition in some areas.[11] All Australian jurisdictions have regulated absolute accuracy for cadastral surveys at between one to two centimetres. Precise positioning using GNSS and augmentation techniques such as RTK are now playing a major role in cadastral surveys.

[10] IBIS Word (2022), Surveying and Mapping Services in Australia.

[11] The cadastre is an official register of the quantity, value, and ownership of property.

Surveyors both 'identify' and 'mark' property boundaries. Lower accuracy is often adequate for identification surveys, in which case single frequency or 'asset grade' GNSS receivers can be employed. In this case 'Differential GPS' (DGPS) can be used, but the accuracy obtained, either via 'real time' augmentation, or 'post-processed', can be of the order of one metre in the horizontal plane.[12]

Cadastral surveying has changed significantly through technological advances in surveying and data-storage technologies. This has reduced the time allocation per transaction. Firms have been increasingly developing positioning applications over the past decade, using satellites and 3D positioning with ground-based equipment for surveying, mapping, and navigation.[13]

Technological disruption derived from advancements in surveying equipment and data retrieval, is expected to improve the service provided by the industry and yield substantial savings in time and labour.

The widespread introduction of electronic measurement systems has resulted in substantial efficiency gains and has improved the accuracy and completeness of projects. In addition, the field of aerial photography for surveying and map making has been impacted by significant reductions in the cost of drone technology.[14]

Site surveying and set out is fundamental to all construction and engineering related projects. Survey information provides the foundation to support concept, design and construction and is the basis on which subsequent project phases are based.

Precise positioning is widely used for site surveying. This has improved both the reliability and efficiency of operations through rapid capture of site information and the fast and reliable set-out of information from design and construction plans.

Typically, surveyors have been at the forefront of GNSS developments and have invested in both equipment and methodology to maximise the benefits of precise GNSS positioning available from RTK technologies. Prior to the introduction of GNSS, surveyors used optical instruments (reliant on line of sight) to verify locations. This approach was labour-intensive and slow, adding cost and regularly delaying other activities that were dependent on survey data.

Site environments mean that these practices are often still required, but the introduction of precise positioning has improved the efficiency of survey operations, reduced errors and improved the timeliness of survey work. Construction survey work requires accuracy at the cm level. RTK technologies and CORS based services are suitable for this level of accuracy.

3.2.1 Literature review

The value of precise positioning for surveying and mapping has been identified in many past reports. The areas where precise positioning using RTK techniques are being heavily utilised in the surveying and mapping sectors have been discussed in recent reports from the European Union,

[12] Real time augmentation relates to the situation when correction signals are broadcast via radio frequencies, such as for RTK GPS, or via Omnistar corrections, or via CORS signals broadcast over a mobile phone network. Post processed means that data collected in the field is not corrected until returning to the office, where an internet connection is used to access base station data for software based 'correction' of the raw data.

[13] IBIS World (2022). *Surveying and Mapping Services in Australia.*

[14] Ibid.

the US, and Canada.[15, 16, 17] A US study undertaken by RTI International in 2019, estimated that the savings to the surveying sector in the US, attributable to GPS techniques, was around US $3 billion in 2017 representing around 0.02 per cent of US GDP in that year. However, this study included all use of GPS, not just precise position at 3 to 5 cm.

A 2019 EY report for the SBAS Test Bed Demonstrator Trial also discussed the application of precise positioning, reporting savings in reduced labour requirements for cadastral surveys and reduced operating costs for aerial imaging.[18]

ACIL Allen (2013) estimated productivity gains in the surveying and mapping sector to be 10 to 15 per cent by 2020.[19] ACIL Allen (2017) reviewed the use of precise positioning in NSW and found savings in several areas (see Table **3.1**). The savings in costs range between 20 per cent for route selection to 80 per cent for mobile laser scanning.

Table 3.1 Savings from precise positioning in the NSW surveying and mapping sector

Application	Savings
Survey control	Savings of up to 75 per cent
Engineering surveys	Route selection – 20-30 per cent savings Detail control – 40-60 per cent savings Detail survey – 40-50 per cent savings Set out – 20-30 per cent savings As constructed surveys – 20-30 per cent savings
Mobile laser scanning	Savings of up to 80 per cent

Source: ACIL Allen (2017) Economic value of spatial information in NSW

3.2.2 Consultations

ACIL Allen consulted six surveying and mapping organisations, and three state government departments during this project. In general, stakeholders noted that they would use CORS network derived services wherever they are available because it reduced costs. One firm noted that companies that use CORS network services do not need to purchase multiple GNSS receivers, as they can use one receiver with CORS data. This also means that only one employee is required to conduct a survey rather than two.

Estimates of savings to the surveying sector ranged from 10 per cent to 50 per cent depending on the application. Surveying companies also noted that their sector generally had good access to CORS networks, in contrast to other sectors such as agriculture or mining, where some users find it difficult to use the network due to the limited mobile phone/internet coverage.

State government departments reported that they used CORS network derived services when available. Typical applications were vegetation mapping, data collection following natural disasters, and in emerging ‘digital twin’ models (3D digital models of the built and/or natural environment).

---

[15] EUSPA (2022). *User needs and requirements (surveying)*

[16] RTI International (2019). *Economic benefits of the Global Positioning System*

[17] EY (2020). *Value of precision GNSS services in Canada, Natural Resources Canada.*

[18] EY (2019). *SBAS Test-bed Demonstrator Trial Economic Benefits Report*

[19] ACIL Allen (2013). *Precise positioning in the surveying sector*

In general, service providers felt that the impact of the NPIC was positive. Some of the larger service providers noted that, while the NPIC program generates positive benefits, it also means that their competitors have access to the data from their private CORS stations through the licensing agreement with Geoscience Australia. This was expected to impact future market share.

A recent entrant to the service provider market said that they do not operate any CORS stations and rely on data available through NPIC. Instead of offering their costumers an annual subscription, they offer a flexible month-by-month service fee. The firm stated that this was only possible due to NPIC and believe that NPIC is providing significant benefits and opportunities for the sector through reducing barriers to entry in the market, providing access to high-quality data with consistent coverage and lowering costs.

Some surveying companies noted that the use of RTK systems and CORS networks, where available, had supported automation of machine guidance for construction projects. This had delivered considerable savings to the construction sector in the set-out stage. This is discussed further in Chapter 5.

Another message was rapid growth in the mapping and geospatial component of the sector. This subsector draws on precise positioning in combination with other technologies including geographic information systems, sensors, control systems and data analytics to support planning, design, and construction activities for both industry and local government.

The consensus view was that this area would continue to grow as the technologies and applications evolved and adoption increased. Some felt that the sector could grow by as much as 10 per cent in the coming years.

3.2.3 Economic benefits survey responses

ACIL Allen received one survey response from the survey and mapping industry. It was submitted by a geospatial firm which serves both metropolitan and regional areas. This firm uses precise positioning technology for the placement of survey controls to MGA2020 that requires one to two centimetre accuracy.

The firm currently uses a network RTK solution through a commercial service provider. From FY2019 to FY2021 the application has helped them decrease their operating costs by up to 5 per cent, increase their productivity by 10 to 20 per cent and increase their profits by up to 5 per cent. The firm also observed that it had contributed to workplace safety of employees as it reduces the need to connect to marks outside project boundaries. It has cost them around $100,000 to realise these benefits. The firm estimates that around 70 per cent to 80 per cent or surveying firms currently use precise positioning services that draw on the NPIC.

The firm expects operating costs to decrease by around 5 to 10 per cent between FY 2022 and FY 2028. From FY 2029 to FY2038, they expect operating costs to decrease by a further 5 per cent to 10 per cent. They do not expect to encounter any additional costs or any further non-quantifiable benefits.

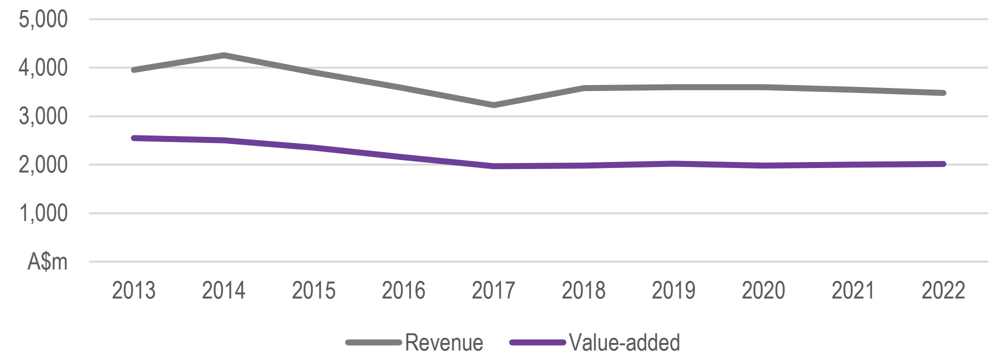
Given the mandatory adoption of MGA2020 for subdivisions and cadastral work, they expect NPIC adoption to increase to around 90 percent to 100 per cent by FY 2028. [20] They expect this high adoption rate to continue, driven by improvements in technology, legal traceability of coordinates/control, the ongoing need for quality and integrity of data, and legislative requirements.

[20] MGA 2020 is latest Map Grid of Australia

3.3 Economic benefit of the NPIC for the surveying and mapping industry sector

The total economic contribution (value-added) of the surveying and mapping sector in the Australian economy in 2020-21 was $2 billion, accounting for 0.10 per cent of Australia's Gross Domestic Product (GDP). The sector's revenue and value-added over the past decade is shown in Figure **3.1.**

Figure 3.1 Revenue and value-added of Australian surveying and mapping sector, FY 2013 - FY 2022



Source: IBISWorld Industry Report M6922, Surveying and Mapping Services in Australia.

The evidence from consultations, the survey and selected case studies, suggest that there is close to 100 per cent adoption of precise positioning technologies in the surveying and mapping sector. These technologies are supporting innovation and ongoing growth in the sector.

Surveying sector stakeholders indicated that precise positioning technologies can realise cost savings of between 15 and 80 per cent depending on the application. Allowing for the fact that the positioning activities of the surveying process represent one third to one half of the activities of surveying and related activities, a conservative figure of 15 per cent was assumed as the overall productivity benefit of the NPIC to the sector.

ACIL Allen assumed adoption rates of 80 per cent in 2019, rising to 95 per cent by 2038.

In addition, it was considered reasonable to assume that the sector would grow by around 4 per cent per year due to the potential for the sector to offer new services such as mobile laser scanning and drones for infrastructure surveys.

Based on these assumptions, ACIL Allen estimated net productivity and economic benefits of the NPIC program to the mapping and surveying sector. These are summarised in Table **3.2.**

Table 3.2 Undiscounted economic benefits of the NPIC to the surveying and mapping sector, by state and territory, FY 2019 to FY 2038

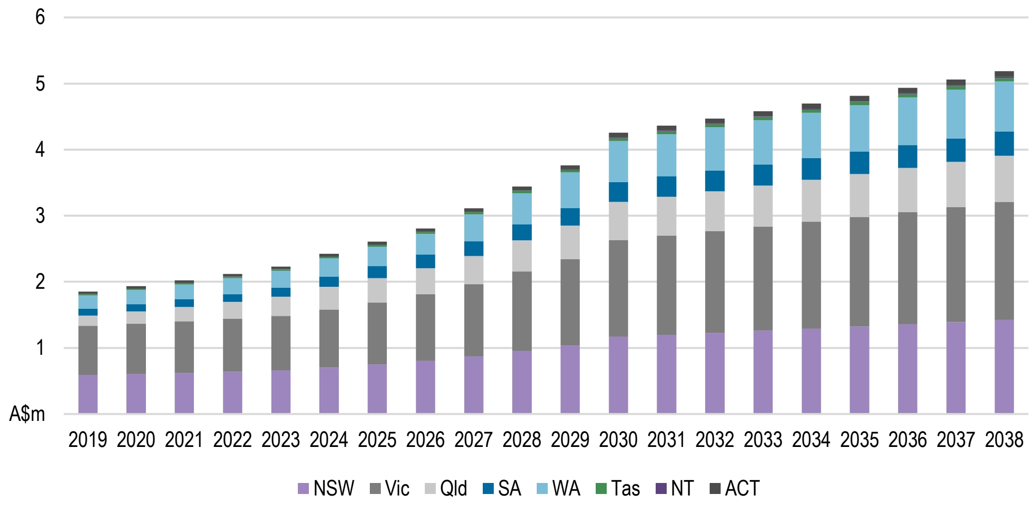
Jurisdiction	Annual average between FY 2019 and FY 2038		Total between FY 2019 and FY 2038	
	Productivity %	Direct economic benefit $m	Productivity %	Direct economic benefit $m
New South Wales	0.13	0.99	2.51	19.9
Victoria	0.20	1.24	3.98	24.9
Queensland	0.10	0.47	1.92	9.3

Jurisdiction	Annual average between FY 2019 and FY 2038		Total between FY 2019 and FY 2038	
South Australia	0.17	0.24	3.39	4.9
Western Australia	0.10	0.48	2.00	9.6
Tasmania	0.18	0.04	3.51	0.7
Northern Territory	0.02	0.01	0.38	0.1
Australian Capital Territory	0.18	0.06	3.51	1.2
Total	**0.13**	**3.54**	**2.70**	**70.7**

Benefits are net of user costs but not Geoscience Australia's costs.
Source: ACIL Allen estimates.

Figure **3.2** below shows the undiscounted net benefits of NPIC to the surveying and mapping services sector in Australia.

Figure 3.2 Annual undiscounted economic benefit of the NPIC to the surveying and mapping sector by state and territory, FY 2019 to FY 2038



Source: ACIL Allen estimates

The discounted direct gross benefits attributable to the sector are provided in Table **3.3**. The present value of total benefits accruing to the surveying and mapping sector from FY 2019 to FY 2038 due to the NPIC program is estimated to be **$43 million** (using a 7 per cent real discount rate).

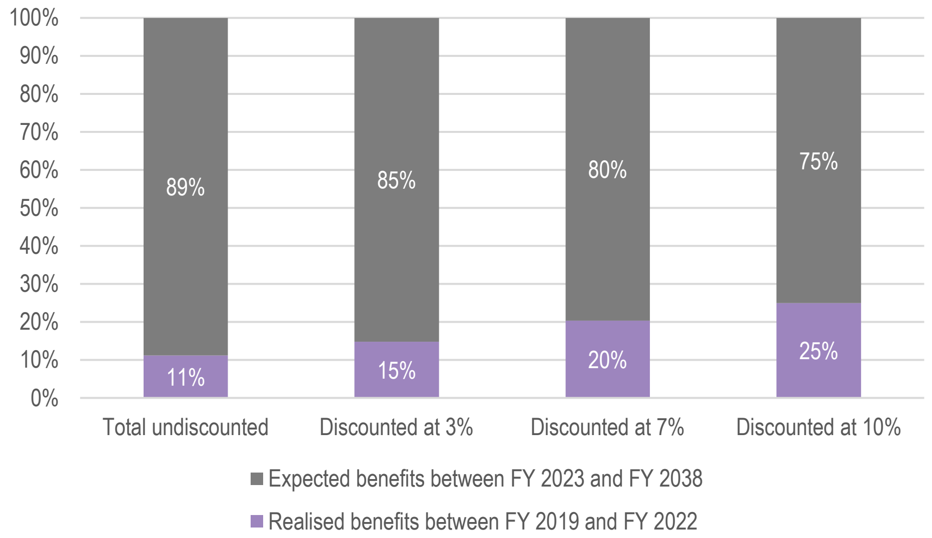
Table 3.3 Economic benefit of the NPIC to the surveying and mapping sector, various discount rates, FY 2019 - FY 2038

	Undiscounted	Discounted at 3%	Discounted at 7%	Discounted at 10%
	A$m FY 2022	**A$m FY 2022**	**A$m FY 2022**	**A$m FY 2022**
Realised direct benefits between FY 2 019 and FY 2022	7.9	8.3	8.8	9.1
Expected direct benefits between FY 2023 and FY 2038	62.7	47.6	34.2	27.4
Total direct benefits between FY2019 and FY2038	**70.7**	**55.9**	**43.0**	**36.6**

Source: ACIL Allen estimates

The share of realised benefits in the sector are as summarised in Figure **3.3**. It is estimated the sector has already realised about 20 per cent of the total expected benefit to FY 2038 (in present value terms, using a 7 per cent discount rate), with the remaining benefits accruing over the next 16 years.

Figure 3.3 NPIC, share of realised and expected direct benefits — Surveying and mapping sector



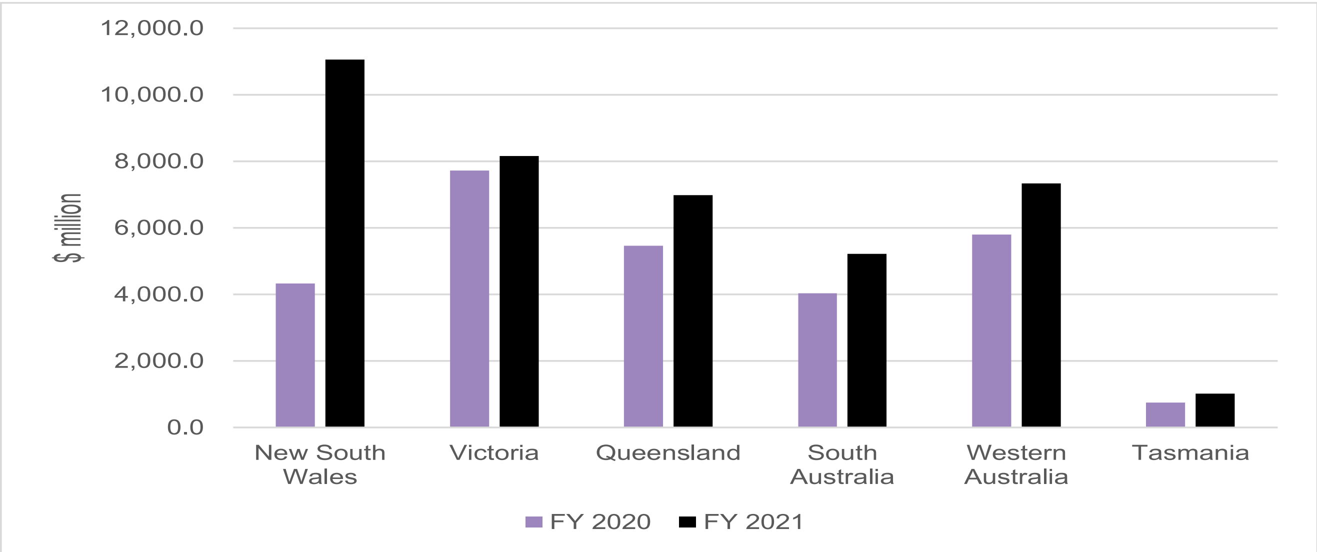
Source: ACIL Allen estimates

Impact on agriculture 4

4.1 Overview of the agriculture sector

Australia's agriculture sector generated $71 billion of gross value added in 2020-21.[21] [22] [23] Cropping and horticulture, which are significant users of positioning technologies, account for more than 56 per cent of this value (second only to livestock production). The total gross value of crops increased 41 per cent in 2019-20, primarily due improved seasonal conditions notably for production of wheat, barley and canola, particularly in New South Wales (refer Figure **4.1**). Easing of drought conditions also saw water allocations improve for irrigators with increases in the production and value of cotton and other irrigated crops.

Figure 4.1 Cropping and horticultural production gross value added, by state



Source: https://www.abs.gov.au/statistics/industry/agriculture/value-agricultural-commodities-produced-australia/2020-21

[21] The value add of an enterprise is the difference between revenue generated and the cost of inputs. Gross value add across all sectors of the economy is the main component of Gross Domestic Product.

[22] ABS (2021). *Value of Agricultural Commodities Produced, Australia*, accessed on 27 March 2023 online at: https://www.abs.gov.au/statistics/industry/agriculture/value-agricultural-commodities-produced-australia/2020-21

[23] Although cattle and calf slaughtering are the largest single contributor to the value of agriculture in Australia (24 per cent)[23], positioning services in this sector are only likely to be taken up if technological change allows low-cost electronic livestock tagging.

Productivity growth is an important measure of performance for Australian agriculture because, in the long term, it reflects changes in the efficiency with which primary producers use land, labour, capital and intermediate inputs (for example, chemicals, fodder and purchased services) in production.

Productivity growth is the fundamental mechanism by which primary producers maintain profits. Profitability improves primary producers' livelihoods and attracts investment and resources into agriculture. It also helps farmers:

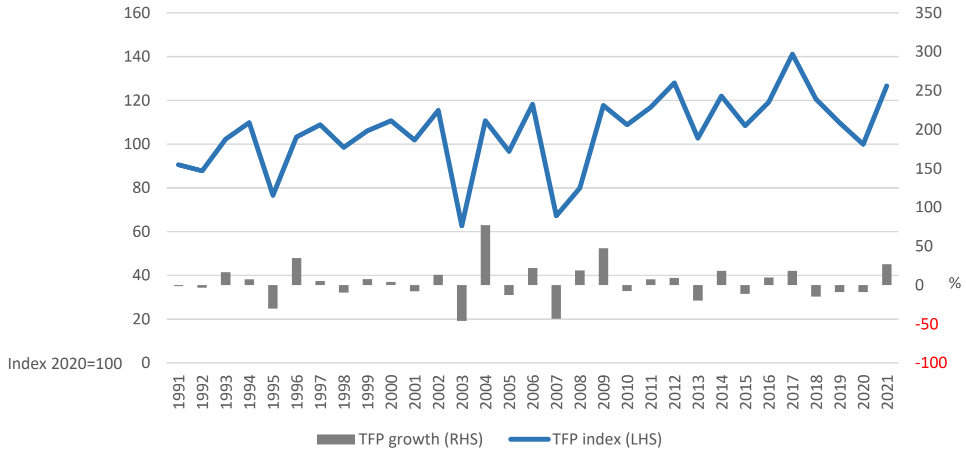
— finance ongoing expenditure on farm inputs
— meet debt-servicing obligations
— fund investments in new technologies
— earn a return on their entrepreneurial ability and capital investments.

Productivity growth helps growers offset the impact on profitability of a declining trend in terms of trade (output prices relative to input prices). Improving productivity is the main way primary producers can meet the challenges of uncertain seasonal conditions and other factors beyond their control.

Each year, the Australian Government publishes input, output and multi-factor productivity (MFP) growth of beef farming, dairy farming, sheep farming, mixed farming, cropping, broadacre average and all agricultural industries by state and ABARES agricultural regions.

Figure **4.2** presents estimated annual average cropping MFP growth estimated for various states between FY 1991 and FY 2021.

Figure 4.2 Multi-factor productivity growth of cropping sector, FY 1991 to FY 2021



Note: Cropping total factor productivity index FY 2020 =100

Source: ABARES, https://www.agriculture.gov.au/abares/research-topics/productivity/agricultural-productivity-estimates, downloaded 21 September 2022.

The estimated annual average agriculture, forestry and fishing value-added based multi-factor productivity[24] growth estimated by ABS between FY 1991 and FY 2021 was 1.08 per cent.

Positioning technologies improve productivity in a range of agricultural activities, and so have contributed to observed MFP growth.

[24] Multifactor productivity (MFP) is a measure of the amount of output obtained from a combined unit of labour and capital. In principle, it reflects the part of economic growth over and above that resulting from growth in hours worked and growth in capital employed and is frequently taken to be an indicator of technological progress.

4.2 The use of precise positioning in agriculture

Productivity is vital in maintaining Australian agriculture's competitiveness in international markets. In agriculture, precise positioning services support technologies such as remote sensing, auto-steer and yield monitoring systems that deliver productivity benefits for agriculture enterprises. Collectively these technologies are referred to as precision agriculture.

This study analysed the impacts of NPIC on the grains, cotton, sugar, viticulture and horticulture sectors, that are the most intensive users of precise positioning. Of these sectors, the largest user of precise positioning services is broadacre cropping, including grains (such as wheat and barley), oilseeds (such as canola and lupins), other pulses for human consumption (such as beans and peas), and cotton.

In Australia precision agriculture has primarily been used to provide vehicle guidance (controlled traffic farming, or CTF) and for variable rate technologies and yield monitoring. Around 80 per cent of grain producers are estimated to use precise positioning for these purposes.

There is also growing interest and application in mapping technologies to better forecast crop yields and understand land dynamics. In-field sensors and surveillance technologies are useful for monitoring and surveillance. They can inform decision-making in real time. However, they are typically static and do not always use precise positioning.

Automation and robotics (other than CTF) are still mainly in the research and development phase, although some commercial examples exist. Agricultural businesses are increasingly using positioning technologies to support integrated farm management.

Current uses in cropping require precision of around 10 centimetres although some applications, such as inter-row sowing, require greater accuracy. Table **4.1** summaries the main cropping and horticulture activities that use precise positioning.

Table 4.1 Precise positioning applications in cropping and horticulture

Positioning technology	Application
Controlled traffic farming	– Autosteer tractors – Inter-row sowing – Soil mapping technologies – Reduced compaction through minimised impact
Variable rate technologies	For targeted and efficient use of inputs such as: – fertilisers and pesticides – chemicals (spray) – water – seed.
Mapping technologies	– Crop forecasting – Yield mapping and yield forecasting – Nutrient mapping – Water flow mapping – Elevation mapping – Drainage mapping
Combinations of technologies utilising positioning	– Decision-making tools – Integrated farm management
In-field sensors and surveillance/monitoring technologies	– Pest surveillance – Water monitoring – Virtual fencing
Automation and robotics	– Robot for weeding or variable rate applications

Source: ACIL Allen

Mobile phone coverage is a limitation on the use of CORS services in Agriculture. The National Farmers' Federation estimates that improved reliability, affordability and quality of telecommunications services could boost the value of agriculture by around 25 per cent ($20.3 billion) and lift the Australian economy by an estimated 1.5 per cent ($24.6 billion) by 2030.[25] Increased use of precise positioning services would benefit from greater mobile phone coverage.

Emerging technologies such as automation and robotics are also likely to deliver significant benefits over the next two decades. They are likely to be particularly important in labour-intensive industries such as horticulture. In 2017, the Australian Farm Institute estimated that increased use of automation and robotics in the horticulture sector could reduce labour costs during planting, crop monitoring and harvesting by 30 per cent.[26]

4.2.1 Literature review

The following comments outline the areas of application of precise positioning from the review of literature.

Applications

Precision agriculture involves the observation, assessment and response to variation in key data that affect yields.[27] Precision agriculture is likely to deliver productivity gains of 18 per cent in the production of wine, 18 per cent for sugar and 17 per cent for grains.[28]

Control traffic farming (CTF) is an important support for precision agriculture. CTF aims to achieve spaced permanent 'traffic lanes' for use in sowing and harvesting in order to minimise soil compaction and overlap of tyre tracks. CTF requires good guidance systems and relies heavily on precise positioning technologies.

Benefits of CTF include:

- greater cropping frequency and reliability
- more efficient use of nutrients and water
- improved soil management, through reduced erosion, compaction and waterlogging
- more efficient use of fuel and pesticides
- reduced expenditure on machinery, and
- understanding the physical layout of a field for crop and paddock management. [29]

In agriculture, precise positioning can also improve the application of farm inputs based on analysis of field conditions. This is known as variable rate technology (VRT), as inputs are applied at varying rates depending on field conditions. For example, in broadacre cropping positioning systems can be used to store and analyse field data that can then be used to optimise the application of inputs such as water, fertiliser and pesticides through precisely targeted boom sprays mounted on lightweight autonomous robots.[30]

[25] National Farmers' Federation (2021). Submission to Regional Connectivity Program Round 2 Draft Program Guidelines.

[26] Australian Farm Institute (2017). Accelerating precision agriculture to decision agriculture.

[27] CRDC (2017) Accelerating Precision Agriculture to Decision Agriculture. Summary Report.

[28] AFI (2017). Accelerating precision agriculture to decision agriculture.

[29] Tullberg et al. (n.d.) "On Track" to Sustainable Cropping Systems for Australia.

[30] GRDC (2017). VRT: maximising returns for Western Australian Grain Producers.

Variable rate technologies (VRT) are also used in horticulture, for example, using canopy mapping systems to identify variation across orchards. [31] Positioning technologies are used for autonomous mowing and slashing in orchards and turf farms.

Other agricultural activities that are enhanced by precise positioning are listed below:

- Biomaterial monitoring enables site-specific biomass monitoring in an agricultural field, providing up-to-date information on crop development.[32]
- Detailed information about fields to create new maps, verify existing maps or add information to existing maps. The maps will have several features such as soil conductivity to identify differences within field soils.[33]
- Elevation mapping assists drainage and crop plans help farmers map the high and low-yield areas of fields so that a varying application of chemicals can improve yield with minimum environmental impact and cost.
- Soil sampling and nutrient mapping applications help map where the fertilisers are needed and the exact quantities to be applied, reducing fertiliser costs.
- Crop surface measurements allow farmers to declare their actual cropped area for insurance claims, without relying on historical cadastre documents that show property boundaries, not the actual agricultural parcels that change every season.

Adoption

Agriculture generally has had some 'early adopters' of positioning technologies including CTF and VRT in broad acre cropping. However, adoption rates vary across agricultural enterprises.

Larger scale operations, such as broadacre cropping, are more likely to be early adopters. For example, adoption is high in grains and cotton, especially for large farms.[34] [35] A 2012 survey found that up to 90 per cent of grain growers had adopted autosteering technology, but only 20-40 per cent used yield mapping and only 15 per cent used VRT.[36]

ACIL Allen (2013) estimated cost savings from precision agriculture for the grains industry of between 12.5 per cent to 20 per cent by 2020.[37] The lower estimate was based on an assumed adoption rate of 40 per cent across controlled traffic, yield monitoring, variable rate applications, inter-row sowing and other yield improvement methods, while the higher estimate assumed 100 per cent adoption of these technologies.[38]

In horticulture precision agriculture is less widespread and adoption is generally less dependent on scale, suggesting significant potential to increase adoption.[39] Adoption in viticulture is also lower

---

[31] APAL (2019). Automation and variable rate spray close to delivery.

[32] GSA. (2015). GNSS Market Report - Location Based Services. Holsovice, Czech Republic: European Global Navigation Satellite Systems Agency.

[33] European Space Agency (ESAc), Precision Agriculture, Navipedia.

[34] Robertson, M., Kirkegaard, J., Rebetzke, G., Llewellyn, R. and Wark, T. (2016). Prospects for yield improvement in the Australian wheat industry: a perspective, Food and Energy Security, 5(2):107-122.

[35] Revell, G.B., Powell, J.W. and Welsh, J.M. (2020). Economic potential of autonomous tractor technology in Australian cotton production systems, Australian Farm Business Management Journal, 17(2).

[36] Llewellyn, R. and Ouzman, J. (2014). Adoption of precision agriculture-related practices: status, opportunities and the role of farm advisers, CSIRO Report for GRDC.

[37] ACIL Allen (2013). Precise positioning in the agricultural sector.

[38] Ibid.

[39] Consultation with Horticulture Innovation Australia.

than broadacre cropping again primarily due to scale.[40] However, some small-scale producers in horticulture and viticulture do use positioning technologies to reduce their costs and remain competitive.

Productivity gains

The potential productivity gains from precision agriculture identified from the literature review are summarised in Table **4.2.**

Table 4.2 Productivity gains from precision agriculture

Application	Industry	Reported benefit	Source
Control traffic farming (CTF)	Grains	5%-50% saving in fuel 10%-15% increase in yield	Allen Consulting, 2008
CTF	Grains	Productivity benefit of $75/ha	GRDC, 2017
Inter-row sowing	Grains	5%-30% increase in yield	Allen Consulting, 2008
Spraying	Grains	15%-33% savings in input costs	Allen Consulting, 2008
Variable rate technologies (VRT)	Whole of sector	Overall productivity gain of $2.3 billion in present value terms	AFI, 2017
VRT	Grains	Productivity benefit of $50/ha	GRDC, 2017
VRT	Horticulture	30%-80% savings in input costs	EY, 2020
Automation	Whole of sector	Overall productivity gain of $7.4 billion in present value terms	AFI, 2017
Yield mapping	Grains	Productivity benefit of $50/ha	GRDC, 2019
Yield mapping	Wine	Overall productivity benefit of 10%	AFI, 2017
Spatial information	Wine	20% increase in income	SPAA, 2013

Source: Various

Precision agriculture can also deliver environmental benefits, such as reduced use of water, chemicals and energy, and reduced soil degradation. Optimised pesticide application benefits the local environment through reduced pesticide run-off and contamination.

4.2.2 Consultations

Consultations were useful in verifying information from the literature review and provided confidence that earlier estimates of productivity impacts found in the literature still apply today. This is particularly the case for broadacre farming. Many cotton, grains and large sugar producers have been using precise positioning technologies since the early 2000s.[41]

Stakeholders outlined the importance of integrating positioning data with information from other sensors in cropping. For example, in field trials in the past, plant breeders have tested the performance of new seed varieties by eye. However, sensors and precise positioning deliver quicker and more accurate results.

Unlike broadacre farming, horticulture has generally exhibited low adoption rates. However, the use of positioning technologies for yield mapping is becoming increasingly popular in orchards and VRT

[40] Maynard, H (2015). An Economic Analysis of Precision Viticulture, Fruit, and Pre-Release Wine Pricing across Three Western Australian Cabernet Sauvignon Vineyards, PhD Thesis, Curtin University.

[41] Consultation with Grains Research and Development Corporation and Society of Precision Agriculture Australia (SPAA).

is being used to minimise input costs and optimise productivity. Smaller horticultural farmers are often interested in applying new technologies to reduce costs and maintain competition with larger producers.[42] Automation and robotics offers potential benefits for the horticultural industry for improved picking efficiency and reducing labour costs.

While most of those contacted understood the role of precise positioning, not all were aware of the role and function of NPIC. Some large-scale operators have installed their own RTK base stations and do not rely on CORS network derived services. Others depend on service providers to support tractor-based technologies, such as CTF or VRT.

Generally, the importance of precise positioning is well recognised and, where available, the precision offered by CORS networks, supported by NPIC, is expected to play an increasing role in delivery of precise positioning and precision farming technologies.

4.2.3 Survey responses

The survey did not receive any responses regarding the specific agricultural sectors examined in this study (grains, cotton, sugar, wine and horticulture).

4.3 Economic benefit of the NPIC for the agricultural sector

As outlined above, there are significant economic benefits of NPIC for the agricultural sector. There is potential for even further benefits should mobile phone coverage be expanded to areas where agricultural activity takes place. In 2021 the National Farmers' Federation found that "connectivity services in regional, rural and remote Australia were not adequate to meet current and future needs".[43] This appears to be the case in western New South Wales, western Queensland, Western Australia and the Northern Territory. Our assessment of levels of adoption and attribution to NPIC have taken this into account as discussed in our approach and methodology outlined in Chapter 2.

Modelling assumptions for productivity gains and adoption rates for the use of NPIC data and services are presented in Table **4.3** below.

Table 4.3 Productivity gains and adoption rates for precision agriculture using NPIC

Commodity	Productivity gains	Adoption rate
Grains	18-22%	64-86%
Cotton	25-26%	64-86%
Sugar	25-26%	8-38%
Horticulture	15-26%	8-29%
Viticulture	10-15%	16-38%

Note: Productivity gains are cumulative from 2000 onwards
Source: ACIL Allen

Based on these assumptions, ACIL Allen estimated productivity benefits to agricultural sectors using NPIC data and services. These are summarised in Table **4.4.**

[42] Consultation with Horticulture Innovation Australia.

[43] NFF (2021) Submission to Regional Connectivity Program Round 2 Draft Program Guidelines.

Table 4.4 Direct economic benefit of the NPIC to the agriculture sector, FY 2019 to FY 2038

Jurisdiction	Grains	Horticulture (incl. wine)	Cotton	Sugarcane	Total
Average annual productivity growth due to NPIC (%)					
New South Wales (a)	0.009	0.006	0.001	0.002	
Victoria	0.014	0.006	0.000		
Queensland	0.007	0.001	0.000	0.001	
South Australia	0.004	0.002			
Western Australia	0.003	0.000			
Tasmania	0.006	0.010			
Cumulative productivity growth due to NPIC (%), FY 2019 to FY 2038					
New South Wales (a)	0.179	0.110	0.029	0.034	
Victoria	0.286	0.118	0.009	0.000	
Queensland	0.143	0.020	0.004	0.028	
South Australia	0.075	0.038			
Western Australia	0.060	0.004			
Tasmania	0.120	0.195			
Total undiscounted economic growth due to NPIC ($m), FY 2019 to FY 2038					
New South Wales (a)	47.7	22.3	4.4	0.2	74.8
Victoria	73.5	54.3	0.4	0.0	128.1
Queensland	25.9	5.4	0.2	3.6	35.1
South Australia	5.5	6.5			12.0
Western Australia	7.3	0.5			7.8
Tasmania	3.2	10.7			13.9
Total	**163.1**	**99.6**	**5.0**	**3.9**	**271.6**

(a) Includes Australian Capital Territory.

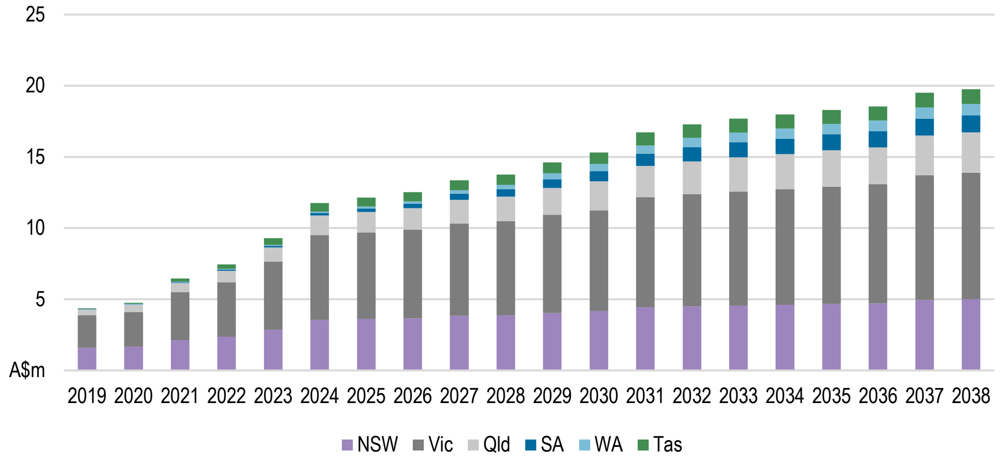
Note: Northern Territory is not reported as the economic benefits are negligible.

Source: ACIL Allen estimates.

ACIL Allen's analysis indicates that the benefits of NPIC to agricultural outside of grains are relatively small. The benefit in grains has increased considerably due to increased uptake by the industry and this is expected to continue. Grain growers are expected to benefit by about $163 million in undiscounted terms between FY 2019 and FY 2038. The total agriculture industry would benefit by $272 million between FY 2019 and FY 2038.

Figure **4.3** shows the annual undiscounted benefits of NPIC precision to the agriculture sector in Australia.

Figure 4.3 Annual undiscounted economic benefit of the NPIC to the agriculture sector by state, FY 2019 to FY 2038



Note: ACT is included in NSW. NT not included as economic benefits are negligible for the NT
Source: ACIL Allen estimates

The present value of economic benefits of the NPIC (discounted at 7 per cent to a present value in FY 2022) are estimated to be $163.1 million. Table **4.5** summarises the economic benefit of the NPIC at various discount rates.

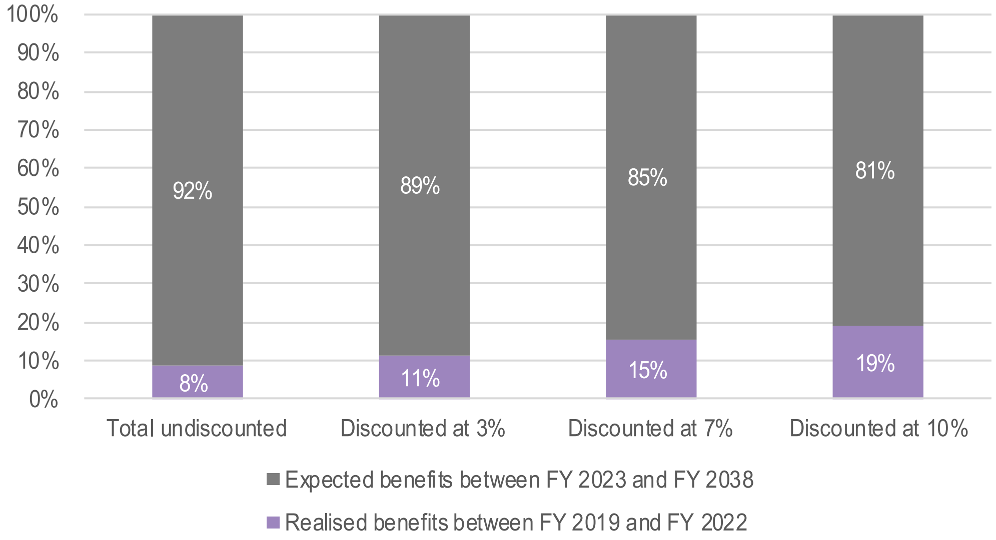
Table 4.5 Economic benefit of the NPIC to the agriculture sector, various discount rates, FY 2022 to FY 2038

	Undiscounted	Discounted at 3%	Discounted at 7%	Discounted at 10%
	A$m FY 2022	A$m FY 2022	A$m FY 2022	A$m FY 2022
Realised direct benefits between FY 2019 and FY 2022	23.0	23.9	25.3	26.1
Expected direct benefits between FY 2023 and FY 2038	248.6	190.0	138.0	111.4
Total direct benefits between FY 2019 and FY 2038	271.6	213.9	163.3	137.5

Source: ACIL Allen estimates

The share of realised benefits in the sector are as summarised in Figure **4.4.** The agriculture sector has already realised about 15 per cent of the total expected benefit to FY 2038 (in present value terms, using a 7 per cent discount rate), with the remaining benefits accruing to the sector over the next 16 years.

Figure 4.4 Share of realised and expected direct benefits due to NPIC —Agriculture sector



Source: ACIL Allen estimates-based on various sources

Impact on construction 5

5.1 Overview of the construction industry

The construction industry includes construction, demolition, renovation, maintenance and repair of building and infrastructure and covers a wide range of services including planning, structural construction and finishing services such as painting and decorating.

In 2020-21 the construction industry generated over $360 billion in revenue, with New South Wales and Victoria accounting for the bulk of construction work (nearly 60 per cent of the national total based on value-added – Figure **5.1**).[44] Construction contributes 7 per cent to GDP. The construction industry is projected to grow by around 1 per cent per annum in the next four years. [45]

Figure 5.1 Value-added of construction sector by state/territory, FY 2021

Source: ABS, State Accounts.

The industry is broken down into four main sectors:

- residential construction
- non-residential construction
- heavy engineering
- construction services.

[44] ABS (2022). Construction Work Done, Australia, Preliminary. Accessed: https://www.abs.gov.au/statistics/industry/building-and-construction/construction-work-done-australia-preliminary/mar-2022

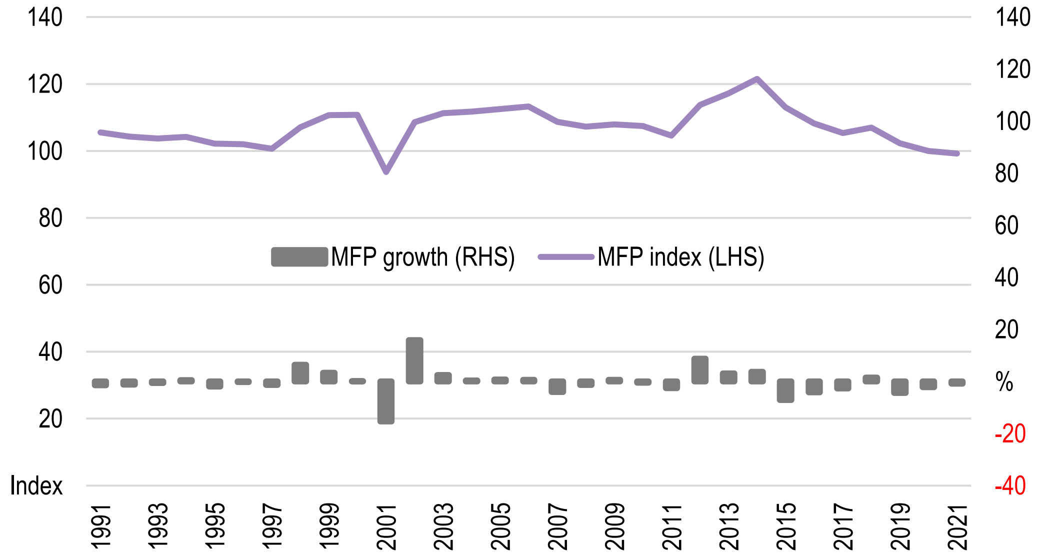
[45] IBISWorld, Construction in Australia, June 2022

Each of these sectors use precise positioning to varying degrees. For this analysis, we focused on heavy and civil engineering construction and non-residential construction. These are the areas where precise positioning has had most penetration.

The construction industry is dominated by sole traders and small-medium enterprises (SMEs), although there are some very large players in the market such as CIMIC Group, Multiplex, John Holland, Downer EDI, Acciona and the Lend Lease Group. Not all construction activities benefit initially from the higher precision offered by NPIC because a proportion use their own RTK base stations or are in areas where there is no mobile phone coverage.

Each year, ABS reports multifactor productivity (MFP) growth in the construction sector. The annual average MFP growth estimated by ABS between FY 1991and FY 2021 is provided in Figure **5.2.** Productivity increased from FY 2011 to around FY 2015. However, it declined after that date. One of the reasons for this decline is thought to be due to labour shortages, poor organisation, data management and the impact of COVID during the FY 2019 to FY 2021 period. Residential construction has been identified as one area of concern in this respect.

Figure 5.2 Multifactor productivity growth of construction sector, FY 1991 to FY 2021



Note: Reference year for MFP = FY 2020.

Source: ABS (2021), Estimates of industry multifactor productivity, https://www.abs.gov.au/statistics/industry/industry-overview/estimates-industry-multifactor-productivity/2020-21, Downloaded 21 August 2022

5.2 Use of precise positioning in construction

The economic benefits from NPIC for engineering surveying have been considered in Chapter 3 under surveying and mapping. This chapter is concerned with the impact of NPIC and precise positioning in machine guidance, asset management and the use of digital twin approaches to design and construction.

The benefit of precise positioning has been most obvious in major infrastructure projects. Precise positioning has improved the entire project lifecycle of many large projects, across design, construction and asset maintenance.

With the support of precise satellite positioning, machine guidance has been able to achieve centimetre level positioning in three dimensions, satisfying the more stringent accuracy requirements of the construction industry. Machine guidance is used for earthworks in excavators, bulldozers and grading machines and needs at least 5 cm accuracy for both precision and safety.

Over the last decade, precise positioning and software integration improvements have enhanced design processes through the development of computer aided design techniques and 3D models of the digital build environment. This has led to design cost savings and efficiencies planning as a result of less changes being needed during the construction phase. Other benefits include better tolerances, improvements in inventory management and resourcing, and site safety due to the reduced need for people on site.

5.2.1 Literature review

The literature review found that precise positioning has been delivering productivity gains in construction from 2000. This was due to the emergence of GNSS positional infrastructure (such as Vicmap Position across Victoria), and the rapid improvement and cost efficiency of positioning technology (distributed via commercial service providers direct to the construction industry).[46]

A 2020 Canadian study estimated that precise positioning in Canada's construction industry had delivered benefits of $199 million due to reduced deaths and serious injuries from falls, $98 million from reduced collisions, and $300 million from improved road construction efficiency over a twenty year period. The same study found productivity gains of 0.4 per cent to 0.6 per cent in construction surveying with 70 per cent adoption, and 0.3 per cent to 3 per cent from machine guidance with 30 per cent adoption.[47]

A 2013 study by ACIL Allen, estimated productivity increases for engineering surveying of between 0.4 per cent and 0.6 per cent (assuming an adoption level of around 60 per cent) and gains for machine guidance of between 1.5 per cent and 3 per cent (assuming 20 per cent adoption).[48] A later study (2017) estimated savings in machine guidance to be much higher – about 10 to 20 per cent – due to further development and wider adoption of precise positioning technologies in autonomous machinery. This study also found that adoption rates for machine guidance had increased significantly to around 70 to 80 per cent.[49]

In another context ACIL Allen (2017) estimated that the use of 3D digital models of the built environment (also referred to as digital twins) could deliver productivity benefits to the construction sector of:

— 1 to 5 per cent for engineering and infrastructure delivery
— 1 to 2 per cent for facilities management
— up to 15 per cent for surveying.

The total value of these savings for the state of Queensland was estimated to be between $800 million and $3 billion in present value terms over 30 years discounted at 7 per cent.[50] Digital twin developments are under active development in Australia.[51]

[46] ACIL Allen (2013). *Precise positioning in the construction sector*

[47] EY (2020), *Value of precision GNSS services in Canada*

[48] ACIL Allen (2013). *Precise positioning in the construction sector*

[49] ACIL Allen (2017) Economic value of spatial information in NSW

[50] ACIL Allen (2017). *3D Qld Road Map Preliminary Findings, 3D Qld Task Force.*

[51] ANZLIC (2022). *ANZLIC Strategic Plan 2020-2024. Australian and New Zealand Land Information Council*

5.2.2 Consultations

ACIL Allen received feedback on the use of positioning in the construction sector from service providers and engineering consultants. Construction companies and the Australian Constructors Association were not able to take part in the consultation process due to limited capacity. Despite this, consultations revealed significant information on adoption and gains from precise positioning in construction.

One service provider estimated a 50 per cent cost saving from engineering surveys and the setting out component of construction, and adoption rates of close to 90 to 95 per cent by larger construction companies. Machine guidance is an important source of these savings.

Another service provider estimated that precise positioning delivers around 30 to 40 per cent cost savings over a whole project, and about 90 per cent adoption by the major contractors. This service provider said that they drew on NPIC where it was available.

Service providers also noted that there is a high use of standalone RTK systems in the construction industry. The reason for this is the limitations in mobile phone coverage and the need to build confidence in the system. There was also concern over legal exposure in the case of accidents and incidents.

An emerging development reported in consultations was the increasing use of digital techniques and precise positioning by engineers for design and construction. This has the potential to realise significant cost savings from project inception through to construction. Previously, significant time was involved during the design phase in transferring data between analytical software. Digital design supported by precise positioning has increased the efficiency of this process by about 30 per cent.

For this work five centimetre accuracy is required. One engineering firm is incorporating NPIC base station capability into its positioning model. This company considered that NPIC will be important to the development of digital design and construction techniques, and they expect a significant increase in the uptake of NPIC infrastructure.

5.2.3 Economic benefits survey responses

ACIL Allen received survey responses from two national firms which service the construction industry. One firm was large and the other small, but their combined turnover was around $100 million. Both firms operate in metropolitan and regional areas. They both need 1 to 2 cm accuracy positioning for their work. The larger company reported that it uses both single-base and networked RTK for precise positioning. The networked RTK service is sourced from a service provider that draws on NPIC infrastructure.

The smaller company operates its own RTK base station. Using precise positioning has decreased the capital expenditure required to complete survey works. It estimated that the adoption rate across the sector is less than 5 per cent, but it is growing. They expect operating costs to continue to decrease through the use of precise positioning. From FY2028 to FY2038, they expect the adoption rate to increase to about 90 to 100 per cent, during which time they expect operating costs to decrease by more than 40 per cent.

5.3 Economic benefit of the NPIC for the construction industry

The benefits of precise positioning technology in the construction industry are primarily improved engineering surveying, and machine guidance for construction equipment such as excavators, bulldozers and grading machines. The emergence of digital twin technologies also provides the prospect of significant innovation and advances in this sector.

When estimating the productivity impacts, this analysis focused on the non-residential and heavy engineering components of the construction industry. These two sectors are considered the most progressive in adopting efficient technologies and data management capabilities.

— Non-residential construction is adopting precise positioning for planning and design and for facilities maintenance. Based on findings in ACIL Allen (2017) for 3D models of the digital built environment we have assumed: a 1 per cent increase in productivity from precise positioning
— adoption levels of 2 per cent in FY 2024, rising to 70 per cent by FY 2038.

Noting that many construction companies use their own RTK base stations, we have also adjusted the adoption curve to recognise that not all companies use CORS networks and hence do not draw on NPIC, even where it is available. Accordingly, we assumed that the percentage of companies that draw on the NPIC was 31 per cent in FY2019 and will rise to 90 per cent by FY 2038.

Heavy engineering is an early adopter of machine guidance and has shown a strong interest in the value and utility of digital twin models. Reflecting this, ACIL Allen has applied the following assumptions for the contribution of precise positioning to construction:

— For machine guidance:
  – a productivity increase of 2 per cent
  – 85 per cent adoption of precise positioning, remaining constant over the study period
  – use of the NPIC where available rising from 30 per cent in 2019 to 72 per cent by FY 2038.
— For digital twin technologies:
  – a productivity increase of 1 per cent
  – precise positioning adoption rising from 2 per cent in FY 2024 to 78 per cent by FY 2038
  – use of the NPIC where available rising from 30 per cent in FY 2019 to 72 per cent by FY 2038.

Based on these assumptions, ACIL Allen estimates economic benefits from the NPIC for the construction sector as summarised in Table **5.1.**

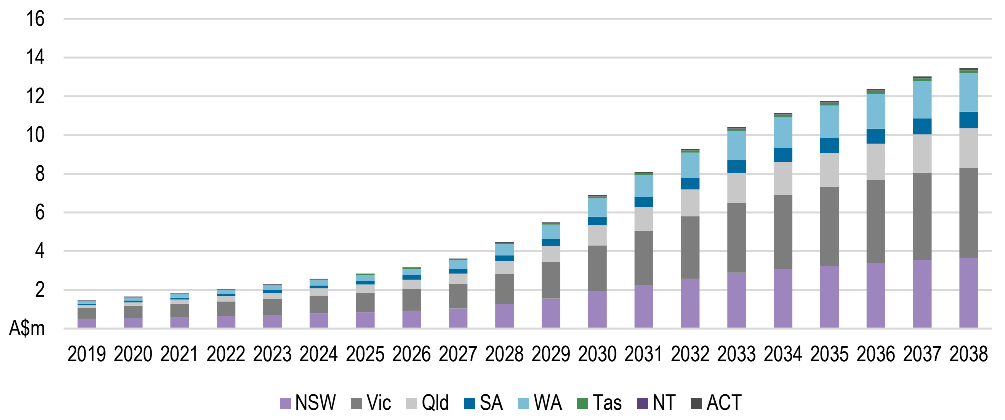
Table 5.1 Undiscounted economic benefits of the NPIC for the construction sector by state and territory, FY 2019 to FY2038

Jurisdiction	Annual average between FY 2019 and FY 2038		Total between FY 2019 and FY 2038	
	Productivity impact	Direct economic benefit	Productivity impact	Direct economic benefit
	%	$m	%	$m
New South Wales	0.01	1.8	0.21	35.9
Victoria	0.02	2.2	0.32	44.6
Queensland	0.01	1.0	0.16	19.1
South Australia	0.01	0.4	0.27	8.1
Western Australia	0.01	0.9	0.15	17.5
Tasmania	0.01	0.1	0.22	1.7
Northern Territory	0.00	0.0	0.01	0.3
Australian Capital Territory	0.01	0.0	0.15	0.8
Total	**0.01**	**6.4**	**0.20**	**127.9**

Benefits are net of user costs but not Geoscience Australia's costs
Source: ACIL Allen estimates.

Figure **5.3** shows the undiscounted benefits of NPIC to construction sector in Australia. The estimated total productivity benefits in construction sector are about $128 million.

Figure 5.3 Annual undiscounted economic benefit of the NPIC to the construction sector, by state or territory, FY 2019 to FY 2038



Source: ACIL Allen estimates

The estimated discounted direct gross benefits attributable to the sector are provided in Table **5.2.** The present value of total benefits accruing to the construction sector from 2019 to 2038, because of the NPIC program are estimated to be **$67.8 million** (using a 7 per cent discount rate).

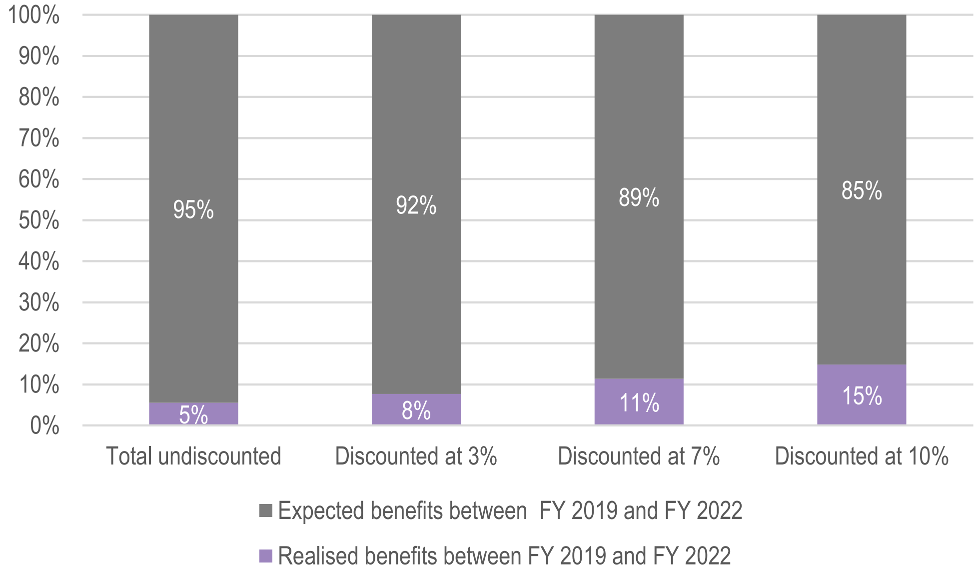
Table 5.2 Economic benefit of the NPIC to the construction sector, various discount rates, FY 2019 to FY 2038

	Undiscounted	Discounted at 3%	Discounted at 7%	Discounted at 10%
	A$m FY 2022	**A$m FY 2022**	**A$m FY 2022**	**A$m FY 2022**
Realised direct benefits between FY 2019 and FY 2022	7.0	7.3	7.7	8.0
Expected direct benefits between FY 2023 and FY2038	120.9	88.2	60.1	46.2
Total direct benefits between FY 2019 and FY 2038	**127.9**	**95.5**	**67.8**	**54.2**

Source: ACIL Allen estimates-based on various sources

The share of realised benefits in the sector are summarised in Figure **5.4**. The sector has already realised about 11 per cent of the total expected benefit to 2038 (in present value terms, using a 7 per cent discount rate), with the remaining benefits accruing to the sector over the next 16 years.

Figure 5.4 Share of realised and expected direct benefits of NPIC — Construction sector, FY 2019 to FY 2038



Source: ACIL Allen estimates-based on various sources

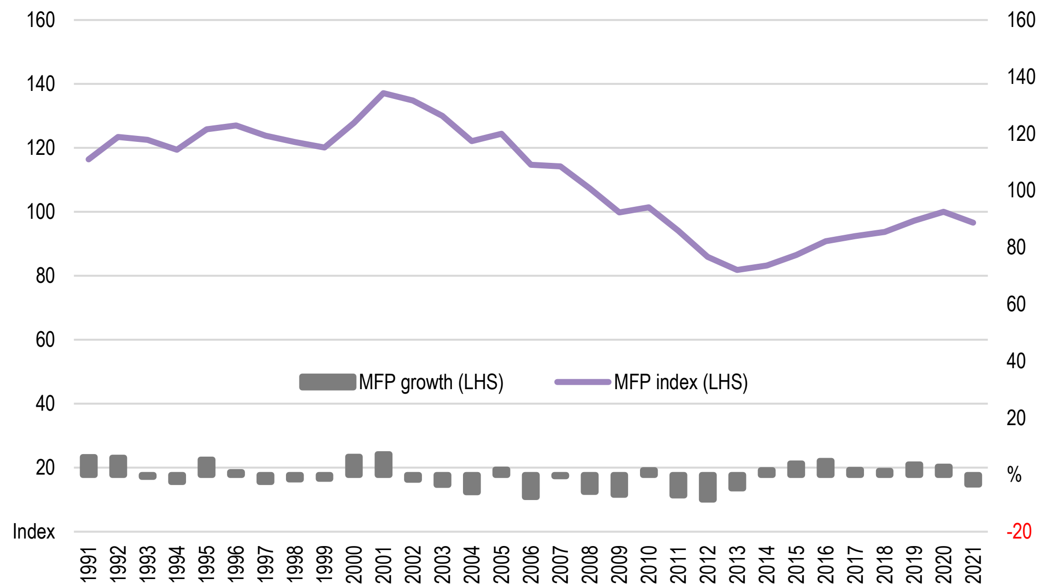
Impact on mining 6

6.1 Overview of the mining industry

The mining industry comprises exploration and development, direct mining (extractive) activities, and exploration and mining support services. In 2018-19 the industry generated $307 billion in revenue and $193 billion in value-added.

Mining sector productivity, as reported by ABS, has been decreasing over the last 30 years. Since 2013, however, there has been a small positive growth in the mining sector multifactor productivity growth as shown in Figure **6.1**. This is thought to be attributable to significant investment in production capability that is yet to feed through into production volumes, exacerbated by resource depletion before massive mining and LNG investments are completed. This appears to have offset other efficiency improvements observed in our case studies and research.

Figure 6.1 Mining sector multifactor productivity (MFP), FY 1991 to FY 2021



Note: Reference year for MFP = FY 2020.

Source: ABS (2021), Estimates of industry multifactor productivity, https://www.abs.gov.au/statistics/industry/industry-overview/estimates-industry-multifactor-productivity/2020-21, Downloaded 21 August 2022.

6.2 Use of precise positioning in mining

Positioning technologies are increasingly being used to support a wide range of mining activities. The mining industry has been an early adopter in precise positioning technology. Positioning information now plays a role in all activities along the production chain, from site surveying, extracting deposits, and mine site remediation. We have accounted for economic benefits from mining site surveying in the surveying and mapping analysis. Precise positioning is increasingly being used to support autonomous vehicles and drones, with Australian miners being at the forefront of adoption of these technologies. The accuracy required depends on the application but for areas such as monitoring tailings dams and safety management, sub 5 cm accuracy is desirable.

Many Australian mining sites are on the edge of or outside mobile phone coverage areas. Accordingly, many large miners set up their own RTK stations/networks. There is some evidence that the use of CORS networks that draw on the NPIC is more common among smaller miners, where it is available.

6.2.1 Literature review

A 2008, an Allen Consulting group report reviewed applications of precise positioning in mining. Applications involved fitting GNSS equipment to excavators to identify the precise location of where to dig. Autonomous haul trucks were in the development stage at that time.[52]

More recent reports demonstrate how the use of positioning technology in the mining sector has evolved since that time. A 2013 report by ACIL Allen on the use of precise positioning in the mining sector found that:

> *Augmented GNSS is an increasingly important enabling technology for the use of geospatial systems in the industry. For most applications, the sector requires accuracies of around the cm to 10 cm level. Higher accuracies are required for mine site surveying, autonomous operation of mine machinery and machine guidance. Lower accuracies are adequate for activities such as environmental surveys, monitoring and material tracking.*[53]

The same report listed the following mining applications for positioning information:

- exploration
- marine operations
- mine site surveying
- autonomous mining and operations control
- remote control of vehicles and machines, including haul tracks and drilling equipment
- vehicle tracking and dispatch
- loading systems
- material tracking along the supply chain
- preserving areas of cultural heritage and high environmental value.

[52] Allen Consulting (2008). Economic benefits of high-resolution positioning services.

[53] ACIL Allen (2013). Precise positioning in the mining sector - An estimate of the economic and social benefits of the use of augmented GNSS in the mining sector.

Maintaining international competitiveness remains a top priority for mining companies and it is not surprising that the use of positioning information by the sector has continued to grow. A 2017 report by CSIRO identified the following as technologies that are likely to see increased adoption in the mining sector over the next 10 years:

- advanced communications and positioning systems for autonomous surface and underground equipment
- collision avoidance software and algorithms
- small-scale robotic fleets to target deposits that cannot be reached with conventional mining equipment
- drones and small-scale autonomous equipment for mapping and environmental monitoring.[54]

Positioning information is also increasing mine safety, for example by using autonomous systems to reduce the need for humans to work in dangerous areas. Autonomous machinery also reduces the need for fly-in fly-out workers, saving costs and avoiding the social dislocation of this type of work.

Australia is leading the way in adopting autonomous mining vehicles. In 2021, Australia's fleet of 575 autonomous mining trucks was the largest in the world, representing over 73 per cent of the world-wide total.[55] Further, Australian miners continue to add to their autonomous fleets.[56] As of 2021, BHP was expecting to add 375 autonomous trucks across its Western Australia iron ore and Queensland coal operations by 2023, and Rio Tinto was planning to add 100 autonomous trucks across its Pilbara operations by 2022.

Research suggests that the number of autonomous trucks operating across the globe is expected to increase from around 1,070 to at least 1,800 by the end of 2025. The additions proposed by Rio Tinto and BHP suggest that Australian miners will continue to dominate the use of this technology.[57]

Large mining companies have previously dominated investment in systems that utilise positioning information for their operations, but now small and mid-tier companies are beginning to catch up. According to GlobalData, more than half (53 per cent) of small-scale miners expect to invest in these technologies over the next two years, making communications a high priority technology among these businesses.

Mining companies are increasingly using drones to remotely survey, measure, monitor and map large areas (see Figure **6.2**). GlobalData's research reported by NS Energy, shows that uptake of drones among miners is growing rapidly, with 21 per cent of sites surveyed saying they had fully invested in the technology during 2019, compared with just 9 per cent during the previous year. More than half (56 per cent) of mine sites invested in drones during 2019, compared with 44 per cent in 2018. Investment in drones is occurring across the industry, with 45 per cent of major

---

[54] CSIRO Futures (2017). Mining Equipment, Technology and Services - A Roadmap for unlocking future growth opportunities for Australia

[55] One (non-mining) stakeholder commented that the automated trucks in use on mine sites were sometimes too accurate in their positioning. This resulted in them always following the same path. This could lead to more rapid degradation of the road by encouraging the formation of ruts and potholes.

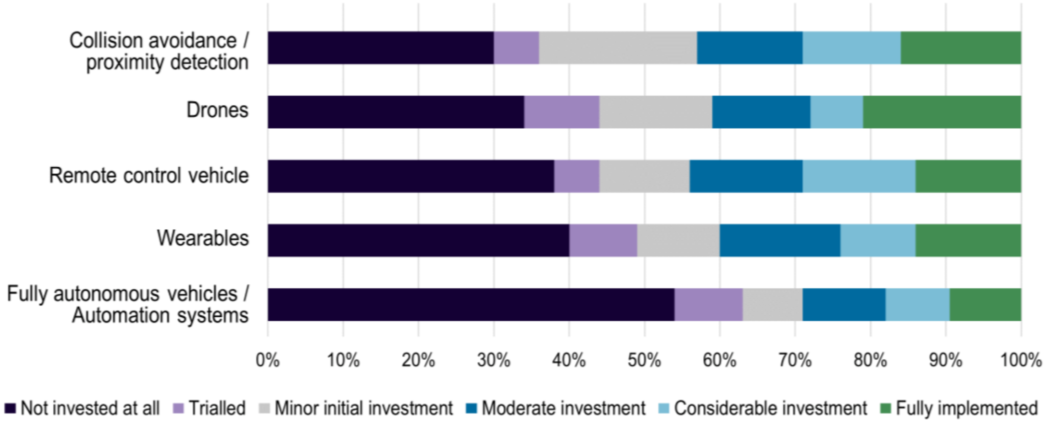
[56] Mahmood, S. (2021). Australia leads the way in autonomous truck use. Accessed: https://www.mining-technology.com/analysis/australia-leads-the-way-in-autonomous-truck-use/

[57] Ibid

mining companies and 41 per cent of smaller companies reportedly planning to invest in drone technology over the period 2020 to 2022.[58]

Figure **6.2** illustrates the importance attached to safety by mine sites, with almost 75 per cent of mines surveyed investing to some extent in collision avoidance and proximity detection technologies.

Figure 6.2 Technologies that mining companies invested in 2019



Source : https://www.nsenergybusiness.com/news/mining-technology-investment-drones/

The 2019 report by Frontier SI and EY on the SBAS Test-bed Demonstrator Trial identified several areas where there could be benefits from the SBAS system[59]. This report analysed the potential benefits of accurate positioning information using a satellite based augmentation system in mining. However, four areas of activity were identified that could benefit from sub-metre or decimetre accuracy. Those four areas, and their estimated benefits (at a discount rate of 6.5 per cent over 30 years), were:

— $3 million from reduced collisions
— $130 million from reduced mine vehicle down time
— $577 million from improved haul truck efficiency
— $6 million from improved exploratory surveying.

The estimated benefits quoted above for SBAS would be similar (and potentially slightly higher) if NPIC had been used to deliver the same or better service in available areas with mobile phone coverage.

A 2019 report by RTI International for the US National Institute of Standards and Technology examined the economic benefits of the global positioning system (GPS). It found that positioning information of one to five centimetre accuracy delivered benefits to surface miners in the following areas:

— extraction activities and machine guidance
— real time optimisation of mine operations
— tracking and measuring ore
— safety.[60]

---

[58] Fawthrop, A. (2020). Communications systems and drones top mining technology investments in 2019. Accessed: https://www.nsenergybusiness.com/news/mining-technology-investment-drones/

[59] Frontier SI and EY (June 2019). SBAS Test-bed Demonstrator Trial - Economic Benefits Report

[60] Economic Benefits of the Global Positioning System (GPS). (June 2019) RTI International

It concluded that GPS increased overall mine productivity by between 21 and 75 per cent, including reducing labour requirements by between 13 and 35 per cent. The report estimated that the economic benefits to the US were in the billions of dollars.

The benefits found by RTI International are informative for those that might be expected to be delivered by NPIC, given the nature of services and the level of accuracy analysed.

Consultations

A very limited number of mining firms were willing to participate in a consultation. One of the reasons for this is that much of the information we were seeking is commercially sensitive.

A general observation from those consulted was that precise positioning had been in use for at least 20 years in the mining sector, with its use in mine site rehabilitation commencing around the mid-1990s. Most miners use their own equipment, including base stations, but may choose to draw on the CORS networks and NPIC where they are available.

After the 1990s, equipment manufacturers used the technology in haul trucks to locate equipment and reduce accidents. Many of the applications were embedded in equipment manufacturer's products, but others were introduced through service providers.

Large firms understand the potential of the technology and have implemented their own advanced systems. Small to medium companies rely more on service providers.

Precise positioning information can find applications across all phases of mining operations from exploration, operations to mine closure:

- *Exploration* – More accurate positioning information can improve targeting of exploration activities. Most exploration applications use 3 to 5 cm accuracy or better.
- *Operations* – more accurate positioning information delivers a number of benefits:
  - reducing fuel consumption by around two to three per cent.
  - improving safety by reducing collisions.
  - better managing the mining process to protect environmentally or culturally sensitive areas.
  - reducing double handling of material by gathering better information about the location of particular grades of ore in a stockpile, providing a productivity benefit of between 0.5 and 2 per cent. Positioning accuracy of 3 to 5 cm is likely to be required for these applications.
- *Mine closure and rehabilitation* – positioning information can help to make the process go more smoothly and quickly.
  - automated rehabilitation equipment can be left running continuously.
- closure and rehabilitation can use 10 cm accuracy positioning for vegetation mapping and monitoring. However, monitoring of tailings dams requires 3 to 5 cm centimetre accuracy.[61]

The above uses of precise positioning information were considered to maintain the environmental sustainability credentials of the company, maintaining its licence to operate, and ensuring that it remains an employer of choice and can attract and retain the required workforce.

The stakeholder noted that it was considering new uses for positioning information, such as:

- to guide the blending of mined product from its stockpiles to ensure that the ore being shipped is of a consistent grade and meets contracted quality standards
- to assist with the berthing and tracking of vessels.

---

[61] Another (non-miner) stakeholder noted that monitoring of spoil and tailings was an area of strong interest.

Consultation confirmed the important role that positioning technologies play in improving safety. A (non-miner) stakeholder noted that 20 per cent of the mine sites they service, require all staff to carry a wearable receiver to help avoid collisions between personnel and equipment. In contrast to some autonomous equipment, that requires 10 cm accuracy, 3 to 5 cm accuracy is required for most safety applications.

A (non-miner) stakeholder stated that the challenge with the CORS network and NPIC was that it is only available in areas where there was mobile coverage. It noted that mining activities are often on the edge or outside the areas where there was mobile coverage, leading to many miners setting up their own RTK stations.

Several stakeholders noted that SouthPAN will provide positioning information in areas outside the reach of the CORS network, but there was some uncertainty around whether it would be sufficiently accurate for all applications.

6.2.2 Economic benefits survey responses

No responses to the survey were received from the mining sector. This is likely to be due to the commercially sensitive nature of the information sought.

6.3 Economic benefit of the NPIC for the mining sector

The mining industry has adopted precise positioning applications at a rapid rate and is likely to continue to adopt new applications and refine existing uses (such as the reliability of autonomous mining), particularly with the increased availability of precise positioning through SouthPAN and CORS network services supported by NPIC.

A large mining company's innovation program has reportedly demonstrated a 14 per cent higher utilisation of autonomous haul trucks than manned trucks and a 15 per cent increase in availability of automated drills over manned drills.[62] Such improvements are likely to continue as uptake of these technologies grows over time.

Multiple mining companies reported increases in productivity with autonomous truck use, with Fortescue Metals Group citing a productivity improvement of more than 30 per cent. BHP claims that autonomous trucks reduced operating costs by about 20 per cent and increased productivity by another 20 per cent.[63]

Based on the mining productivity gains identified in the literature and through consultation, ACIL Allen estimates economic benefits from the NPIC to the mining sector as summarised in Table **6.1**.

[62] Matysek, A., & Fisher, B. (2016). Productivity and Innovation in the Mining Industry, BAEconomics

[63] Mahmood, S. (2021). Australia leads the way in autonomous truck use. Accessed: https://www.mining-technology.com/analysis/australia-leads-the-way-in-autonomous-truck-use/

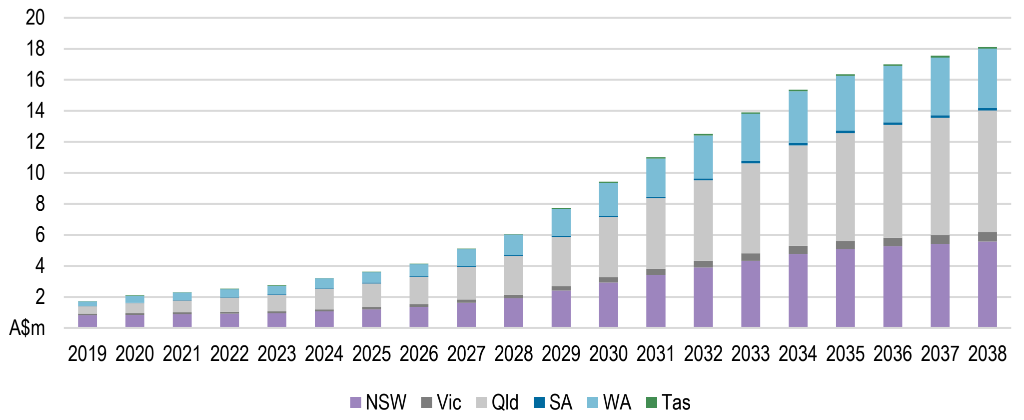
Table 6.1 Undiscounted economic benefits of NPIC to the mining sector by state, FY 2019 to FY 2038

Jurisdiction	Annual average between FY 2019 and FY 2038		Total between FY 2019 and FY 2038	
	Productivity benefit %	Direct economic benefit $m $m	Productivity benefit% %	Direct economic benefit $m $m
New South Wales	0.01	2.7	0.22	54.6
Victoria	0.01	0.3	0.27	6.2
Queensland	0.01	3.6	0.15	71.8
South Australia	0.00	0.1	0.08	1.7
Western Australia	0.00	1.8	0.05	36.9
Tasmania	0.01	0.1	0.13	1.3
Total	**0.01**	**8.6**	**0.11**	**172.5**

Benefits are net of user costs but not Geoscience Australia's costs.
Source: ACIL Allen estimates.

Figure **6.3** shows the undiscounted benefits of NPIC to the mining sector in Australia. The estimated total productivity benefits in mining are $172.5 million.

Figure 6.3 Annual undiscounted economic benefits of the NPIC to the mining sector by state, FY 2019 to FY 2038



Source: ACIL Allen estimates

The estimated discounted direct gross economic benefit of the NPIC for the mining sector are summarised in Table **6.2**. The present value of total benefits accruing to the mining sector from FY 2019 to FY 2038 attributed to the NPIC program are estimated to be $90.7 million (using a 7 per cent discount rate).

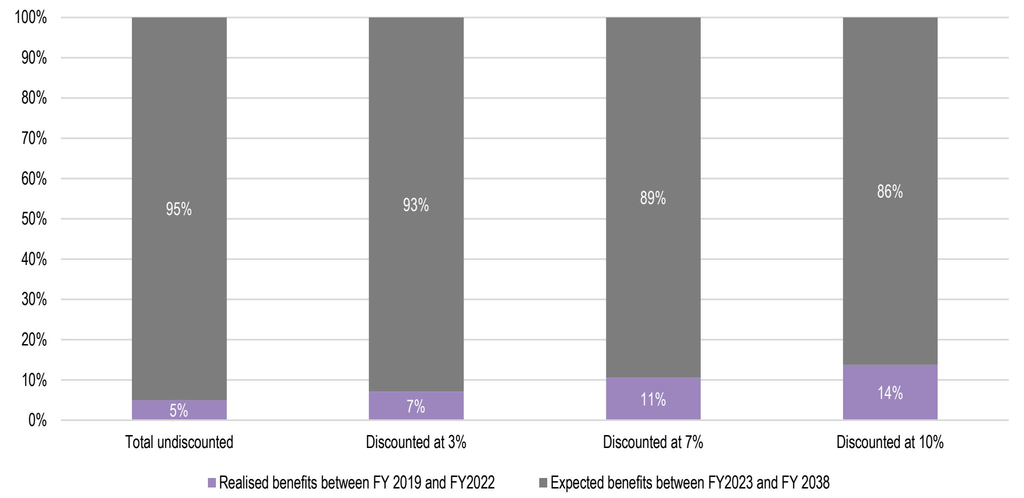
Table 6.2 Economic benefits of the NPIC to the mining sector, various discount rates, FY 2019 to FY 2038

	Undiscounted	Discounted at 3%	Discounted at 7%	Discounted at 10%
	A$m FY 2022	A$m $FY 2022	A$m FY 2022	A$m FY 2022
Realised direct benefits between FY 2019 and FY 2022	8.7	9.0	9.5	9.9
Expected direct benefits between FY 2023 and FY 2038	163.9	119.4	81.1	62.3
Total direct benefits between FY 2019 and FY 2038	172.5	128.4	90.7	72.2

Source: ACIL Allen estimates-based on various sources

The share of realised benefits in the sector are summarised in Figure **6.4**. The mining sector has already realised about 11 per cent of the total expected benefit to FY2038 (in present value terms, using a 7 per cent discount rate), with remaining benefits accruing to the sector over the next 16 years.

Figure 6.4 Share of realised and expected direct benefits due to NPIC — Mining sector, FY 2019 to FY 2038



Source: ACIL Allen estimates-based on various sources

Impact on research and innovation 7

7.1 Use of precise positioning in research and innovation

Research and Development (R&D) and innovation is important for the evolution of the use of precise positioning. Equally precise positioning can also drive innovation and R&D in applications. R&D and innovation can both improve existing positioning technologies and create entirely new ones. We have not quantified the economic benefits of NPIC to R&D and innovation. It is very difficult to do so as the outcomes of R&D and innovation are by their very nature uncertain.

7.1.1 Literature review

A 2020 report by EY on the value of GNSS services in Canada discussed the growing interest in GNSS reflectometry in recent years, where researchers analyse the characteristics of reflected signals to derive detailed vegetation biomass data.[64] These data can be used to monitor changes in sensitive ecosystems over time or estimate carbon stocks for climate change modelling.

The report also discussed how precision GNSS could improve monitoring of sea levels. Researchers were able to demonstrate that precision GNSS-based tide measurements can not only reach the accuracy level of one centimetre, comparable to traditional tide gauges, but also can deliver high temporal resolution. Again, this information can provide rich streams of sea level data that can be used for climate change monitoring and modelling.

Another area of research identified by the EY report was how GNSS information can be used to forecast space weather events, which is particularly significant for Canada as it experiences problems with its power supply caused by geomagnetic storms.

Frontier SI is undertaking a number of projects relevant to positioning technologies. One recent project investigates the application of 5G technology as a vehicle for providing precise positioning corrections to mobile platforms. The NPIC network provided the data upon which corrections were generated.

[64] EY (2020). Value of precision GNSS services in Canada, Natural Resources Canada.

7.1.2 Consultations

ACIL Allen spoke with several stakeholders from different research institutions.

UNSW

Dr Chris Rizos from the Surveying & Geospatial Engineering School at UNSW provided useful background into the history of research efforts involving positioning information. In the 1980s it could take as long as three hours before centimetre accuracy could be achieved (i.e., convergence was extremely slow). Now centimetre accuracy can be achieved in seconds (i.e., rapid convergence).

Dr Rizos noted that the graduate students in the 1990s developed software systems for GA, with a focus on improving the algorithms to get more rapid and accurate positioning. Later, the focus shifted to improving the algorithm for precise point positioning techniques, which was essential for encouraging uptake. For example, surveyors did not want to spend a long time waiting for a solution.

Dr Rizos believes that researchers have now "squeezed the maximum amount out of the CORS network" (i.e., optimised the algorithms of the CORS network as much as possible). However, he did note that every new signal (including from Russian, American, European or Chinese satellites) led to an opportunity for a researcher to develop a new algorithm. He also expects that researchers' attention will turn to improving the performance of SouthPAN, which would remove the need for ground-based infrastructure and will make positioning information more widely available.

Dr Rizos is now working to ensure the integrity and accuracy of the positioning information. He noted that emerging technologies such as autonomous vehicles needed to have access to high integrity data for them to be deployed. A lack of such data could put people's lives at risk. Even a perception that the technology might not be safe would be a major barrier to deployment.

Dr Rizos commented that the benefits really start to flow when adoption rates are high. It was his view that it has to be made easier and cheaper to get the right technology into the vehicles. When this occurs benefits will become mainstream.

His research is therefore examining how to combine GNSS information with different sources of information, such as lasers, cameras or other types of sensors. The aim of his research is to improve the integrity of the positioning information provided by a portfolio of sensors.

RMIT

Suelynn Choy, Director of the SPACE Research Centre at RMIT, spoke about the Centre's efforts to integrate GNSS with WiFi for use in indoor positioning. This technology will be important for driverless cars, for example to manage vehicles when they go into a tunnel. The Centre is also working to make positioning services cheaper. This will expand the application of these services, such as to the tracking of ebikes, as ebike operators are very cost-conscious.

Dr Choy said that car manufacturers are keen to know more about GNSS, and to use it to develop low-cost positioning solutions for cars. Current solutions are complex and piecemeal, and it costs too much to put lots of different sensors in a vehicle.

The RMIT, GA and the Bureau of Meteorology (BoM) have collaborated on research to use GNSS to provide more accurate, real time weather forecasts, harnessing the growing network of GPS receivers.[65] This research exploits the fact that GPS signals can be slightly delayed on their journey from satellites to Earth by moisture in the troposphere, causing what's known as a zenith total

65 RMIT (2019). How GPS now helps us forecast rain more accurately. Accessed 15 May 2022: https://www.rmit.edu.au/news/all-news/2019/oct/gps-weather-prediction

delay. The researchers could establish how to use precise measurements of this delay to accurately calculate air moisture and estimate likely rainfall.

Following successful trials across Australia, the method is now part of BoM's weather forecast models. RMIT Adjunct Professor and BoM Senior Principal Research Scientist, John Le Marshall, said it was an exciting new capability for real-time weather measurements and forecasting. He observed that while the technology could be applied almost anywhere, it was particularly valuable in a sparsely populated country like Australia with its relative lack of ground-based meteorological observation stations. He noted that:

> *Weather forecasting is dependent on accurate atmospheric observations, but the limited stations we can draw measurements from across our vast continent has always been an issue. With this technology we were able to tap into an Australia-wide network of receiving stations, and that number of stations is set to continue increasing over coming years.*[66]

Dr Robert Norman from RMIT University's School of Science, a study co-author, said the decade-long collaboration between RMIT and BoM had delivered massive value for both partners. He noted that:

> *Ultimately, the improvement in BoM weather forecasting benefits Australian industry and the wider community as well.*

FrontierSI

FrontierSI said it was essential to recognise that users want reliability and integrity of the information as much as they want accuracy.[67] Users must be able to trust the information they are getting. Convergence of different sensor technologies will be necessary, for example in horticulture.

7.1.3 Survey responses

ACIL Allen received responses from 12 research and innovation users, who work for a variety of organisations. Seven responses were from research institutions and five were from user organisations.

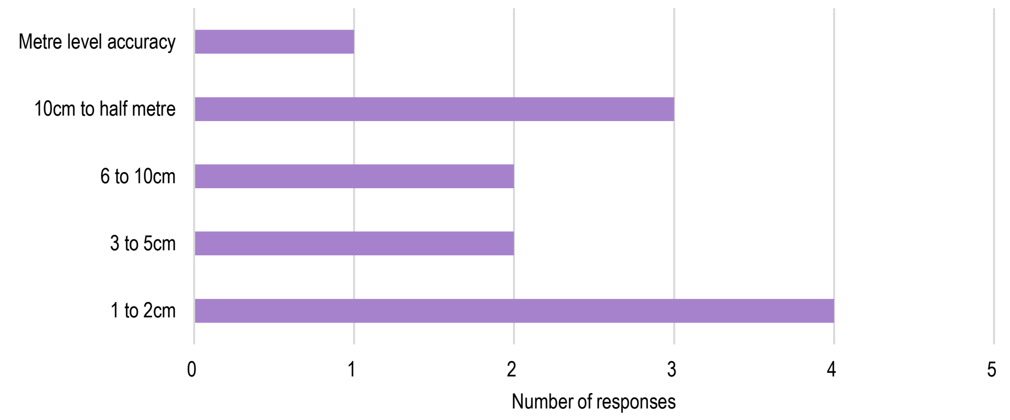
Respondents' organisations operate in all states and territories across Australia apart from Tasmania, some operate nationally, and two respondents' organisations operate internationally.

Four respondents reported they need 1 to 2 cm accuracy for their research, two need 3 to 5 cm accuracy, a further two need 6 to 10 cm, three respondents need 10 cm to 50 cm accuracy, and one respondent only needs 1 metre accuracy for their research (see Figure **7.1** below). Ten respondents' accuracy needs are currently being met, while two respondents are currently getting 3 to 5 cm accuracy but need 1 to 2 cm.

[66] Ibid

[67] Integrity is the measure of trust that can be placed in the correctness of the information supplied by a GNSS.

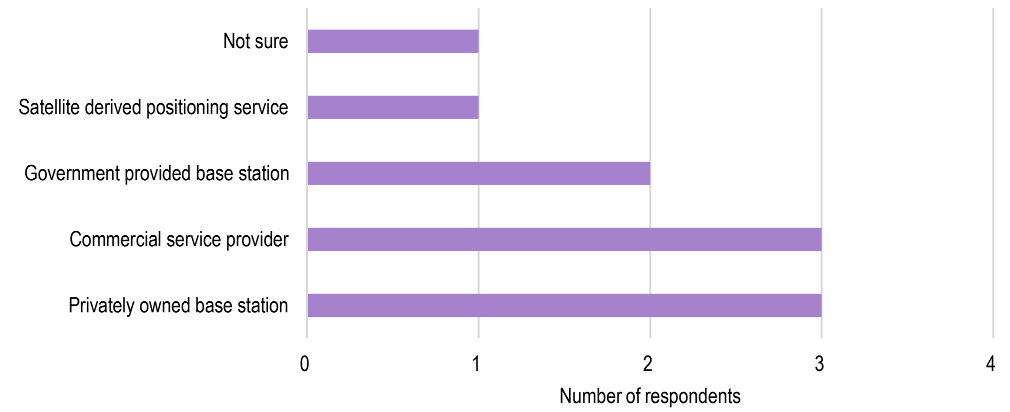
Figure 7.1 Level of positioning accuracy needed for research – Research and innovation users



Source: ACIL Allen Impacts of precise positioning survey

Three respondents reported getting their precise positioning capability from a privately-owned base station, another three are using a commercial service provider, two use a government-provided base station and one uses a satellite-derived positioning service (see Figure **7.2** below).

Figure 7.2 Technique used to achieve precise positioning - Research and innovation users



Source: ACIL Allen

The survey highlighted a range of precise positioning applications:

— One company operating nationally uses precise positioning to position mobile and aerial LiDAR systems. They are currently getting precise positioning capability accurate to 3 to 5 cm through an RTK network from a commercial service provider, but they need 1 to 2 cm accuracy. Access to positioning data helps the organisation implement accurate LiDAR systems and replace some traditional forms of survey. This has commercial applications in road authorities and infrastructure organisations. The systems have been integrated and are continuously refined, along with mobile and aerial LiDAR. Due to clients' varying needs for accuracy, any improvement of any system integrations will result in broad adoption and replacement for more traditional survey methodologies.

— Another company reported that positioning data has enabled them to concentrate funds and resources on building and enhancing services. Outputs of their research include automated high-quality positioning solutions and products, as well as online access to results (and analysis) of these solutions and products. These outputs are unlikely to have been achieved without access to government-provided positioning data, because freely available positioning data removes a significant barrier to entry. This company sees that the adoption and opportunities of these innovations is increasing, and they see a strong future for their services in industries such as oil and gas, mining, civil engineering, government and spatial/positioning.

— The School of Civil & Environmental Engineering within the University of New South Wales gets precise positioning of 1 to 2 cm accuracy from a government provided RTK network. The school trains PhD and Master-by-Research students, so precise positioning results may validate their own GNSS research contributions, and educates undergraduate surveyors, civil engineers, geographers and architects who use precise positioning results to assist their projects and learning. They would not be able to educate undergraduates in the same way if they did not have access to positioning data, but their training of postgraduates would be unaffected because they make the data themselves.
— A respondent from the University of South Australia reported that they need precise positioning data accurate to 1 to 2 cm for their research, which they get from a network RTK service from Trimble Centrepoint VRS and RTX. They use precise positioning for calibration and validation (ground-truthing) of remotely sensed imagery data (from a drone or satellite for example) or derived mapping data, as well as research for a positioning solution for sub-metre positioning under dense canopy. This has produced outputs in the form of journal papers and industry reports.[68, 69] Without access to positioning data, parts of it would not have been achieved or the results would have been less accurate. They collaborate with the SA forestry industry (e.g., OneFortyOne Plantations) and expect the forestry industry to adopt many innovations that occur as a result of their R&D. One such example is unsupervised spectral-spatial processing of drone imagery for the identification of pine seedlings.
— The Centre for Transformative Innovation at Swinburne University needs precise positioning data accurate to one meter to conduct research about how firms learn and innovate, which has shown that a core component of innovation is physical proximity to suppliers, universities, or competitors.
— Researchers at Swinburne also use precise positioning data to conduct research on land administration and management, as it supports sustainable development objectives. Secondary data sources with positioning information, for example cadastral boundaries and satellite imagery), are used to support data capture and creation techniques, including machine learning methodologies. These outputs would not have been achieved without access to positioning data.

[68] Peters, S, Liu, J, Bruce, D, Li, J, Finn, A & O'Hehir, J (2021). 'Research note: cost-efficient estimates of Pinus radiata wood volumes using multitemporal LiDAR data', Australian Forestry, vol. 84, no. 4, pp. 206-214

[69] Finn, A, Kumar, P, Peters, S & O'Hehir, J (2022). 'Unsupervised spectral-spatial processing of drone imagery for identification of pine seedlings', ISPRS Journal of Photogrammetry and Remote Sensing, vol. 183, pp. 363-388.

7.2 Summary of findings

Consultations demonstrated that researchers have largely optimised the algorithms used to process the data provided through NPIC. Reflecting this, research efforts have shifted to integrating data from other sources such as radar, cameras, and inertial navigation with precise positioning data.

These integration efforts can improve the integrity of the positioning data and extend the areas in which it can be used. By giving users the necessary confidence in precise positioning technologies, research can help to drive mass market adoption of new technologies such as autonomous vehicles, machine picking in the horticulture sector, and faster and more accurate outcomes from seed trials.

It was clear from the consultations and survey that the availability of NPIC data was valued by the research community and helped to stimulate research and innovation both in research institutions and in companies.

The value of the NPIC program for research is a factor to consider when assessing future levels of adoption of precise positioning across a range of industries, and therefore the impact of the NPIC program on end-users. The assessment of economic benefits in the end use sectors discussed in Chapters 3 to 6, includes consideration of the effects of relevant research and innovation on future levels of adoption in these sectors.

Impacts on other sectors 8

This project focussed on the benefit of the NPIC program on surveying and mapping, agriculture, mining and construction sectors, as required in the scope of work. Greater access to national positioning infrastructure and improved accuracy of GNSS services through the NPIC will enable more industries and more users to leverage precise positioning for their specific services.

Our work has identified other sectors that will benefit from the NPIC. These sectors were not assessed separately in the benefit calculations. However, their use of the CORS network and NPIC is relevant to the overall assessment of value of precise positioning and NPIC. This chapter outlines some of these other applications.

8.1 Infrastructure

The NPIC supports governments in infrastructure planning and implementation. Chapters 3 and 5 discuss the impact of CORS sourced services on design and construction activities which are relevant to infrastructure planning and implementation.

The Queensland Department of Transport and Main roads indicated that it depends on CORS installations and NPIC for:

— surveying and planning for main roads
— construction
— supporting their cooperative and automated vehicle initiative.

The Department requires positioning accuracy of one to two centimetres for planning and construction, and five centimetres to support autonomous vehicles. The NPIC program reduces the number of base stations the Department needs to establish, saving it time and money. Studies of the use of precise positioning services saves up to 50 per cent of the cost of engineering surveying and around 20 per cent for the cost of machine guidance[70].

The Australian Rail Track Corporation (ARTC) relies on CORS for designing, constructing and maintaining the Inland Rail track. Before the Inland Rail project commenced, the continuously operating reference stations (CORS) network in Southeast Queensland did not provide full coverage over the proposed rail corridor. To address critical gaps in the precise positioning service needed to support construction and operations, ARTC worked Geoscience Australia, Queensland Government, local councils and industry to establish seven additional CORS stations. The Savings from the use of positioning services based on unified data from the CORS network were estimated to be up to 75 per cent for survey control, 50 per cent for engineering surveys and 20 per cent for machine guidance.[71]

[70] ACIL Allen (2017) Economic value of spatial information in NSW

[71] ACIL Allen (2023). Economic impact of the National Positioning Infrastructure Capability Program

The Australian Rail Track Corporation estimated this saved around 2 per cent of a total construction budget of $100 million.

8.2 Government and professional services

A range of government and professional services can use the mapping and geographic information technologies enabled through precise positioning services were highlighted in Chapter 3. This includes uses in local government, arboriculture, engineering services, cultural heritage, infrastructure design and management, and environmental management.

Not all these applications require positioning accuracy at the 3 to 5 cm level. However, consultations suggested that most users will use the best accuracy that they can get, subject to cost. For example, mapping wide areas using airborne LiDAR is generally conducted using the best accuracy available to ensure the widest possible use.

Professional services and government organisations use both their own GNSS equipment and commercial service providers for their positioning requirements. In the past, many industries had to employ spatial experts, typically surveyors or other specialists, in the application of positioning technology. With greater access to national positioning infrastructure, cheaper and better receivers and improved accuracy, this has changed. Their use of positioning data is underpinned by NPIC program providing free access to a high precision location correction service.

The following examples describe professional and government users of spatial information (that do not have expertise in relation to positioning services) making use of the technology where there is the availability of appropriate GNSS base stations and wireless data access.

8.2.1 Flood management

The Queensland Department of Resources depends on precise positioning for several activities. For example, the Department used precise positioning to collect data on the lower catchment of the Brisbane River during flooding events to assist in future planning of flood mitigation programs. The Department officers need to be on the ground quickly during such events and require precise positioning to record flood encroachment. These data are important to planning recovery and for future flood mitigation activities. The Department also uses precise positioning for vegetation management and enforcement.

8.2.2 Pipeline engineers

Pipeline engineers conducting condition surveys can accurately locate faults easily to 250 mm - 500 mm using an inexpensive professional GNSS receiver integrated into their field software. The inspector can collect many attributes on a phone or tablet, including any pipeline faults, as well as the urgency for repair, the risk and the materials, equipment and expertise required for repair. Because the pipeline can cover a large area and, in most cases, will be buried, the addition of an accurate coordinate will unambiguously pinpoint the location.

> *It took five minutes to query our data and identify seven pipe segments from more than 1,100 that had been installed, together with their exact locations in the field.*[72]

8.2.3 Arboriculturists

Arboriculturists work in environments that are often not 'GNSS-friendly', for example because trees can have a deleterious effect on raw GNSS signals. In the past, this required a surveyor to map the location and an arborist to assess each tree. With correct training and an appropriate high

---

[72] McGlincy, J. GIS supervisor at Southern Company Gas (2022). Comment provided to Oilman Magazine. Accessed 16 May 2022: https://oilmanmagazine.com/article/how-gnss-speeds-up-pipeline-mapping/

performance GNSS, it is possible for an arborist to assess and map individual trees at sub-metre accuracy. The improved positioning capability provides real cost and time savings.

> *Landscapes are always in a state of flux, and as an arborist, you need to know where you are in that state of change.*[73]

8.2.4 Cultural heritage

Cultural heritage legislation in some states of Australia stipulates that any artefact mapped must be to an accuracy of better than one metre. This requirement has often been difficult to meet due to the cost of equipment and the need for satellite corrections to achieve accuracy of the required level. The NPIC program allows smaller consulting companies to comply with these requirements where they have access to the mobile or internet networks.

> *It's imperative to the effective, efficient and timely management of the places that we record, and all stakeholders need to have absolute faith in the data.*[74]

8.2.5 Local councils

Local councils require accurate location data for many purposes. A reliable precise positioning service greatly reduces the cost for a council to accurately map assets such as parks and gardens, sports and playing fields, playgrounds, open spaces, road furniture, traffic control, footpath and road defects, signage and drainage networks.

> *The technology hasn't been as good as it is now.*[75]

8.3 Economic value of applications in other sectors

Precise positioning technologies provide significant scope for users to make economic decisions that require accurate locational data. Applications that rely on positioning infrastructure will become more effective by improving the accessibility and accuracy of positioning services, providing substantial economic benefits as demonstrated above. NPIC enhances the accuracy and accessibility of such infrastructure to users, reducing the need for costlier access to information and expertise.

These wider benefits were not specifically quantified in the economic analysis. However, where appropriate, their impacts were considered when estimating the benefits of the CORS network and NPIC in the specific areas assessed Chapters 3 to 6 of this report.

For example, the use of data acquisition through airborne imagery capture was considered in the productivity impacts in the surveying sector. The value of data capture technologies was also considered in estimating the productivity impacts for the construction sector.

Accordingly, the estimates in this report are likely to be conservative.

[73] Lamb, A. (2022). How Mapping Trees Helped a University's Urban Forest Thrive. Accessed 16 May 2022: https://www.esri.com/about/newsroom/blog/campus-urban-forest-vegetation-management/

[74] Dr Canning, S. (managing director of Australian Cultural Heritage Management) (2020). Australian Organization Surveys Remote Archaeology Sites. Accessed 16 May 2022: https://eos-gnss.com/successes/sessions/australian-cultural-heritage-management

[75] Grunig. M. (Hyde Park City public works director) (2019). Comment provided to Juniper Systems Blog. Accessed 16 May 2022: https://blog.junipersys.com/affordable-subsurface-utility-mapping/

Economic benefits of the NPIC program 9

The direct net benefits of NPIC for the surveying and mapping, agriculture, construction, and mining sectors were discussed in Chapters 3 to 6. Each chapter estimated productivity improvements and set out the direct impacts of the NPIC on each sector.

In this chapter we first undertake a cost-benefit analysis of the NPIC program, drawing only on direct impacts in these four sectors.

We then discuss the results of Computable General Equilibrium (CGE) modelling that examines the broader, indirect effects on the economy.

9.1 Cost-benefit analysis based on direct impacts

As with any attempt to forecast potential future benefits, it is necessary to make a range of assumptions about innovation and rates of adoption. We have sought to ensure that the assumptions supporting the analysis are well informed, while erring on the side of caution where significant uncertainties are involved.

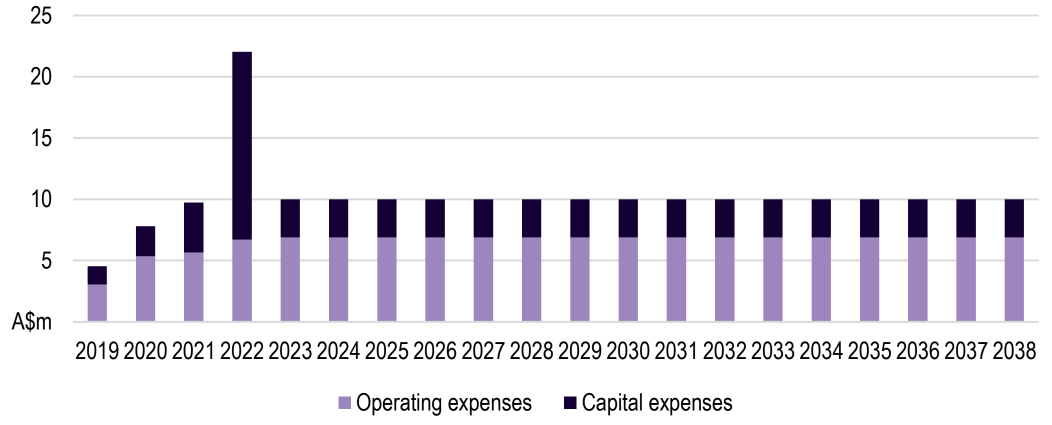
The anticipated future benefits associated with NPIC are discounted to arrive at a 'present value' of benefits and costs in FY 2022 dollars. The ratio of the present value of the benefits to the present value of the costs is referred to as the benefit-cost ratio (BCR) and is an indicator of the value of a program or project. A BCR of greater than one indicates that a program or policy is delivering an overall benefit to society.

The benefits represent the benefits to users take taking into account their implementation costs as far as possible. The costs represent the costs incurred by Geoscience Australia under the NPIC program.

9.1.1 NPIC costs

The costs of the NPIC program since its inception and expected costs to FY 2038 were detailed in Section 2.7, and are summarised in Figure **9.1.** In total, the program involves a commitment around $204 million over the 20 year period. This includes an initial four year establishment investment period to FY 2022, and then sustaining expenditure of about $10 million per year up to FY 2038.

Figure 9.1 Annual undiscounted Australian government NPIC costs, FY 2019 to FY 2038



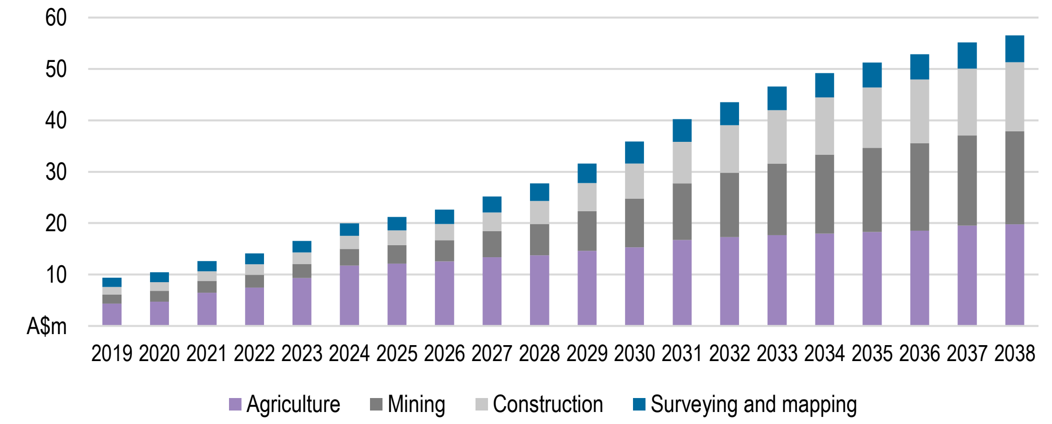
Source: GA

9.1.2 Benefits

Benefits by sector

The annual direct economic benefits estimated for each sector are summarised in Figure **9.2** below. ACIL Allen's methodology for estimating these benefits is provided in their respective chapters and sections in this report.

Figure 9.2 Annual undiscounted direct economic benefits of NPIC by sector, FY2019 to FY 2038



Source: ACIL Allen estimates based on various sources and assumptions

Benefits by period

Table **9.1** breaks down the benefits into three time periods, presented as a present value in FY 2022 (discounted at 7 per cent per year). On this basis, it is estimated that NPIC has delivered $51 million dollars of benefits from FY 2019 to FY 2022 and will deliver a further $313 million from FY 2023 to FY 2038. The total present value of the benefits arising out of the program is $365 million. The present value of the benefits delivered to FY 2022 represent 14 per cent of the total discounted benefits.

Table 9.1 NPIC Direct net economic benefits by period for selected sectors, present value in FY 2022

Sector	FY 2019 to FY 2022	FY 2022 to FY 2038	FY 2019 to FY 2038
	$million (FY 2022 prices)	$million (FY 2022 prices)	$million (FY 2022 prices)
Surveying and mapping	8.8	34.2	43.0
Agriculture	25.1	138	163.1
Construction	7.7	60.1	67.8
Mining	9.5	81.1	90.7
Total	**51.1**	**313.4**	**364.6**

Note: Net economic benefits in terms of present value as at FY 2022 calculated with a real discount rate of 7 per cent.
Source: ACIL Allen

9.1.3 Benefit-cost ratio of NPIC

NPIC delivers a Benefit Cost Ratio (BCR) of greater than one over a range of discount rates (Table **9.2**). The calculated BCR of 2.58 at a central real discount rate of 7 per cent, indicates that the Australian Government's spending on the NPIC delivers a strong overall benefit to Australia.

The BCR is not highly sensitive to the discount rate, indicating that this is a robust finding. The program will deliver positive benefits even using a 10 per cent discount rate.[76]

As well as the central 7 per cent discount rate, Table **9.2** also presents results using discount rates of 3 and 10 percent. This aligns with best practice cost-benefit analysis required by the Office of Impact Analysis and Transport for New South Wales.[77]

Table 9.2 Discounted costs, benefits and Benefit Cost Ratio of the NPIC

Discounted at	NPIC costs	NPIC measurable benefits	Benefit Cost Ratio
	$million (FY2022 prices)	$million (FY2022 prices)	Ratio
Undiscounted	204	643	3.15
3%	171	494	2.89
7%	141	365	2.58
10%	126	301	2.38

Note: Present value of costs and benefits calculated as at FY 2022.
Source: ACIL Allen

[76] A higher discount rate reduces the net benefit of the NPIC, as it involves significant upfront expenditure, but then a long stream of benefits over time. A higher discount rate reduces the value of this stream of benefits relative the front-loaded expenditure on the NPIC

[77] Office of Impact Analysis Cost Benefit Analysis, accessed online on 27 March 2023. https://oia.pmc.gov.au/resources/guidance-assessing-impacts/cost-benefit-analysis.

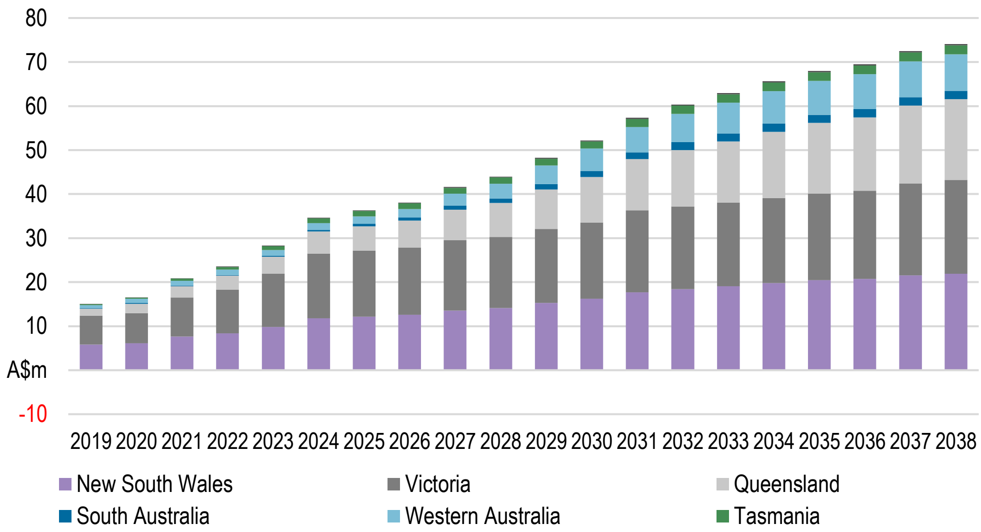
9.2 Overall economic impacts

ACIL Allen's CGE model, Tasman Global, was used to model the overall impact of the NPIC on the Australian economy and on the regions.

9.2.1 Overall economic benefit of the NPIC

Figure **9.3** shows the overall benefit of the NPIC to Australia's economy. This is measured as the change between the NPIC Scenario and the Counterfactual Scenario. The overall benefit includes both the direct benefits estimated in Section 9.1, and indirect or second-round benefits estimated through CGE modelling. These indirect benefits accrue as the productivity benefits in the directly impacted sectors. They allow resources to be reallocated within the economy, improving economic activity more broadly. The benefits presented are net of user costs.

Figure 9.3 Annual overall (direct and indirect) net economic benefit of the NPIC by state, FY 2019 to FY 2038



Note: Net economic benefits are not discounted. All dollars are in 2022 prices.
Source: ACIL Allen modelling

The NPIC delivers a net economic benefit of $545 million over the period from FY 2019 to FY 2038, calculated in present value terms using a 7 per cent discount rate.

This compares to total direct benefits accruing to the four sectors of $365 million in present value terms (Table **9.1**), indicating that the NPIC delivers about $180 million in benefits across the economy.

The Gross State Product of individual states and territories is summarised in Table **9.3**, and shows increases in present value terms (discounted at 7 per cent) of:

- $176 million in New South Wales (including the Australian Capital Territory)
- $194 million in Victoria
- $101 million in Queensland
- $12 million in South Australia
- $44 million in Western Australia
- $16 million Tasmania.

All jurisdictions apart from the Northern Territory are estimated to have an increased benefit from the CORS network and the NPIC program. The Northern Territory experiences a slight relative negative result. This is because the program does not have as significant an impact in the Northern Territory as in the other jurisdictions due to limited mobile phone coverage outside of the main population centres. Hence there is a slight reallocation of resources of labour and capital from the Northern Territory to the other jurisdictions. This is a relative effect and does not mean that the Northern Territory economy contracts in absolute terms.

Table 9.3 Net economic benefits of NPIC, FY 2019 to FY 2038

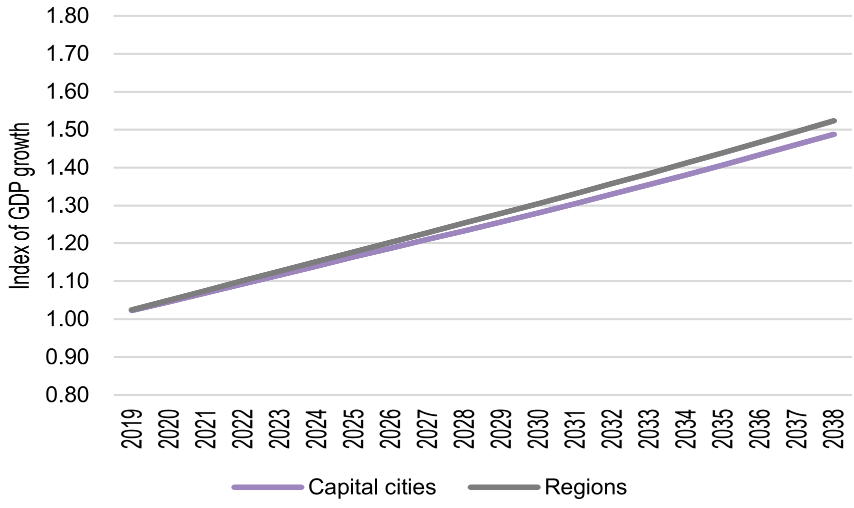
State	Total impacts between 2018-19 and 2037-38		
	Net Present Value (NPV) at 3%	NPV at 7%	NPV at 10%
	$million (FY 2022 prices)	$million (FY 2022 prices)	$million (FY 2022 prices)
New South Wales	230.9	176.4	149.1
Victoria	249.7	193.9	165.7
Queensland	140.6	101.1	81.6
South Australia	16.3	11.6	9.2
Western Australia	62.8	44.4	35.3
Tasmania	21.3	15.8	13.1
Northern Territory	-1.0	-0.8	-0.7
Australian Capital Territory	3.2	2.4	2.1
Australia	**723.8**	**544.8**	**455.4**

Note: Net economic benefits calculated as a present value as at FY 2022.
Source: ACIL Allen

9.2.2 Effect of the NPIC on capital cities and regions

Figure **9.4** summarises the effect of the NPIC on both capital cities and regions. Both are projected to grow under the NPIC Scenario. As a result of capital and labour mobility, there is a higher **relative** increase in output in the regions compared to the output of the capital cities. This does not mean that the capital cities decline in absolute terms. It is just that the capital cities do not grow as fast as the regions.

Figure 9.4 Index of capital and regions Gross Regional Product impact due to NPIC, FY 2018 to FY 2038

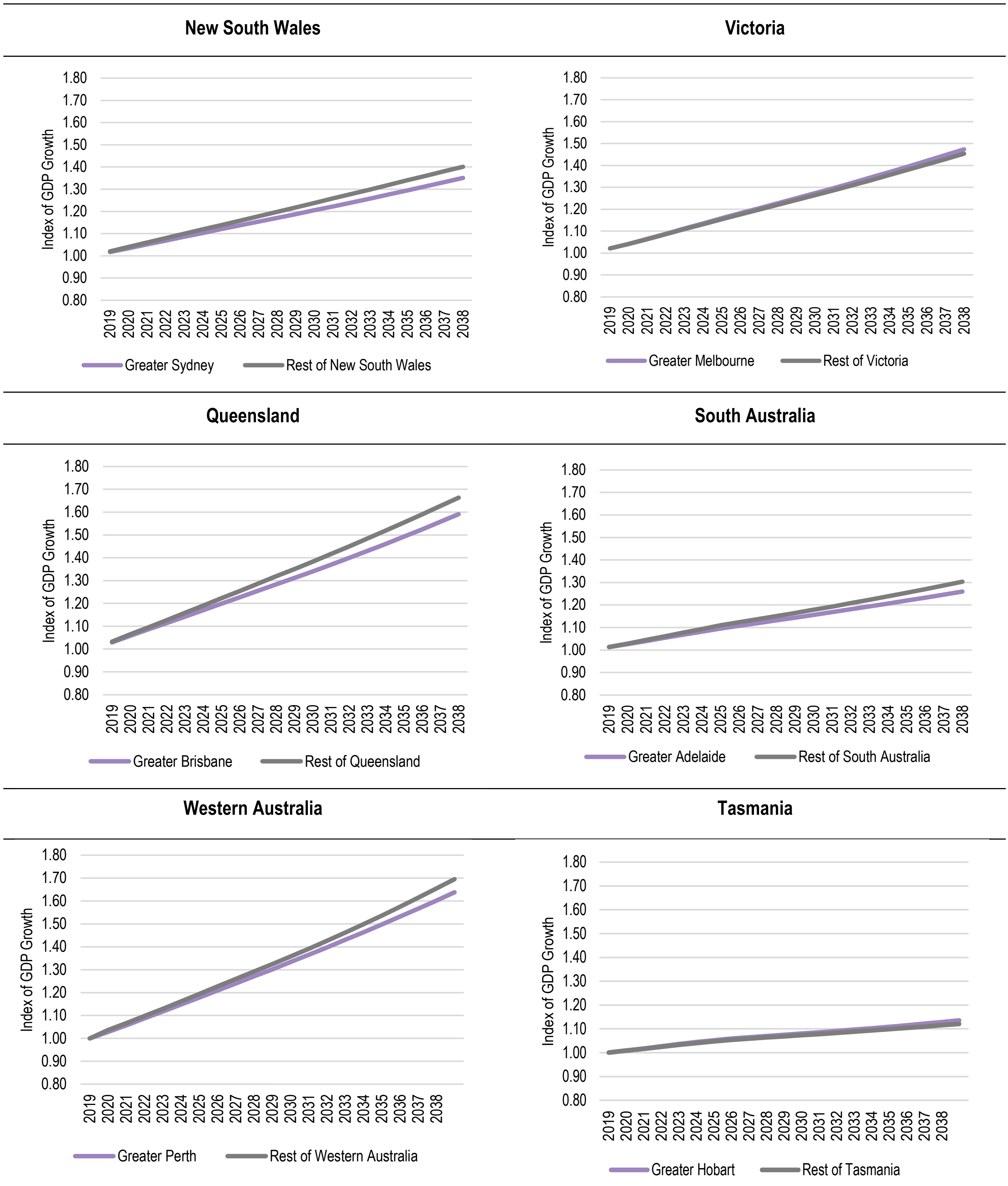


Note: FY 2018 =1.00

Source: ACIL Allen modelling based on the direct impact estimates

The estimated regional effects in each state are summarised in Figure **9.5**. The magnitude of relative differences between the states is mainly related to the geographic concentration of the sectors assessed in each state.

Figure 9.5 Regional output (Gross Regional Product) impacts of NPIC, FY 2019 to FY 2038



Note: Financial year 2018 =1.00

Source: ACIL Allen modelling based on the direct impact estimates

9.3 Estimated employment impacts

The NPIC will create both direct and indirect employment. Direct employment is the number of full-time equivalent workers employed in each of the four sectors assessed under the NPIC Scenario compared to the Counterfactual Scenario.

Indirect employment is the number of workers employed because of the increased productivity of NPIC-using sectors, which results in greater profits and wages across the economy generating additional demand and additional jobs. Job creation is expressed in terms of full-time equivalent (FTE) employed years.[78]

Table **9.4** shows the projected increase in FTE employment attributable to the NPIC program. The average annual increase in FTE is 116. The total additional employment generated over the FY 2019 to FY 2038 period is 2,316 FTE years.

Table 9.4 Employment growth due to NPIC, Full-time Equivalent (FTE), FY 2019 to FY 2038

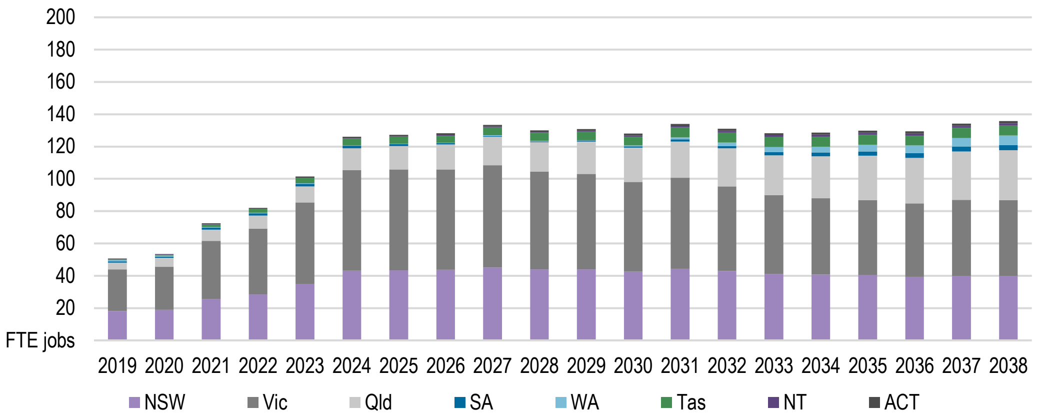
Regions	Annual average in employment	Increase in employment in FY 2038	Total increase in employment (FY 2019 to FY 2038)
	FTE	FTE	FTE
New South Wales	38	40	760
Victoria	50	47	996
Queensland	18	31	368
South Australia	2	3	31
Western Australia	2	6	35
Tasmania	5	6	90
Northern Territory	1	1	15
Australian Capital Territory	1	1	21
Australia	**116**	**136**	**2,316**

Note: Columns do not add to total due to rounding errors.
Source: ACIL Allen modelling

Overall, employment is projected to increase throughout the projection period. The largest increases occur in Victoria, New South Wales and Queensland. This reflects the size of the economics and population as well as the geographic distribution of benefits between different states and territories. The annual change in employment across each state due to NPIC is shown in Figure **9.6**.

[78] An employment year is employment of one full time equivalent (FTE) person for one year. A casual employee who works only 50 per cent of the time would be equivalent to 0.5 FTE employment for one year.

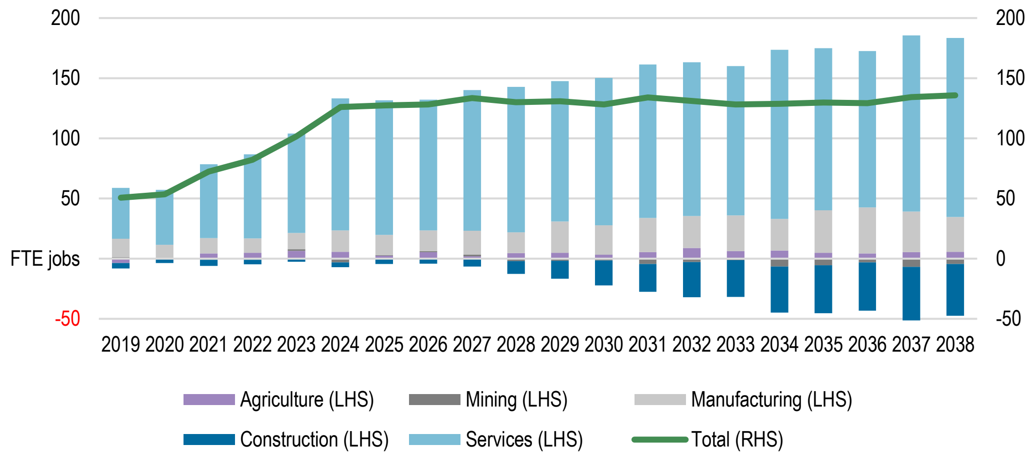
Figure 9.6 Employment growth due to NPIC by state/territory, Full-time Equivalent (FTE) employment for FY 2019 to FY 2038



Note: The data behind this figure is provided at Appendix E.
Source: ACIL Allen modelling

Figure **9.7** shows the impact on employment in different economic sectors. The NPIC program generates increased employment in the services sector (which includes the surveying and mapping sector), manufacturing, and agriculture. By FY 2038, the service sector employment is projected to increase by 149 FTEs and the manufacturing sector employment is projected to be 29 FTE higher by FY 2038 and agriculture is higher by 6 FTE.

Figure 9.7 Employment impacts of NPIC by broad sectors, Full-time Equivalent (FTE) employment, FY 2019 to FY 2038



Note: Surveying and mapping is included in the services sector.
The date behind this table is provided at Appendix E.
Source: ACIL Allen modelling

Employment in construction declines in relative terms over the evaluation period compared to the Counterfactual Scenario. This reflects the fact that precise positioning delivers improvements in labour productivity, which, in turn, reduces the number of employees required for a given level of output in the construction sector. The mining sector is highly capital-intensive, and any primary factor productivity benefits primarily increase profits, rather than increasing employment.

The NPIC program results in a shift in labour from the construction sector to the services sector, particularly after 2030. An average of around 19 FTE moves from construction sector to the services sector over the period from financial year 2019 to financial year 2038.

It should be noted that these findings do not imply that total employment in mining and construction will decline. These are relative changes due NPIC. Overall employment trends will be driven by broader economic trends in each sector. Employment in all sectors grows over time in the NPIC and Counterfactual scenarios, reflecting Australia's growing population and economy.

References

Australian Broadcasting Corporation (2021). Innovative agricultural robots land $4.5 million in funding for start-up SwarmFarm. Accessed 27 April 2022: https://www.abc.net.au/news/2021-02-28/swarmfarm-agricultural-robots-queensland/13193394.

ABS (2022). Construction Work Done, Australia, Preliminary. Accessed: https://www.abs.gov.au/statistics/industry/building-and-construction/construction-work-done-australia-preliminary/mar-2022

ACIL Allen (2008). Value of spatial information in Australia, CRCSI

ACIL Allen (2011). The value of spatial information for Tasmania, Department of Premier and Cabinet

ACIL Allen (2013). Precise positioning in the agricultural sector

ACIL Allen (2013). Precise positioning in the construction sector

ACIL Allen (2013). Precise positioning in the surveying sector

ACIL Allen (2013). Precise positioning in the utilities sector

ACIL Allen (2017) Economic value of spatial information in NSW

ACIL Allen (2017). 3D Qld Road Map Preliminary Findings, 3D Qld Task Force.

AgriFutures (2021). Broadacre cropping and space-based technologies, Fact sheet 3, Accessed 9 May 2022: https://www.agrifutures.com.au/wp-content/uploads/2021/04/21-043.pdf

AFI (2017). Accelerating precision agriculture to decision agriculture

APAL (2019). Automation and variable rate spray close to delivery

Allen Consulting (2008), Economic benefits of high-resolution positioning services, CRC for Spatial Information

Allen consulting Group (2007). Economic benefits of making GPSNet available to Victorian Agriculture.

Allen Consulting Group (2011), Benefit-cost evaluation of GPS Net for farming

ANZLIC (2022). ANZLIC Strategic Plan 2020-2024. Australian and New Zealand Land Information Council

ANZLIC (2019). Principles for Spatially Enabled Digital Twins of the Built and Natural Environment in Australia. Accessed 23 May 2022: https://www.anzlic.gov.au/sites/default/files/files/principles_for_spatially_enabled_digital_twins_of_the_built_and_natural_.pdf.

Australian Farm Institute (2017). Accelerating precision agriculture to decision agriculture

Australian Financial Review (2020). How a farm in remote Queensland became a high-tech AI hub. Accessed 26 April 2022: https://www.afr.com/technology/how-a-farm-in-remote-queensland-became-a-high-tech-ai-hub-20200116-p53s5f.

Australian Space Agency (2018). State of Space Report 2018-19

Bate, A. (SwarmFarms CEO) (n.d.), Comment provided to Queensland Government. Accessed 17 June 2022: https://advance.qld.gov.au/whats-happening/stories-about-innovation/regional-entrepreneur-reinventing-agriculture-robotic-innovation

Dr Canning, S. (managing director of Australian Cultural Heritage Management) (2020). Australian Organization Surveys Remote Archaeology Sites. Accessed 16 May 2022: https://eos-gnss.com/successes/sessions/australian-cultural-heritage-management

CRDC (2017). Accelerating Precision Agriculture to Decision Agriculture. Summary Report.

CSIRO Futures (2017). Mining Equipment, Technology and Services - A Roadmap for unlocking future growth opportunities for Australia

Department of Environment, Land, Water and Planning (2021). Digital Twin Victoria. Accessed 16 May 2022: https://www.land.vic.gov.au/maps-and-spatial/projects-and-programs/digital-twin-victoria.

Department of Environment, Land, Water and Planning (2022). Digital Twin Victoria's record LiDAR survey investment. Accessed 18 May 2022: https://www.land.vic.gov.au/maps-and-spatial/maps-and-spatial-news/digital-twin-victorias-record-lidar-survey-investment.

Department of Environment, Land, Water and Planning (2022). eComply. Accessed 18 May 2022: https://www.land.vic.gov.au/maps-and-spatial/projects-and-programs/digital-twin-victoria/ecomply.

Department of Environment, Land, Water and Planning (2021). Elevation Data. Accessed 16 May 2022: https://www.land.vic.gov.au/maps-and-spatial/imagery/elevation-data.

Department of Environment, Land, Water and Planning (2022). Great Ocean Road Action Plan. Accessed 11 May 2022: https://www.planning.vic.gov.au/policy-and-strategy/great-ocean-road-action-plan.

Department of Environment, Land, Water and Planning (2021). Great Ocean Road as You've never seen it. Accessed 16 May 2022: https://www.land.vic.gov.au/maps-and-spatial/maps-and-spatial-news/great-ocean-road-as-youve-never-seen-it-before.

Department of Environment, Land, Water and Planning spokesperson (2020). Comment provided to Surf Coast Times. Accessed 16 May 2022: https://timesnewsgroup.com.au/surfcoasttimes/news/scanning-the-road/

Department of Infrastructure, Transport, Regional Development and Communications (2021). National Road Safety Strategy 2021-30. Accessed 17 June 2022: https://www.roadsafety.gov.au/sites/default/files/documents/National-Road-Safety-Strategy-2021-30.pdf

El-Mowafy, A, Kubo, N., Kealy, A. (2020). Reliable Positioning and Journey Planning for Intelligent Transport Systems. Chapter 3, Advanced Energy Management, Modelling and Control for Intelligent and Efficient Transport Systems. InTech Publisher, UK, ISBN: 978-1-78984-104-6. pp 509-528. doi: 10.5772/intechopen.90305.

European Space Agency (ESA). Precision Agriculture, Navipedia.

EU Court of Auditors (2021). European Space Programmes

EUSPA (2021). User needs and requirements, surveying, European Union for the Space Program

EY (2020). Value of precision GNSS services in Canada, Natural Resources Canada.

Fawthrop, A. (2020). Communications systems and drones top mining technology investments in 2019. Accessed: https://www.nsenergybusiness.com/news/mining-technology-investment-drones/

Finn, A, Kumar, P, Peters, S & O'Hehir, J (2022). 'Unsupervised spectral-spatial processing of drone imagery for identification of pine seedlings', ISPRS Journal of Photogrammetry and Remote Sensing, vol. 183, pp. 363-388.

Frontier SI and EY (2019). SBAS Test-bed Demonstrator Trial, Economic Benefits Report,

Geoscience Australia (2018). *CEO statement on Budget 2018-19*, accessed online 6 June 2022 at: https://www.ga.gov.au/news-events/news/latest-news/ceo-statement-on-budget-2018-19

Geoscience Australia, (n.d.). Positioning Australia: About the Program, accessed online 6 June 2022 at: https://www.ga.gov.au/scientific-topics/positioning-navigation/positioning-australia/about-the-program

Grain Central (2021). SwarmFarm robots double down on herbicide savings. Accessed 17 June 2022: https://www.graincentral.com/machinery/swarmfarm-robots-double-down-on-herbicide-savings/

GRDC (2017). The economics of precision agriculture

GRDC (2017). VRT: maximising returns for Western Australian Grain Producers.

GRDC (2019). A profit first approach to precision agriculture

Grunig. M. (Hyde Park City public works director) (2019). Comment provided to Juniper Systems Blog. Accessed 16 May 2022: https://blog.junipersys.com/affordable-subsurface-utility-mapping/

GSA. (2015). *GNSS Market Report - Location Based Services.* Holsovice, Czech Republic: European Global Navigation Satellite Systems Agency.

IBISWorld (2022), Construction in Australia

IBIS World (2022). Surveying and Mapping Services in Australia

iMove Australia (2020). How Automated Vehicles Will Interact with Road Infrastructure Now and in the Future. Accessed 14 June 2022: https://imoveaustralia.com/wp-content/uploads/2020/02/P1-007-Milestone-6-Final-Report-Second-Revision.pdf

Infrastructure Australia (2019). Urban Transport Crowing and Congestion. Accessed 17 June 2022: https://www.infrastructureaustralia.gov.au/sites/default/files/2019-08/Urban%20Transport%20Crowding%20and%20Congestion.pdf

Institute of Navigation (2002). Network RTK Versus Single Base RTK - Understanding the Error Characteristics, accessed online 8 June 2022: https://www.ion.org/publications/abstract.cfm?articleID=2304

Lamb, A. (2022). How Mapping Trees Helped a University's Urban Forest Thrive. Accessed 16 May 2022: https://www.esri.com/about/newsroom/blog/campus-urban-forest-vegetation-management/

Llewellyn, R. and Ouzman, J. (2014). Adoption of precision agriculture-related practices: status, opportunities and the role of farm advisers, CSIRO Report for GRDC.

Maynard, H (2015). An Economic Analysis of Precision Viticulture, Fruit, and Pre-Release Wine Pricing across Three Western Australian Cabernet Sauvignon Vineyards, PhD Thesis, Curtin University.

Mahmood, S. (2021). Australia leads the way in autonomous truck use. Accessed: https://www.mining-technology.com/analysis/australia-leads-the-way-in-autonomous-truck-use/

Matysek, A., & Fisher, B. (2016). Productivity and Innovation in the Mining Industry, BAEconomics

McGlincy, J. GIS supervisor at Southern Company Gas (2022). Comment provided to Oilman Magazine. Accessed 16 May 2022. https://oilmanmagazine.com/article/how-gnss-speeds-up-pipeline-mapping/

Melissa Harris, Chief Executive Land Use Victoria. (2021). Comment provided to ZDNet. Accessed 18 May 2022: https://www.zdnet.com/article/victorian-government-sets-aside-au35m-to-build-a-digital-twin-of-the-state/

Mining Technology (2008). QMASTOR to Provide Bulk Terminal Management Solution to Newcastle Coal Infrastructure Group. Accessed 25 May 2022: https://www.mining-technology.com/contractors/resource/qmastor/pressreleases/press2-39/.

Mining Technology (2008). QMASTOR to Provide Bulk Terminal Management Solution to Newcastle Coal Infrastructure Group. Accessed 25 May 2022: https://www.mining-technology.com/contractors/resource/qmastor/pressreleases/press2-39/.

National Farmers' Federation (2021). Submission to Regional Connectivity Program Round 2 Draft Program Guidelines.

National Transport Commission (2020). In-Service Safety for Automated Vehicles Decision Regulation Impact Statement

OBPR (2016). COST-BENEFIT ANALYSIS, accessed online 10 June 2022 at: https://www.pmc.gov.au/sites/default/files/publications/cosst-benefit-analysis.docx#:~:text=The%20discount%20rate%20for%20regulatory,rate%20of%207%20per%20cent.

Peters, S, Liu, J, Bruce, D, Li, J, Finn, A & O'Hehir, J (2021). 'Research note: cost-efficient estimates of Pinus radiata wood volumes using multitemporal LiDAR data', Australian Forestry, vol. 84, no. 4, pp. 206-214

Queensland cotton grower Jamie Grant (2021). Comment provided to ABC. Accessed 17 June 2022: https://www.abc.net.au/news/2021-02-28/swarmfarm-agricultural-robots-queensland/13193394

Queensland Government (2019). CAVI Components. Accessed 14 June 2022: https://www.qld.gov.au/transport/projects/cavi/cavi-components

Queensland Government (2018). C-ITS Pilot. Accessed 17 June 2022: https://www.publications.qld.gov.au/dataset/cavi-resources/resource/b8a5ab55-21af-4ab4-9bd0-126c239ced94

Queensland Government (2021). Cooperative and Automated Vehicle Initiative. Accessed 8 June 2022: https://www.qld.gov.au/transport/projects/cavi/cavi-project

Queensland Government (2018). Smart state supports smart vehicles. Minister for Transport and Main Roads. Accessed 17 June 2022: https://statements.qld.gov.au/statements/84664

Revell, G.B., Powell, J.W. and Welsh, J.M. (2020). Economic potential of autonomous tractor technology in Australian cotton production systems, *Australian Farm Business Management Journal*, 17(2).

RMIT (2019). How GPS now helps us forecast rain more accurately. Accessed 15 May 2022: https://www.rmit.edu.au/news/all-news/2019/oct/gps-weather-prediction

Robertson, M., Kirkegaard, J., Rebetzke, G., Llewellyn, R. and Wark, T. (2016). Prospects for yield improvement in the Australian wheat industry: a perspective, *Food and Energy Security*, 5(2):107-122.

RTI International (2019). Economic benefits of the Global Positioning System

Tullberg et al. (undated.). "On Track" to Sustainable Cropping Systems for Australia.

US Department of Transportation (2015). Traffic Safety Facts. Accessed 17 June 2022: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115

US RTI International (2019). Economic Benefits to the Global Positioning System

US TRB (2021). Preparing for Automated Vehicles and Shared Mobility: State-of-the-Research Topical Paper #6

ZDNet (2021). Victorian government sets aside AU$35m to build a digital twin of the state. Accessed 18 May 2022: https://www.zdnet.com/article/victorian-government-sets-aside-au35m-to-build-a-digital-twin-of-the-state/.

Appendices

A Consultation list

Organisation by sector	Stakeholder position
Equipment manufacturers and service providers	
Hexagon	– Regional Manager, Asia/Pacific
HxGN	– GNSS Network Manager, HxGN SmartNet
Map Gear	– General Manager at Mangoesmapping, Farm Doctors and Map Gear
MondoPin	– Business Development Manager
Position Partners	– Positioning Infrastructure Manager
RTK Netwest	– Director
SITECH	– Northern Region Manager – Corporate Account Manager
Trimble	– Marketing Director
4D Global	– Managing Director
Agriculture	
Australian Farm Institute	– General Manager (note discussion focused on AFI 2017 report)
Data Farming	– Managing Director
Farm Doctors	– General Manager at Mangoesmapping, Farm Doctors and Map Gear
Goanna Ag	– CEO
Horticulture Innovation Australia	– Head of R&D
Society of Precision Agriculture (SPAA)	– Vice President – President – Immediate Past President
Mining	
Minerals Council of Australia	– Chief Economist
Rio Tinto	– Office of the Chief Scientist

Organisation by sector	Stakeholder position
Construction	
GHD	– Technical Director (Geophysics) – Senior Geophysicist
Surveying and mapping	
Bennett and Bennett Surveyors	– Cadastral Manager – Managing Director
Consulting Surveyors National	– CEO
ESRI	– Managing Consultant, Advisory Services – Principal Consultant, Solution Engineering
Jacobs	– Site Information Project Manager
PHL Surveyors	– Director/Surveyor
Queensland Department of Resources	– Senior Surveyor – Executive Director (spatial information)
Tasmanian Department of Natural Resources and Environment	– A/g Surveyor-General of Tasmania – Program Manager Cadastral Standards
Veris and SIBA/GITA	– Principal Surveyor
Victorian Department of Environment, Land, Water and Planning	– Surveyor-General of Victoria – Geodesy Manager
Research and Innovation	
AuScope	– CEO
Curtin University	– Director of Graduate Research, Earth and Planetary Sciences
Frontier SI	– Positioning and Geodesy Technical Lead – Product Development Manager
GRDC	– Senior Manager, enabling technologies – Manager, AgTech
METS Ignited	– CEO
RMIT	– Professor of Satellite Navigation
TAFE NSW	– Teacher
UNSW	– Professor, Researcher
Infrastructure	
Australian Rail Track Corporation	– Program Manager Survey
Queensland Department of Transport and Roads	– Director (geospatial technologies)

Organisations approached to distribute the survey

B

ACIL Allen's economic assessment was also informed by a web-based survey examining the impact of precise positioning technology in Australia. The survey was launched on 25 April 2022 and closed on 28 June 2022.

The organisations approached to publicise the survey were:

— Spatial Industries Business Association and the Geospatial Information and Technology Association (SIBA/GITA)
— Surveying and Spatial Sciences Institute (SSSI)
— FrontierSI
— SmartSat Cooperative Research Centre
— Minerals Council of Australia
— Australian Constructors Association
— Consulting Surveyors National
— Australian Farm Institute
— National Farmer's Federation
— Australian Pipeline and Gas Association
— Regional Universities Network
— Universities Australia
— Australian Technology Network
— Group of Eight Universities
— Australian Fresh Produce Association
— Tech Council of Australia
— Position Australia Magazine

Tasman Global CGE Model

C

Tasman Global is a dynamic, global computable general equilibrium (CGE) model that has been developed by ACIL Allen for the purpose of undertaking economic impact analysis at the regional, state, national and global level.

A CGE model captures the interlinkages between the markets of all commodities and factors, taking into account resource constraints, to find a simultaneous equilibrium in all markets. A global CGE model extends this interdependence of the markets across world regions and finds simultaneous equilibrium globally. A dynamic model adds onto this the interconnection of equilibrium economies across time periods. For example, investments made today are going to determine the capital stocks of tomorrow and hence future equilibrium outcomes depend on today's equilibrium outcome, and so on.

A dynamic global CGE model, such as *Tasman Global*, has the capability of addressing total, sectoral, spatial and temporal efficiency of resource allocation as it connects markets globally and over time. Being a recursively dynamic model, however, its ability to address temporal issues is limited. In particular, *Tasman Global* cannot typically address issues requiring partial or perfect foresight. However, as documented in Jakeman et al (2001), it is possible to introduce partial or perfect foresight in certain markets using algorithmic approaches. Notwithstanding this, the model does have the capability to project the economic impacts over time of given changes in policies, tastes and technologies in any region of the world economy on all sectors and agents of all regions of the world economy.

Tasman Global was developed from the 2001 version of the Global Trade and Environment Model (GTEM) developed by ABARE (Pant 2001) and has been evolving ever since. In turn, GTEM was developed out of the MEGABARE model (ABARE 1996), which contained significant advancements over the GTAP model of that time (Hertel 1997).

C.1 A Dynamic Model

Tasman Global is a model that estimates relationships between variables at different points in time. This contrasts with comparative static models, which compare two equilibriums (one before an economic disturbance and one following). A dynamic model such as *Tasman Global* is beneficial when analysing issues for which both the timing of and the adjustment path that economies follow are relevant in the analysis.

C.2 The Database

A key advantage of *Tasman Global* is the level of detail in the database underpinning the model. The database is derived from the Global Trade Analysis Project (GTAP) database (Aguiar et al. 2019). This database is a fully documented, publicly available global data base which contains complete bilateral trade information, transport and protection linkages among regions for all GTAP commodities. It is the most detailed database of its type in the world.

Tasman Global builds on the GTAP database by adding the following important features:

— a detailed population and labour market database

— detailed technology representation within key industries (such as electricity generation and iron and steel production)

— disaggregation of a range of major commodities including iron ore, bauxite, alumina, primary aluminium, brown coal, black coal and LNG

— the ability to repatriate labour and capital income

— explicit representation of the states and territories of Australia

— the capacity to represent multiple regions within states and territories of Australia explicitly.

Nominally, version 10.1 of the *Tasman Global* database divides the world economy into 153 regions (145 international regions plus the 8 states and territories of Australia) although the regions are frequently disaggregated further. ACIL Allen regularly models Australian or international projects or policies at the regional level including at the or at the state/territory/provincial level for various countries.

The *Tasman Global* database also contains a wealth of sectoral detail currently identifying up to 76 industries. The foundation of this information is the input-output tables that underpin the database. The input-output tables account for the distribution of industry production to satisfy industry and final demands.

Industry demands, so-called intermediate usage, are the demands from each industry for inputs. For example, electricity is an input into the production of communications. In other words, the communications industry uses electricity as an intermediate input.

Final demands are those made by households, governments, investors and foreigners (export demand). These final demands, as the name suggests, represent the demand for finished goods and services. To continue the example, electricity is used by households – their consumption of electricity is a final demand.

Each sector in the economy is typically assumed to produce one commodity, although in *Tasman Global*, the electricity, transport and iron and steel sectors are modelled using a ‘technology bundle’ approach. With this approach, different known production methods are used to generate a homogeneous output for the ‘technology bundle’ industry. For example, electricity can be generated using brown coal, black coal, petroleum, base load gas, peak load gas, nuclear, hydro, geothermal, biomass, wind, solar or other renewable based technologies – each of which has its own cost structure.

The other key feature of the database is that the cost structure of each industry is also represented in detail. Each industry purchases intermediate inputs (from domestic and imported sources) primary factors (labour, capital, land and natural resources) as well as paying taxes or receiving subsidies.

Table C.1 Standard sectors in the Tasman Global model

No	Name	No	Name
1	Paddy rice	39	Diesel (incl. nonconventional diesel)
2	Wheat	40	Other petroleum, coal products
3	Cereal grains nec	41	Chemical, rubber, plastic products
4	Vegetables, fruit, nuts	42	Iron ore
5	Oil seeds	43	Bauxite
6	Sugar cane, sugar beet	44	Mineral products nec
7	Plant- based fibres	45	Ferrous metals
8	Crops nec	46	Alumina
9	Bovine cattle, sheep, goats, horses	47	Primary aluminium
10	Pigs	48	Metals nec
11	Animal products nec	49	Metal products
12	Raw milk	50	Motor vehicle and parts
13	Wool, silkworm cocoons	51	Transport equipment nec
14	Forestry	52	Electronic equipment
15	Fishing	53	Machinery and equipment nec
16	Brown coal	54	Manufactures nec
17	Black coal	55	Electricity generation
18	Oil	56	Electricity transmission and distribution
19	Liquefied natural gas (LNG)	57	Gas manufacture, distribution
20	Other natural gas	58	Water
21	Minerals nec	59	Construction
22	Bovine meat products	60	Trade
23	Pig meat products	61	Road transport
24	Meat products nec	62	Rail and pipeline transport
25	Vegetables oils and fats	63	Water transport
26	Dairy products	64	Air transport
27	Processed rice	65	Transport nec
28	Sugar	66	Warehousing and support activities
29	Food products nec	67	Business services nec
30	Wine	68	Communication
31	Beer	69	Financial services nec
32	Spirits and RTDs	70	Insurance
33	Other beverages and tobacco products	71	Business services nec
34	Textiles	72	Recreational and other services
35	Wearing apparel	73	Public Administration and Defence
36	Leather products	74	Education
37	Wood products	75	Human health and social work activities
38	Paper products, publishing	76	Dwellings

C.3 Model Structure

Given its heritage, the structure of the *Tasman Global* model closely follows that of the Global Trade Analysis Project (GTAP) and the Global Trade and Environmental (GTEM) models and interested readers are encouraged to refer to the documentation of these models for more detail (namely Hertel 1997 and Pant 2001, respectively). In summary:

- The model divides the world into a variety of regions and international waters.
  - Each region is fully represented with its own 'bottom-up' social accounting matrix and could be a local community, an LGA, state, country or a group of countries. The number of regions in each simulation depends on the database aggregation. Each region consists of households, a government with a tax system, production sectors, investors, traders and finance brokers.
  - 'International waters' are a hypothetical region in which global traders operate and use international shipping services to ship goods from one region to the other. It also houses an international finance 'clearing house' that pools global savings and allocates the fund to investors located in every region.
  - Each region has a 'regional household'[79] that collects all factor payments, taxes, net foreign borrowings, net repatriation of factor incomes due to foreign ownership and any net income from trading of emission permits.
- The income of the regional household is allocated across private consumption, government consumption and savings according to a Cobb-Douglas utility function, which, in practice, means that the share of income going to each component is assumed to remain constant in nominal terms.
- Private consumption of each commodity is determined by maximising utility subject to a Constant Difference of Elasticities (CDE) function which includes both price and income elasticities.
- Government consumption of each commodity is determined by maximising utility subject to a Cobb-Douglas utility function.
- Each region has *n* production sectors, each producing single products using various production functions where they aim to maximise profits (or minimise costs) and take all prices as given. The nature of the production functions chosen in the model means that producers exhibit constant returns to scale.
  - In general, each producer supplies consumption goods by combining an aggregate energy-primary factor bundle with other intermediate inputs and according to a Leontief production function (which in practice means that the quantity shares remain in fixed proportions). Within the aggregate energy-primary factor bundle, the individual energy commodities and primary factors are combined using a nested-CES (Constant Elasticity of Substitution) production function, in which energy and primary factor aggregates substitute according to a CES function with the individual energy commodities and individual primary factors substituting with their respective aggregates according to further CES production functions.
  - Exceptions to the above include the electricity generation, iron and steel and road transport sectors. These sectors employ the 'technology bundle' approach developed by ABARE (1996) in which non-homogenous technologies are employed to produce a homogenous output with the choice of technology governed by minimising costs according to a modified-CRESH production function. For example, electricity may be generated from a variety of technologies (including brown coal, black coal, gas, nuclear, hydro, solar etc.), iron and steel may be produced from blast furnace or

[79] The term 'regional household' was devised for the GTAP model. In essence it is an agent that aggregates all incomes attributable to the residents of a given region before distributing the funds to the various types of regional consumption (including savings).

electric arc technologies while road transport services may be supplied using a range of different vehicle technologies. The 'modified-CRESH' function differs from the traditional CRESH function by also imposing the condition that the quantity units are homogenous.

- There are four primary factors (land, labour, mobile capital and fixed capital). While labour and mobile capital are used by all production sectors, land is only used by agricultural sectors while fixed capital is typically employed in industries with natural resources (such as fishing, forestry and mining) or in selected industries built by ACIL Allen.
  - Land supply in each region is typically assumed to remain fixed through time with the allocation of land between sectors occurring to maximise returns subject to a Constant Elasticity of Transformation (CET) utility function.
  - Mobile capital accumulates because of net investment. It is implicitly assumed in *Tasman Global* that it takes one year for capital to be installed. Hence, supply of capital in the current period depends on the last year's capital stock and investments made during the previous year.
  - Labour supply in each year is determined by endogenous changes in population, given participation rates and a given unemployment rate. In policy scenarios, the supply of labour is positively influenced by movements in the real wage rate governed by the elasticity of supply. For countries where sub-regions have been specified (such as Australia), migration between regions is induced by changes in relative real wages with the constraint that net interregional migration equals zero. For regions where the labour market has been disaggregated to include occupations, there is limited substitution allowed between occupations by individuals supplying labour (according to a CET utility function) and by firms demanding labour (according to a CES production function) based on movements in relative real wages.
  - The supply of fixed capital is given for each sector in each region.

- The model has the option for these assumptions to be changed at the time of model application if alternative factor supply behaviours are considered more relevant.
  - It is assumed that labour (by occupation) and mobile capital are fully mobile across production sectors implying that, in equilibrium, wage rates (by occupation) and rental rates on capital are equalised across all sectors within each region. To a lesser extent, labour and capital are mobile between regions through international financial investment and migration, but this sort of mobility is sluggish and does not equalise rates of return across regions.
  - For most international regions, for each consumer (private, government, industries and the local investment sector), consumption goods can be sourced either from domestic or imported sources. In any country that has disaggregated regions (such as Australia), consumption goods can also be sourced from other intrastate or interstate regions. In all cases, the source of non-domestically produced consumption goods is determined by minimising costs subject to a Constant Ratios of Elasticities of Substitution, Homothetic (CRESH) utility function. Like most other CGE models, a CES demand function is used to model the relative demand for domestically produced commodities versus non-domestically produced commodities. The elasticities chosen for the CES and CRESH demand functions mean that consumers in each region have a higher preference for domestically produced commodities than non-domestic commodities and a higher preference for intrastate- or interstate-produced commodities than foreign commodities.
  - The capital account in *Tasman Global* is open. Domestic savers in each region purchase 'bonds' in the global financial market through local 'brokers' while investors in each region sell bonds to the global financial market to raise investible funds. A flexible global interest rate clears the global financial market.
  - It is assumed that regions may differ in their risk characteristics and policy configurations. As a result, rates of return on money invested in physical capital may differ between regions and therefore may be different from the global cost of funds.

Any difference between the local rates of return on capital and the global cost of borrowing is treated as the result of the existence of a risk premium and policy imperfections in the international capital market. It is maintained that the equilibrium allocation of investment requires the equalisation of changes in (as opposed to the absolute levels of) rates of return over the base year rates of return.

- Any excess of investment over domestic savings in each region causes an increase in the net debt of that region. It is assumed that debtors service the debt at the interest rate that clears the global financial market. Similarly, regions that are net savers gives rise to interest receipts from the global financial market at the same interest rate.
- Investment in each region is used by the regional investor to purchase a suite of intermediate goods according to a Leontief production function to construct capital stock with the regional investor cost minimising by choosing between domestic, interstate and imported sources of each intermediate good via the CRESH production function. The regional cost of creating new capital stock versus the local rates of return on mobile capital is what determines the regional rate of return on new investment.
- In equilibrium, exports of a good from one region to the rest of world are equal to the import demand for that good in the remaining regions. Together with the merchandise trade balance, the net payments on foreign debt add up to the current account balance. *Tasman Global* does not require that the current account be in balance every year. It allows the capital account to move in a compensatory direction to maintain the balance of payments. The exchange rate provides the flexibility to keep the balance of payments in balance.
- Detailed bilateral transport margins for every commodity are specified in the starting database. By default, the bilateral transport mode shares are assumed to be constant, with the supply of international transportation services by each region solved by a cost-minimising international trader according to a Cobb-Douglas demand function.
- Emissions of six anthropogenic greenhouse gases (namely, carbon dioxide, methane, nitrous oxide, HFCs, PFCs and SF_6) associated with economic activity are tracked in the model. Almost all sources and sectors are represented; emissions from agricultural residues and land-use change and forestry activities are not explicitly modelled but can be accounted for externally. Prices can be applied to emissions which are converted to industry-specific production taxes or commodity-specific sales taxes that impact on demand. Abatement technologies similar to those adopted in a report released by the Australian Government (2008) are available and emission quotas can be set globally or by region along with allocation schemes that enable emissions to be traded between regions.

More detail regarding specific elements of the model structure is discussed in the following sections.

C.4 Population Growth and Labour Supply

Population growth is an important determinant of economic growth through the supply of labour and the demand for final goods and services. Population growth for each region represented in the *Tasman Global* database is projected using ACIL Allen's in-house demographic model. The demographic model projects how the population in each region grows and how age and gender composition changes over time and is an important tool for determining the changes in regional labour supply and total population over the projected period.

For each of region, the model projects the changes in age-specific birth, mortality and net migration rates by gender for 101 age cohorts (0-99 and 100+). The demographic model also projects changes in participation rates by gender by age for each region, and, when combined with the age and gender composition of the population, endogenously projects the future supply of labour in each region. Changes in life expectancy are a function of income per person as well as assumed technical progress on lowering mortality rates for a given income (for example, reducing malaria-related mortality through better medicines, education, governance etc.). Participation rates are a function of life expectancy as well as expected changes in higher education rates, fertility rates and changes in the work force as a share of the total population.

Labour supply is derived from the combination of the projected regional population by age by gender and regional participation rates by age by gender. Over the projected period labour supply in most developed economies is projected to grow slower than total population because of ageing population effects.

For the Australian states and territories, the projected aggregate labour supply from ACIL Allen's demographic module is used as the base level potential workforce for the detailed Australian labour market module, which is described in the next section.

Tasman Global has a detailed representation of the Australian labour market which has been designed to capture:

— different occupations
— changes to participation rates (or average hours worked) due to changes in real wages
— changes to unemployment rates due to changes in labour demand
— limited substitution between occupations by the firms demanding labour and by the individuals supplying labour, and
— limited labour mobility between states and regions within each state.

Tasman Global recognises 97 different occupations within Australia – although the exact number of occupations depends on the aggregation. The firms that hire labour are provided with some limited scope to change between these 97 labour types as the relative real wage between them changes. Similarly, the individuals supplying labour have a limited ability to change occupations in response to the changing relative real wage between occupations. Finally, as the real wage for a given occupation rises in one state relative to other states, workers are given some ability to respond by shifting their location. The model produces results at the 97 3-digit ANZSCO (Australian New Zealand Standard Classification of Occupations) level which are presented in Table C.2

The labour market structure of *Tasman Global* is thus designed to capture the reality of labour markets in Australia, where supply and demand at the occupational level do adjust, but within limits.

Labour supply in *Tasman Global* is presented as a three-stage process:

1. labour makes itself available to the workforce based on movements in the real wage and the unemployment rate
2. labour chooses between occupations in a state based on relative real wages within the state; and
3. labour of a given occupation chooses in which state to locate based on movements in the relative real wage for that occupation between states.

By default, *Tasman Global*, like all CGE models, assumes that markets clear. Therefore, overall, supply and demand for different occupations will equate (as is the case in other markets in the model).

Table C.2 Occupations in the *Tasman Global* Database, ANZSCO 3-digit level (minor groups)

1. MANAGERS
111 Chief Executives, General Managers and Legislators
121 Farmers and Farm Managers
131 Advertising and Sales Managers
132 Business Administration Managers
133 Construction, Distribution and Production Managers
134 Education, Health and Welfare Services Managers
135 ICT Managers
139 Miscellaneous Specialist Managers
141 Accommodation and Hospitality Managers
142 Retail Managers
149 Miscellaneous Hospitality, Retail and Service Managers

2. PROFESSIONALS
211 Arts Professionals
212 Media Professionals
221 Accountants, Auditors and Company Secretaries
222 Financial Brokers and Dealers, and Investment Advisers
223 Human Resource and Training Professionals
224 Information and Organisation Professionals
225 Sales, Marketing and Public Relations Professionals
231 Air and Marine Transport Professionals
232 Architects, Designers, Planners and Surveyors
233 Engineering Professionals
234 Natural and Physical Science Professionals
241 School Teachers
242 Tertiary Education Teachers
249 Miscellaneous Education Professionals
251 Health Diagnostic and Promotion Professionals
252 Health Therapy Professionals
253 Medical Practitioners
254 Midwifery and Nursing Professionals
261 Business and Systems Analysts, and Programmers
262 Database and Systems Administrators, and ICT Security Specialists
263 ICT Network and Support Professionals
271 Legal Professionals
272 Social and Welfare Professionals

3. TECHNICIANS & TRADES WORKERS
311 Agricultural, Medical and Science Technicians
312 Building and Engineering Technicians
313 ICT and Telecommunications Technicians
321 Automotive Electricians and Mechanics
322 Fabrication Engineering Trades Workers
323 Mechanical Engineering Trades Workers
324 Panel beaters, and Vehicle Body Builders, Trimmers and Painters
331 Bricklayers, and Carpenters and Joiners
332 Floor Finishers and Painting Trades Workers
333 Glaziers, Plasterers and Tilers
334 Plumbers
341 Electricians
342 Electronics and Telecommunications Trades Workers
351 Food Trades Workers
361 Animal Attendants and Trainers, and Shearers
362 Horticultural Trades Workers
391 Hairdressers
392 Printing Trades Workers
393 Textile, Clothing and Footwear Trades Workers
394 Wood Trades Workers
399 Miscellaneous Technicians and Trades Workers

4. COMMUNITY & PERSONAL SERVICE
411 Health and Welfare Support Workers
421 Child Carers
422 Education Aides
423 Personal Carers and Assistants
431 Hospitality Workers
441 Defence Force Members, Fire Fighters and Police
442 Prison and Security Officers
451 Personal Service and Travel Workers
452 Sports and Fitness Workers

5. CLERICAL & ADMINISTRATIVE
511 Contract, Program and Project Administrators
512 Office and Practice Managers
521 Personal Assistants and Secretaries
531 General Clerks
532 Keyboard Operators
541 Call or Contact Centre Information Clerks
542 Receptionists
551 Accounting Clerks and Bookkeepers
552 Financial and Insurance Clerks
561 Clerical and Office Support Workers
591 Logistics Clerks
599 Miscellaneous Clerical and Administrative Workers

6. SALES WORKERS
611 Insurance Agents and Sales Representatives
612 Real Estate Sales Agents
621 Sales Assistants and Salespersons
631 Checkout Operators and Office Cashiers
639 Miscellaneous Sales Support Workers

7. MACHINERY OPERATORS & DRIVERS
711 Machine Operators
712 Stationary Plant Operators
721 Mobile Plant Operators
731 Automobile, Bus and Rail Drivers
732 Delivery Drivers
733 Truck Drivers
741 Storepersons

8. LABOURERS
811 Cleaners and Laundry Workers
821 Construction and Mining Labourers
831 Food Process Workers
832 Packers and Product Assemblers
839 Miscellaneous Factory Process Workers
841 Farm, Forestry and Garden Workers
851 Food Preparation Assistants
891 Freight Handlers and Shelf Fillers
899 Miscellaneous Labourers

Source: ABS (2009), ANZSCO – AUSTRALIAN AND NEW ZEALAND STANDARD CLASSIFICATIONS OF OCCUPATIONS, FIRST EDITION, REVISION 1, ABS CATALOGUE NO. 1220.0.

C.5 Labour Market Database

The *Tasman Global* database includes a detailed representation of the Australian labour market that has been designed to capture the supply and demand for different skills and occupations by industry. To achieve this, the Australian workforce is characterised by detailed supply and demand matrices.

On the supply side, the Australian population is characterised by a five-dimensional matrix consisting of:

- 7 post-school qualification levels
- 12 main qualification fields of highest educational attainment
- 97 occupations
- 101 age groups (namely 0 to 99 and 100+)
- 2 genders.

The data for this matrix is measured in persons and was sourced from the ABS 2011 Census. As the skills elements of the database and model structure have not been used for this project, it will be ignored in this discussion.

The 97 occupations are those specified at the 3-digit level (or Minor Groups) under the Australian New Zealand Standard Classification of Occupations (ANZSCO).

On the demand side, each industry demands a particular mix of occupations. This matrix is specified in units of full-time equivalent (FTE) jobs where someone working FTE works an average of 37.5 hours per week. Consistent with the labour supply matrix, the data for FTE jobs by occupation by industry was also sourced from the ABS Census as at 2016 and updated using the latest labour force statistics.

Matching the demand and supply side matrices means that there is the implicit assumption that the average hours per worker are constant, but it is noted that mathematically changes in participation rates have the same effect as changes in average hours worked.

C.6 Labour Market Model Structure

In the model, the underlying growth of each industry in the Australian economy results in a growth in demand for a particular set of skills and occupations. In contrast, the supply of each set of skills and occupations each year is primarily driven by the underlying demographics of the resident population. This creates a market for each skill by occupation that (unless specified otherwise) needs to clear at the start and end of each time period.[80] The labour markets clear by a combination of different prices (i.e., wages) for each labour type and by allowing a range of demand and supply substitution possibilities, including:

- changes in firms' demand for labour driven by changes in the underlying production technology
  - for technology bundle industries (electricity, iron and steel and road transportation) this occurs due to changes between explicitly identified alternative technologies
  - for non-technology bundle industries this includes substitution between factors (such as labour for capital) or energy for factors
- changes to participation rates (or average hours worked) due to changes in real wages

[80] For example, at the start and end of each week for this analysis. *Tasman Global* can be run with different steps in time, such as quarterly or bi-annually in which case the markets would clear at the start and end of these time points.

— changes in the occupations of a person due to changes in relative real wages
— substitution between occupations by the firms demanding labour due to changes in the relative costs
— changes to unemployment rates due to changes in labour demand, and
— limited labour mobility between states due to changes in relative real wages.

All the labour supply substitution functions are modified-CET functions in which people supply their skills, occupation and rates of participation as a positive function of relative wages. However, unlike a standard CET (or CES) function, the functions are 'modified' to enforce an additional constraint that the number of people is maintained before and after substitution.[81]

Although technically solved simultaneously, the labour market in *Tasman Global* can be thought of as a five-stage process:

— labour makes itself available to the workforce based on movements in the real wage (that is, it actively participates with a certain number of average hours worked per week)
— the age, gender and occupations of the underlying population combined with the participation rate by gender by age implies a given supply of labour (the potentially available workforce)
— a portion of the potentially available workforce is unemployed, implying a given available labour force
— labour chooses to move between occupations based on relative real wages
— industries alter their demands for labour as a whole and for specific occupations based on the relative cost of labour to other inputs and the relative cost of each occupation.

By default, *Tasman Global*, like all CGE models, assumes that markets clear at the start and end of each period. Therefore, overall, supply and demand for different occupations will equate (as is the case in other markets in the model). In principle, (subject to zero starting values) people of any age and gender can move between any of the 97 occupations while industries can produce their output with any mix of occupations. However, in practice the combination of the initial database, the functional forms, low elasticities and moderate changes in relative prices for skills, occupations etc. means that there is only low to moderate change induced by these functions. The changes are sufficient to clear the markets, but not enough to radically change the structure of the workforce in the timeframe of this analysis. Factor-factor substitution elasticities in non-technology bundle industries are industry specific and are the same as those specified in the GTAP database[82], while the fuel-factor and technology bundle elasticities are the same as those specified in GTEM.[83] The detailed labour market elasticities are ACIL Allen assumptions, previously calibrated in the context of the model framework to replicate the historical change in the observed Australian labour market over a five-year period[84]. The unemployment rate function in the policy scenarios is a non-linear function of the change in the labour demand relative to the counterfactual case with the elasticity

81 As discussed in Dixon et al (1997), a standard CES/CET function is defined in terms of *effective units*. Quantitatively this means that, when substituting between, say, X_1 and X_2 to form a total quantity X using a CET function a simple summation generally does not actually equal X. Use of these functions is common practice in CGE models when substituting between substantially different units (such as labour versus capital or imported versus domestic services) but was not deemed appropriate when tracking the physical number of people. Such 'modified' functions have long been employed in the technology bundles of *Tasman Global* and GTEM. The Productivity Commission have proposed alternatives to the standard CES to overcome similar and other weaknesses when applied to internationally traded commodities.

82 Narayanan et al. (2012).

83 Pant (2007).

84 This method is a common way of calibrating the economic relationships assumed in CGE models to those observed in the economy. See for example Dixon and Rimmer (2002).

being a function of the unemployment rate (that is, the lower the unemployment rate the lower the elasticity and the higher the unemployment rate the higher the elasticity).

C.7 References

Aguiar, A., Chepeliev, M., Corong, E., McDougall, R., & van der Mensbrugghe, D. (2019). The GTAP Data Base: Version 10. *Journal of Global Economic Analysis, 4(1)*, 1-27. Retrieved from https://www.jgea.org/ojs/index.php/jgea/article/view/77.

Australian Government (2008), *Australia's Low Pollution Future: the economics of climate change mitigation*, Australian Government, Canberra.

Dixon, P.B., Parmenter, B., Sutton, J., & Vincent, D. (1997), *ORANI: A Multisectoral Model of the Australian Economy*, Amsterdam: North Holland.

Dixon, P.B. and Rimmer, M.T. (2002), *Dynamic General Equilibrium Modelling for Forecasting and Policy*. Contributions to Economic Analysis 256, Amsterdam: North Holland.

Hertel, T. (1997), *Global Trade Analysis: modelling and applications*, Cambridge University Press, Cambridge.

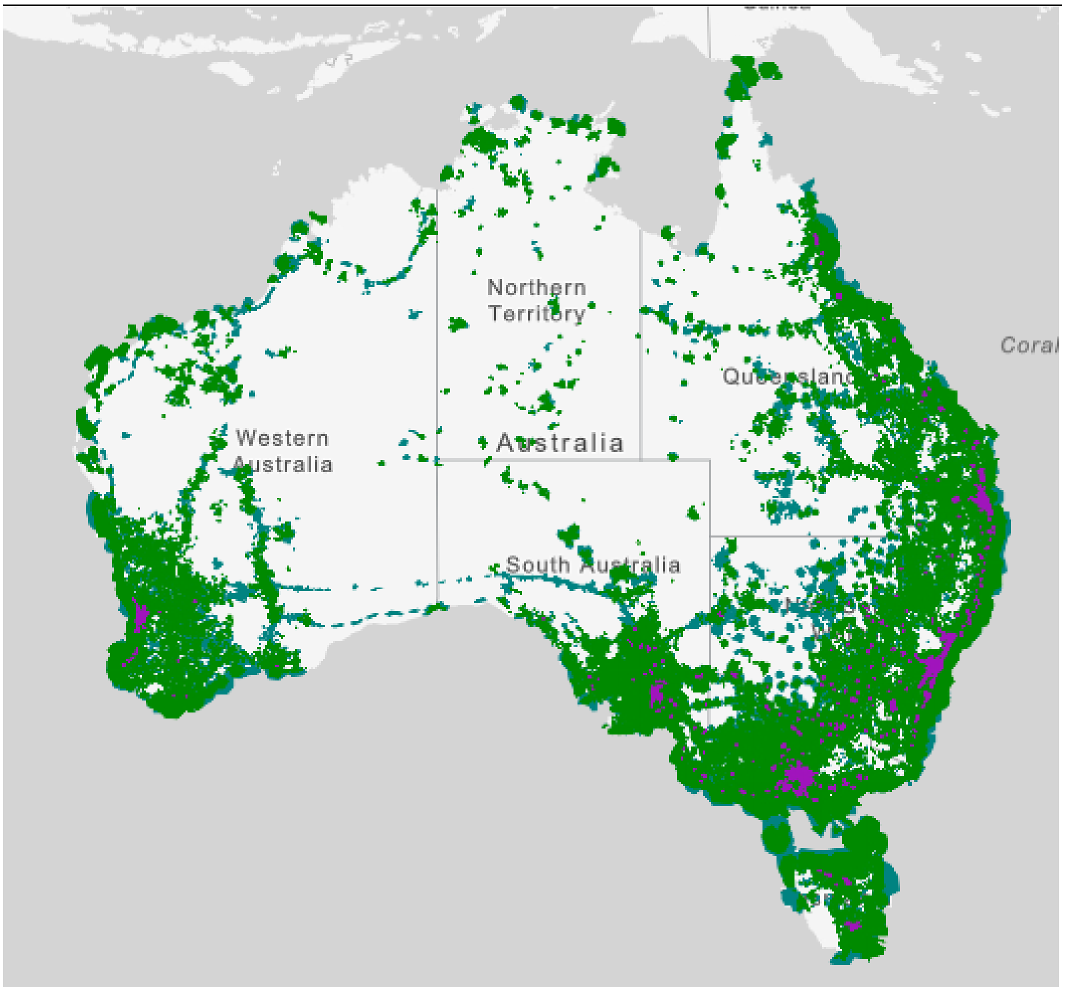
Jakeman, G., Heyhoe, E., Pant, H., Woffenden, K. and Fisher, B.S. (2001), *The Kyoto Protocol: economic impacts under the terms of the Bonn agreement*. ABARE paper presented to the International Petroleum Industry Environmental Conservation Association conference, 'Long Term Carbon and Energy Management - Issues and Approaches', Cambridge, Massachusetts, 15-16 October.

Pant, H.M. (2007), *GTEM: Global Trade and Environment Model*, ABARE Technical Report, Canberra, June.

D Maps

D.1 Mobile phone coverage

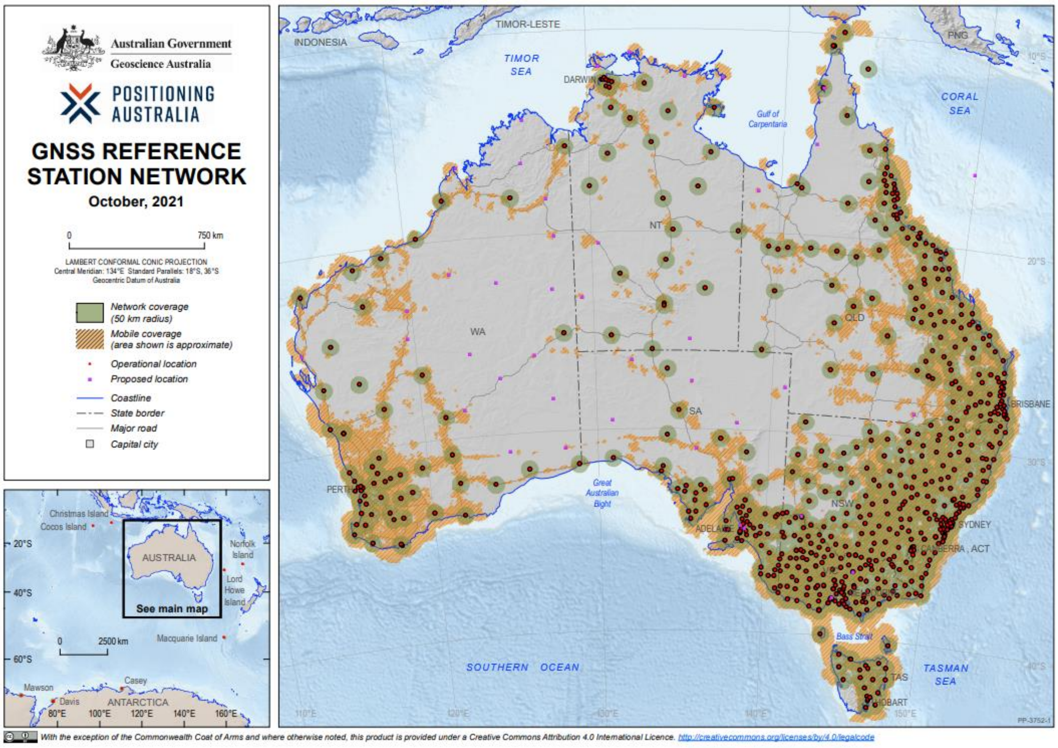
Figure D.1 Telstra mobile coverage, March 2022



Source : https://www.telstra.com.au/coverage-networks/our-coverage (2022)

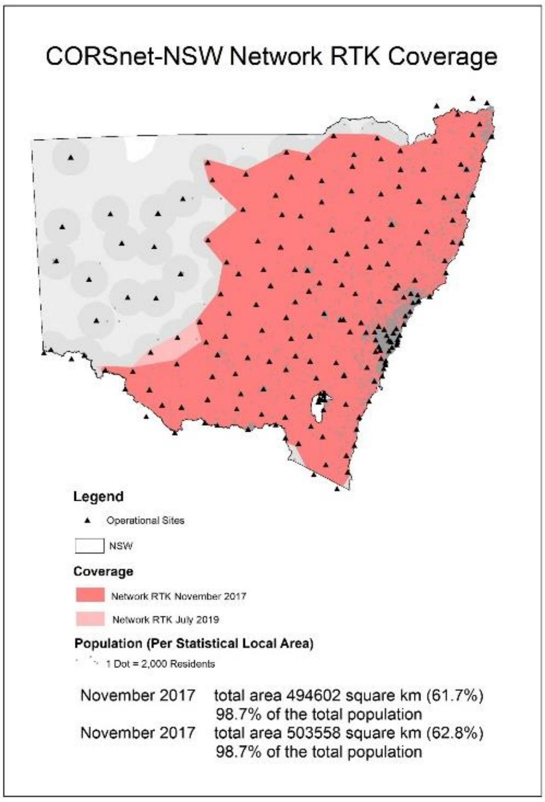
D.2 CORS coverage

Figure D.2 GNSS reference station network, October 2021



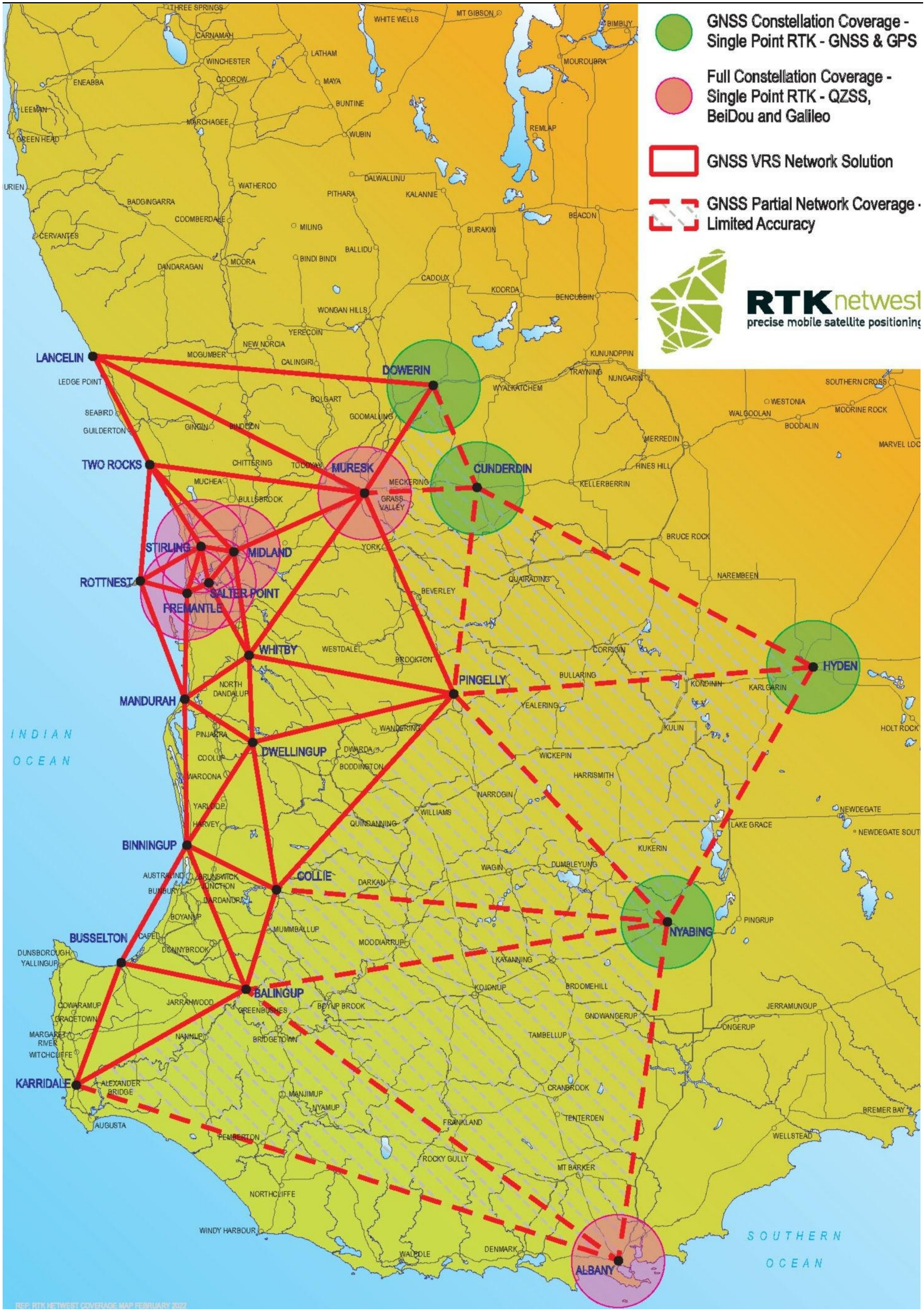
Source: Geoscience Australia, as accessed March 2022

Figure D.3 NSW CORS network map, July 2019



Source: https://www.spatial.nsw.gov.au/surveying/corsnet-nsw/network_information. (2022)

Figure D.4 RTK Netwest coverage map (WA), February 2022

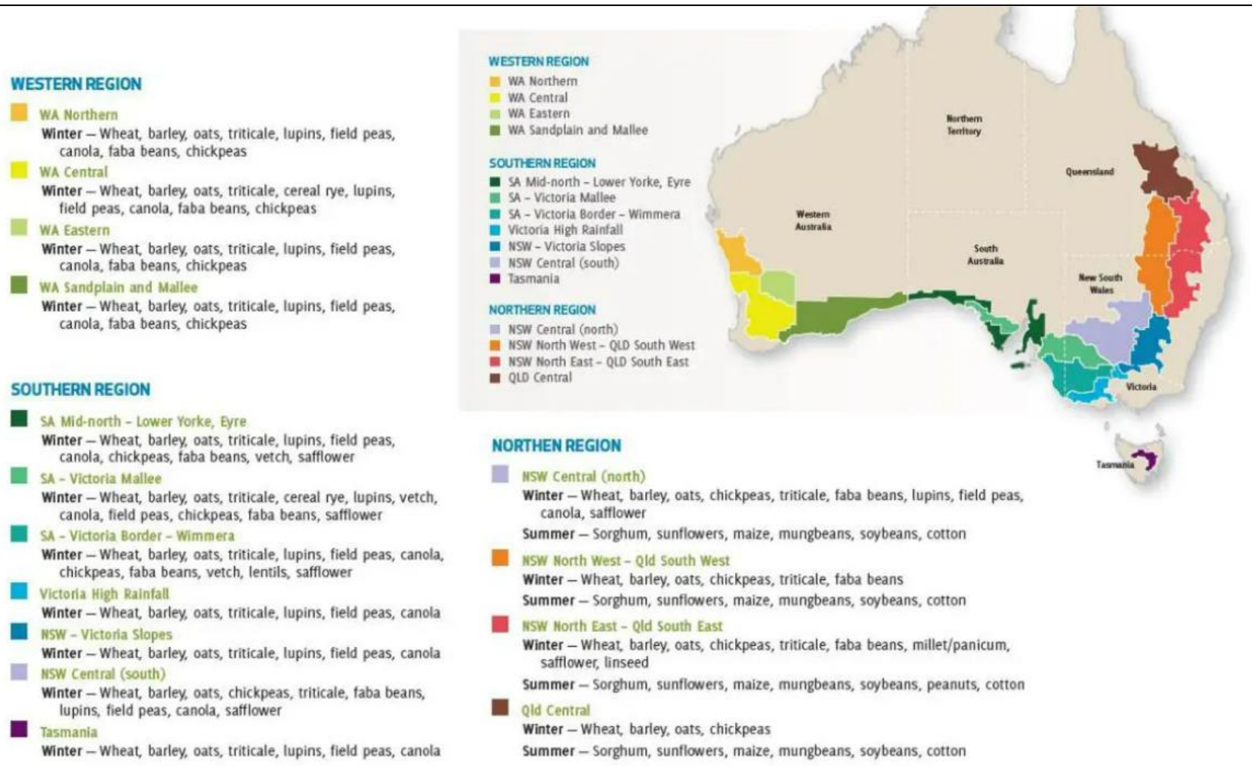


Source: /www.rtknetwest.com.au. (March 2022).

D.3 Agriculture

D.3.1 Grains

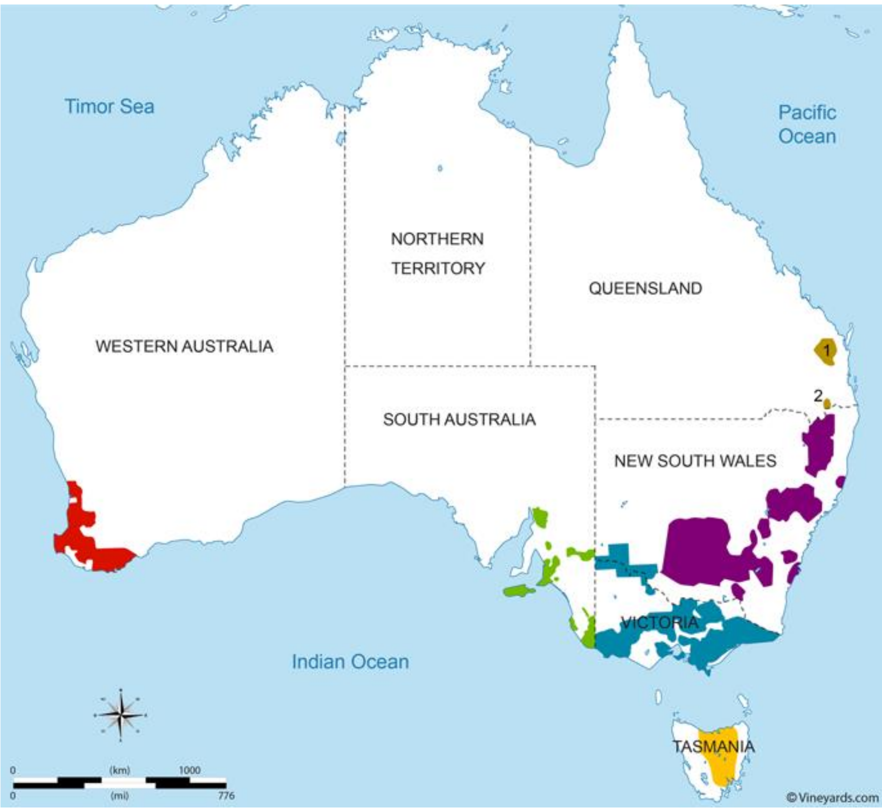
Figure D.5 Australian Grain Regions



Source: https://www.aegic.org.au/australian-grain-production-a-snapshot (2022)

D.3.2 Wine

Figure D.6 Australian Wine Regions



Source: https://vineyards.com/wine-map/australia. (2022)

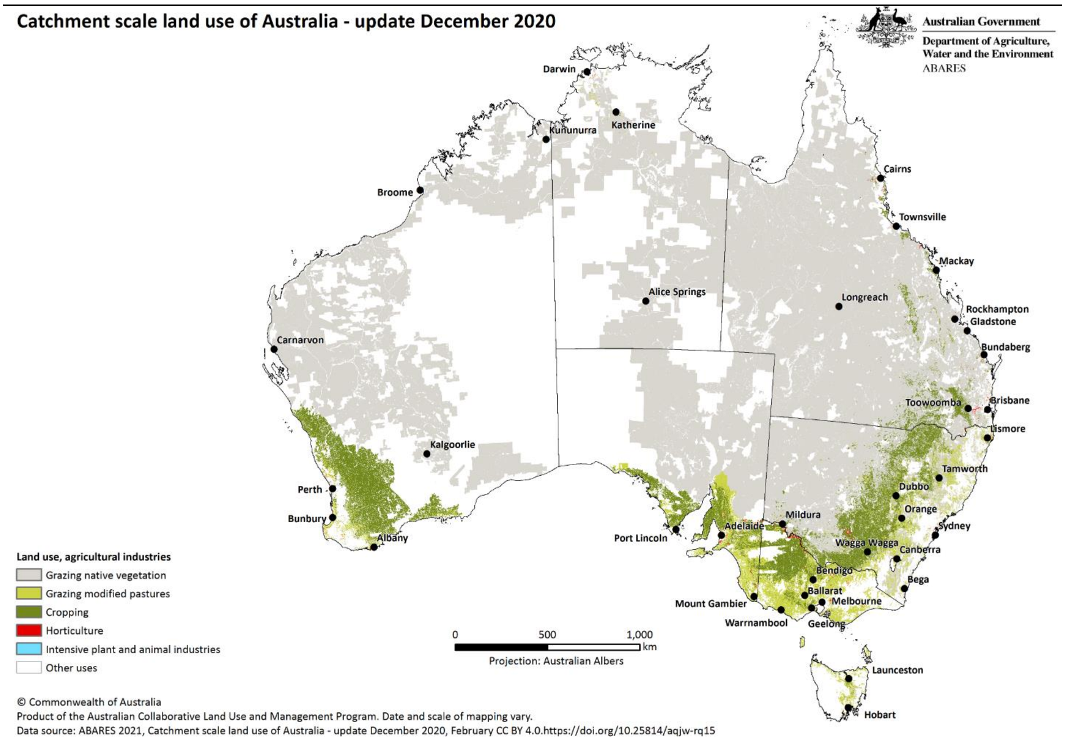
D.3.3 Horticulture

There is limited information on mapping of horticultural crops in Australia. The Department of Agriculture Water and the Environment has produced a map of catchment scale land use that includes horticulture (Figure ES 3). It provides a general indication of the current location of horticulture enterprises. A report prepared for Horticulture Australia in 2006 provides more detail of the location of horticulture producing areas.[85] This provides a more detailed indication of areas where horticulture is a feature of land use. The principal differences between these two sources of data are in the northern parts of Western Australia and Queensland.

Land use for horticulture in the southern parts of each state has not changed significantly since the Horticulture Australia report was released. The southern areas of Australia were considered for the analysis for this report.

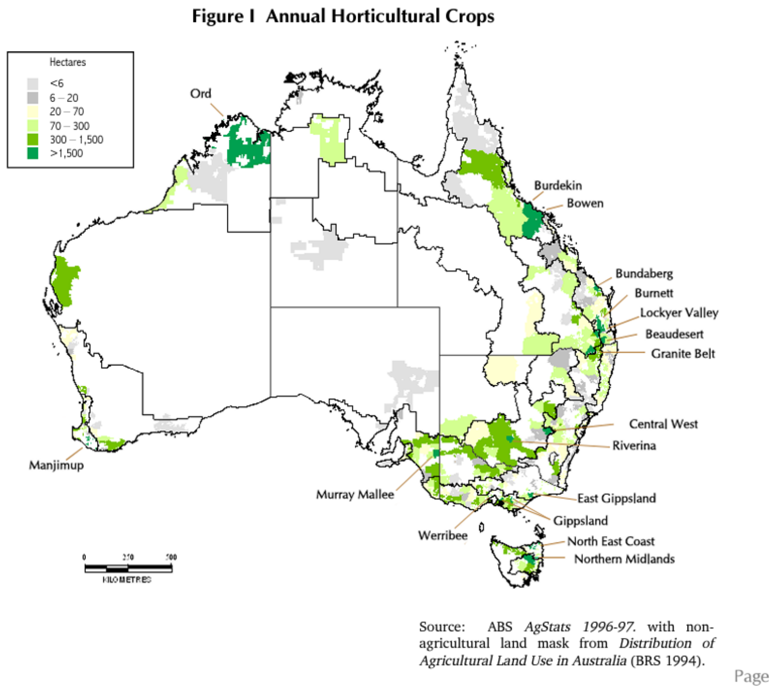
[85] Colquhoun, E (2006). Horticultural audit of production and sustainability,

Figure ES 3 Catchment scale land use of Australia, December 2020



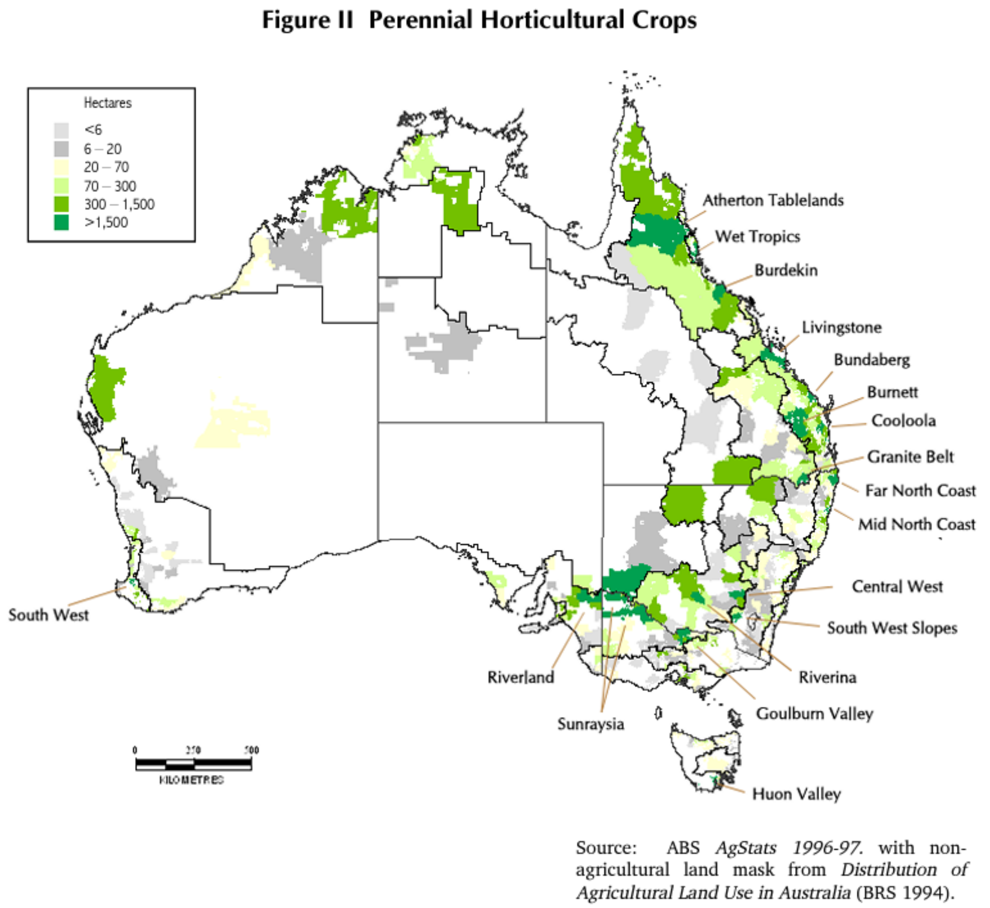
Source: Department of Agriculture Fisheries and Forestry, Australian Bureau of Agricultural and Resource Economics and Sciences (2020), Catchment Scale Land Use of Australia.

Figure D.7 Australian Horticulture Annual Crops, 1996-97



Source: Colquhoun E, 2006, Horticultural audit of production and sustainability, Horticulture Australia Limited

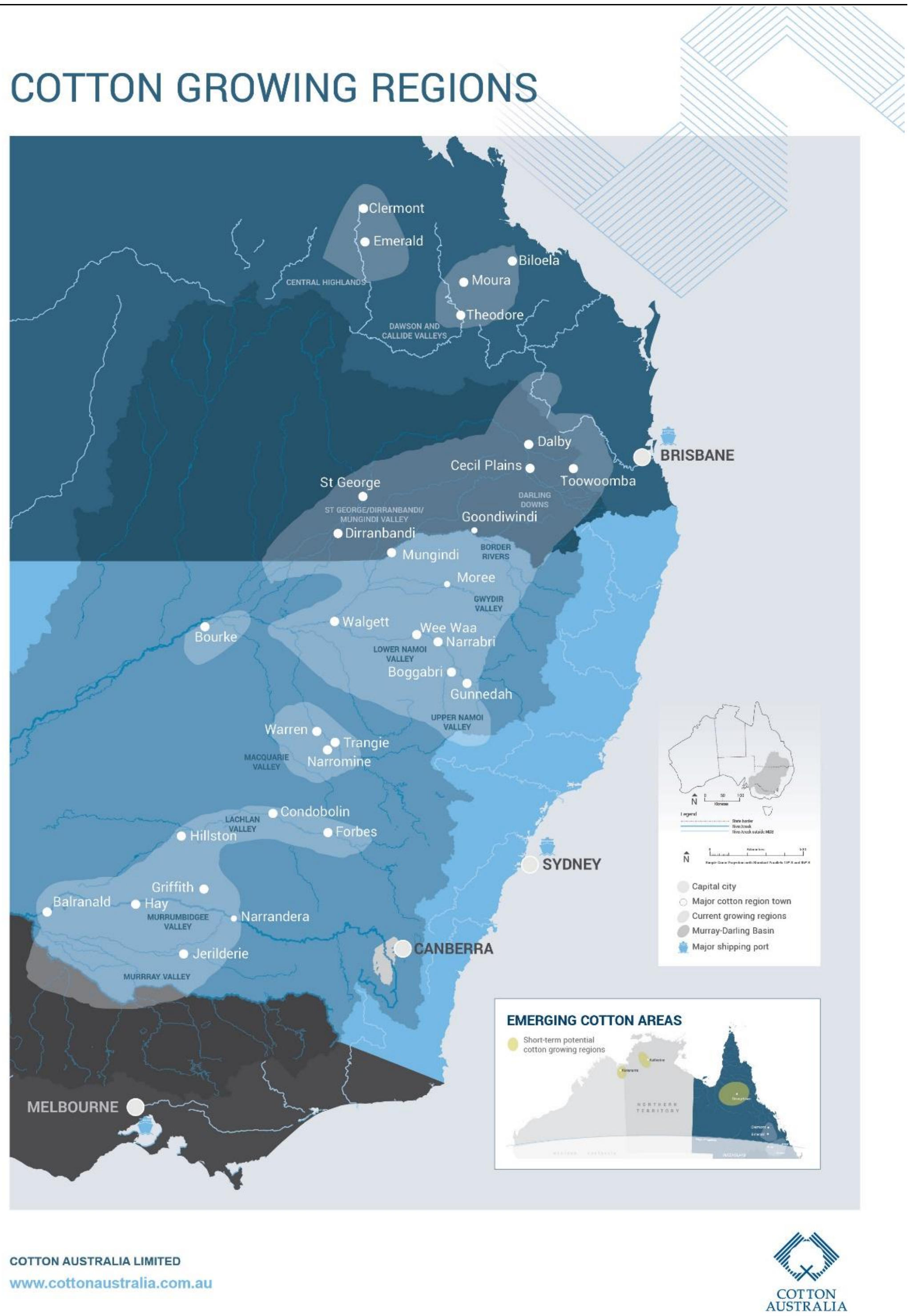
Figure D.8 Australian Horticulture Perennial Crops, 1996-97



Source Colquhoun E, 2006, Horticultural audit of production and sustainability, Horticulture Australia Limited.

D.3.4 Cotton

Figure D.9 Australian Cotton Growing Regions



Source : Where is cotton grown? (2022) Cotton Australia

Figure D.10 Emerging Australian Cotton Areas

Source: Where is cotton grown? (2022) Cotton Australia

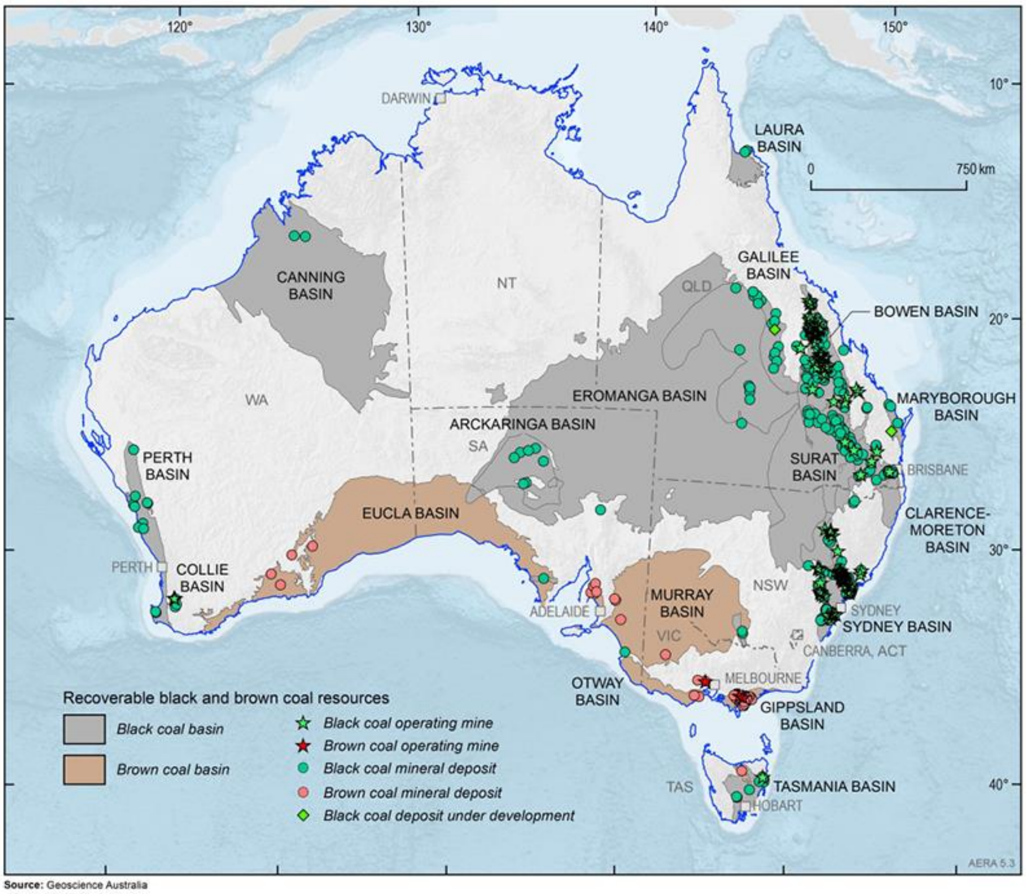
D.3.5 Sugar

Figure D.11 Australian Sugar Regions

Source: The sweet facts about sugar cane (2022), Queensland Cane Growers.

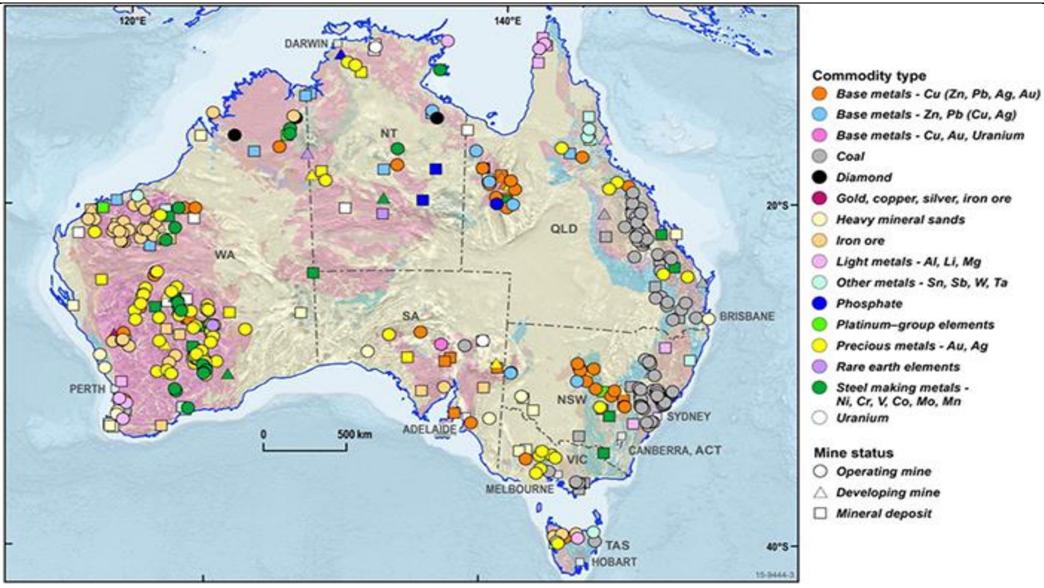
D.4 Mining

Figure D.12 Australian Mining Regions – Coal, 2020



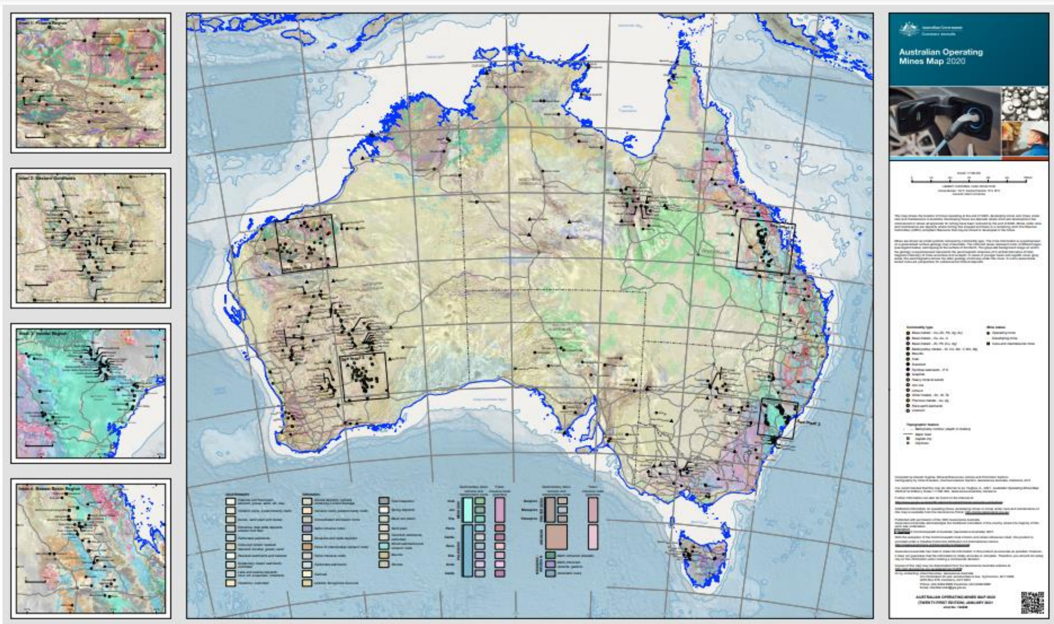
Source : Geoscience Australia (2023)

Figure D.13 Australian Mining Regions – Commodities and Mine Status, 2016



Source: Geoscience Australia (2022)

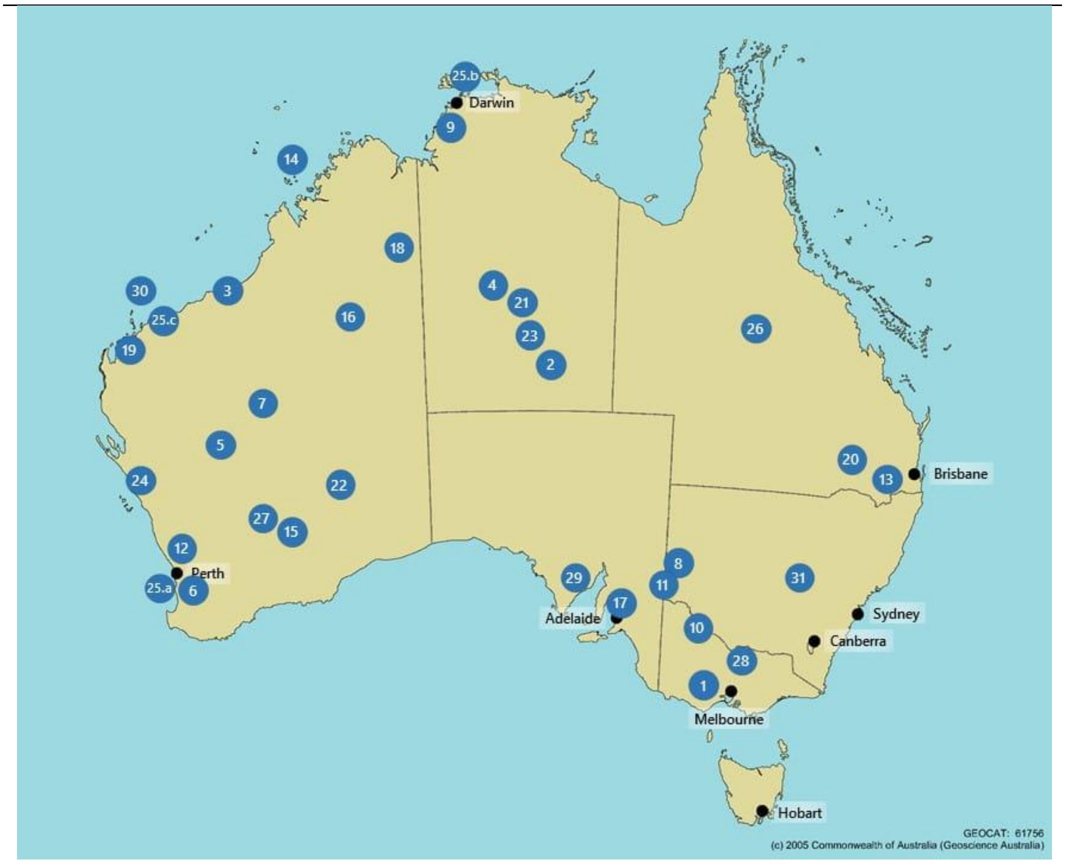
Figure D.14 Australian Mining – operating map, 2020



Source: Geoscience Australia (2022)

D.5 Construction

Figure D.15 Major Australian Construction Projects in March 2022.



Source : Current major projects (2022) Business.gov.au

Tables of employment impacts

E

Employment impacts of NPIC by state and territory, Full-time Equivalent (FTE), FY 2019 to FY 2038 are shown in **Table E.1** below.

Employment impacts of NPIC by broad sector, Full-time Equivalent (FTE), FY 2019 to FY 2038 are shown in **Table E.2** below.

Table E.1 Employment impacts of NPIC by state and territory, Full-time Equivalent (FTE), FY 2019 to FY 2038

Employment (FTE)	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
NSW	18	19	25	29	35	43	43	44	45	44	44	43	44	43	41	41	40	39	40	40
Vic	26	27	36	41	50	62	62	62	63	61	59	55	56	52	49	47	46	45	47	47
Qld	4	6	7	8	10	13	14	15	18	18	20	21	23	23	25	26	28	28	30	31
SA	1	1	1	1	2	2	1	1	0	0	0	1	1	1	2	2	3	3	3	3
WA	1	0	0	0	0	0	0	0	1	0	0	1	1	2	3	4	4	5	5	6
Tas	0	1	2	2	3	4	4	4	5	5	5	5	6	6	6	6	6	6	6	6
NT	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
ACT	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Total	**51**	**54**	**72**	**82**	**102**	**126**	**127**	**128**	**133**	**130**	**131**	**128**	**134**	**131**	**128**	**129**	**130**	**129**	**134**	**136**

Note: Columns do not add to total due to rounding errors.

Table E.2 Employment growth due to NPIC by broad sectors, Full-time Equivalent (FTE), FY 2019 to FY 2038

Employment (FTE)	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Agriculture	-4	0	4	5	7	6	3	5	2	5	5	3	6	9	6	7	5	4	5	6
Mining	1	1	-1	-1	1	-3	0	1	1	-2	-2	-1	-4	-3	-1	-7	-6	-3	-7	-4
Manufacturing	15	11	13	12	13	18	17	18	20	17	26	24	28	27	30	26	35	38	34	29
Construction	-5	-4	-5	-4	-3	-4	-4	-4	-7	-11	-15	-21	-23	-29	-30	-38	-40	-40	-44	-43
Service	42	46	61	70	83	110	112	109	117	121	117	122	127	128	124	141	135	130	146	149
Total	**51**	**54**	**72**	**82**	**102**	**126**	**127**	**128**	**133**	**130**	**131**	**128**	**134**	**131**	**128**	**129**	**130**	**129**	**134**	**136**

Note: Columns do not add to total due to rounding errors.

Melbourne
Suite 4, Level 19; North Tower
80 Collins Street
Melbourne VIC 3000 Australia
+61 3 8650 6000

Sydney
Suite 603, Level 6
309 Kent Street
Sydney NSW 2000 Australia
+61 2 8272 5100

Brisbane
Level 15, 127 Creek Street
Brisbane QLD 4000 Australia
+61 7 3009 8700

Canberra
Level 6, 54 Marcus Clarke Street
Canberra ACT 2601 Australia
+61 2 6103 8200

Perth
Level 12, 28 The Esplanade
Perth WA 6000 Australia
+61 8 9449 9600

Adelaide
167 Flinders Street
Adelaide SA 5000 Australia
+61 8 8122 4965

ACIL Allen Pty Ltd
ABN 68 102 652 148

acilallen.com.au