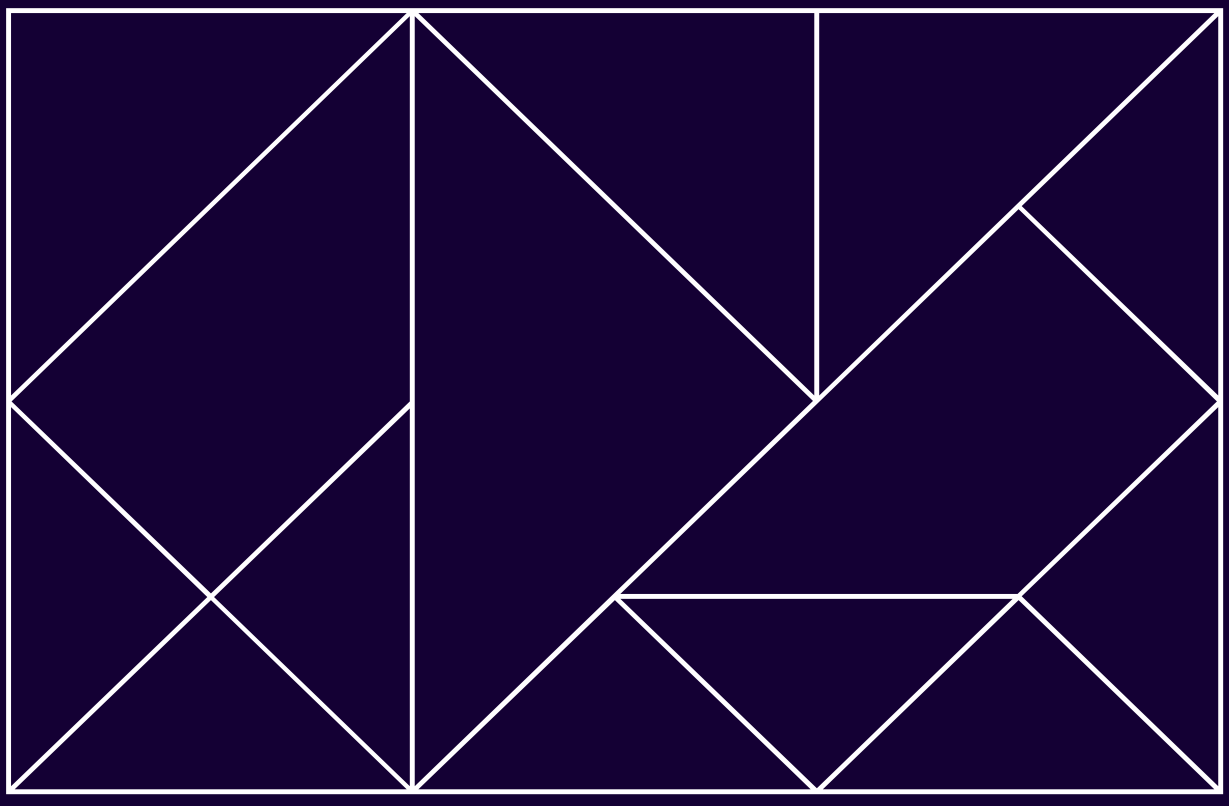
ACIL ALLEN

24 April 2023

Report to Australian Research Council

Impact assessment of ARC-funded research

Final report



Contents

Glossary

ACIAR	Australian Centre for International Agricultural Research
ACOLA	Australian Council of Learned Academies
AIATSIS	Australian Institute of Aboriginal and Torres Strait Islander Studies
AIJA	Australian Institute of Judicial Administration
AISRF	Australia-India Strategic Research Fund
ANROWS	Australia's National Research Organisation for Women's Safety
ANU	Australian National University
ANZOG	Australian New Zealand School of Governance
ANZSIC	Australian and New Zealand Standard Industrial Classification
AQN	ANU Quantum Numbers
ARC	Australian Research Council
ASSDA	Australian Social Science Data Archive
ATAR	Australian Tertiary Admission Rank
ATN	Australia Technology Network of Universities
AWA	Australian Water Association
BCR	Benefit-cost ratio
BEIS	Business, Energy and Industrial Strategy
CABAH	Centre of Excellence for Australian Biodiversity and Heritage
CBA	Cost Benefit Analysis
CBR	Cost Benefit Ratio
CE	ARC Centres of Excellence
CGE	Computable General Equilibrium
CI	Chief Investigator
CNRS	National Centre for Scientific Research, France
CQC^{2}T	Centre of Excellence for Quantum Computation & Communications Technology
CQCT	Centre for Quantum Computing Technology
CRC	Cooperative Research Centre
CRM	Customer relationship management

CS	Supporting Responses to Commonwealth Science Council Priorities
CWQRC	Curtin Water Quality Research Centre
DE	Discovery Early Career Researcher Award
DECRA	Discovery Early Career Research Award
DFV	Domestic and family violence
DI	Discovery Indigenous
DOI	Digital Object Identifier
DP	Discovery Projects
DR	Distribution Ratio
FT	Future Fellowships
ECR	Early career researcher
ECU	Edith Cowan University
EI	Engagement and Impact
EQUIS	Environmental Quality Information System
EQUS	Engineered Quantum Systems
ERA	Excellence in Research for Australia
ESA	European Space Agency
EU	European Union
FL	Australian Laureate Fellowships
FLEET	Future Low-Energy Electronics Technologies
FoR	Field of Research
FTE	Full-time equivalent
GBK	Gur A Baradharaw Kod Sea and Land Council Torres Strait Islander Corporation
GDP	Gross Domestic Product
GMID	Goulburn-Murray Irrigation District
Go8	Group of Eight
HASS	Humanities and Social Sciences
HERD	Higher education expenditure on research and development
ICID	International Commission of Irrigation and Drainage
IEDM	International Electron Devices Meeting
IEEE	Institute of Electrical and Electronics Engineers
IH	Industrial Transformation Research Hubs
IPO	Initial Public Offering
IQC	Intermediate quantum computing
IRDS	Indigenous Researchers Development Scheme
IWA	International Water Association
JCU	James Cook University
KALCC	Kimberley Aboriginal Law and Cultural Centre
KBJNL	Krishna Bhagya Jala Nigam Ltd

KMIP	Key Management Interoperability Protocol
LA	Linkage Learned Academies Special Projects
LE	Linkage Infrastructure, Equipment and Facilities
LIEF	Linkage Infrastructure, Equipment and Facilities
LP	Linkage Projects
LQ	Linear Quadratic
MBIE	New Zealand Ministry of Business and Employment
MoU	Memorandum of Understanding
MRFF	Medical Research Future Fund
NCGP	National Competitive Grants Program
NCRIS	National Collaborative Research Infrastructure Strategy
NFS	Non-fatal strangulation
NGO	Non-governmental organisation
NHMRC	National Health and Medical Research Council
NHS	National Health Service
NICTA	National ICT Australia
NJC	National Judicial Council
NLA	Noiseless Linear Amplifier
NLBC	Narayanpur Left Bank Canal
NLTK	National Language Toolkit
NMA	National Museum Australia
NPV	Net Present Value
NRA	Ngarrindjeri Regional Authority
NRIS	New Zealand Research Information System
NTRO	Non-traditional Research Outputs
OFTA	Office of the Arts
PI	Partner Investigator
QKD	Quantum key distribution
RCMP	Royal Canadian Mounted Police
RDC	Research and Development Corporation
RDTI	Research and Development Tax Incentive
RMS	Research Management System
ROR	Rate of return
RRR	Return Reconcile Renew
RUN	Regional Universities Network
RWQI	Recycled Water Quality Indicators
RWQP	Recycled Water Quality Parameters
SEO	Socio-economic Objectives
SFI	Science Foundation Ireland

SME	Small-medium enterprise
SQC	Silicon Quantum Computing Pty. Ltd.
SR	Special Research Initiatives
STEM	Science, Technology, Engineering and Mathematics
TAPS	Transitional Academic Pastoral Support
TCC	Total Channel Control
TRL	Technology Readiness Level
UA	Universities Australia
UKRI	United Kingdom Research and Innovation

Executive summary

Introduction

The Australian Research Council (ARC) has a key role in Australia's innovation and research system in supporting Australia's universities to produce high-quality and impactful research through the delivery of the National Competitive Grants Program (NCGP). It achieves this by allocating funding on a competitive basis to universities undertaking world-class research.

The ARC also has the national responsibility for assessing the quality, engagement and impact of university research and working in partnership with the sector to safeguard research integrity.

The National Competitive Grants Program

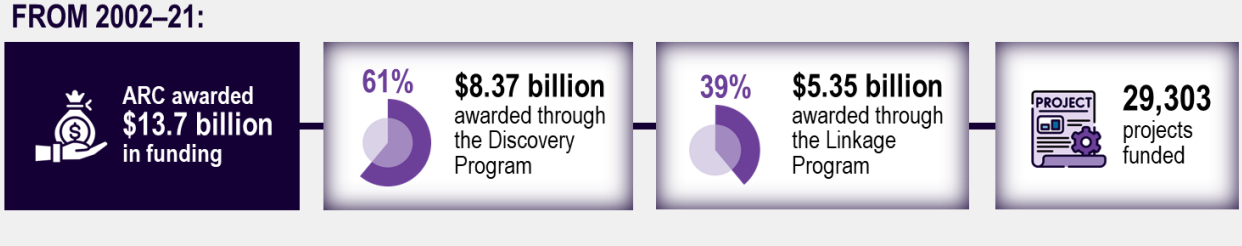
This evaluation is focused on the NCGP, which allocates research grant funding via a competitive peer review process through the Discovery Program and the Linkage Program. The Discovery Program plays a crucial role in funding blue-sky research in Australia, while the Linkage Program focuses on collaborative research that links universities, industry and other research users.

Under these programs, the ARC funds a range of complementary schemes. The aim is to support researchers at different stages of their careers, build Australia's research capability, expand and enhance research networks and collaborations, and develop centres of excellence. ARC funding ensures Australia can **maximise the benefits of having a strong and vibrant research sector**.

The intended outcome of the Programs is to **contribute to the growth of Australia's research and innovation capacity**, which generates new knowledge and results in the development of new technologies, products and ideas, the creation of jobs, economic growth, and an enhanced quality of life in Australia.

An overview of ARC funding awarded through the NCGP is provided in Figure ES 1.

Figure ES 1 ARC funding awarded through the NCGP



Source: ACIL Allen

This evaluation

The ARC commissioned ACIL Allen to independently evaluate the outcomes and impacts of NCGP-funded research over the past 2 decades and consider the potential future benefits delivered from the funding. In addition, ACIL Allen was asked to assess the effectiveness with which the ARC supports, monitors, and reports on research impact and identify opportunities for improvement.

In assessing the outcomes and impact of NCGP-funded research, ACIL Allen has drawn on data provided by the ARC from 2002-2021. This includes funding data for 29,303 projects, 22,352 grant final reports, a survey of 3,361 researchers, and consultation with system leaders in Australia and international funding agencies. The evidence was analysed and synthesised using whole of economy modelling, impact case studies and qualitative and quantitative analysis.

There are several challenges in assessing the impact of a research program such as the NCGP. These challenges include the large number of projects funded, the time lags to impact, the diverse range of research activities supported and impacts delivered, and the attribution of impact when there is more than one source of funding.

Key findings

This report demonstrates that **ARC-funded research has delivered significant and diverse benefits** to a broad range of end-users and beneficiaries in Australia and internationally that will continue into the future.

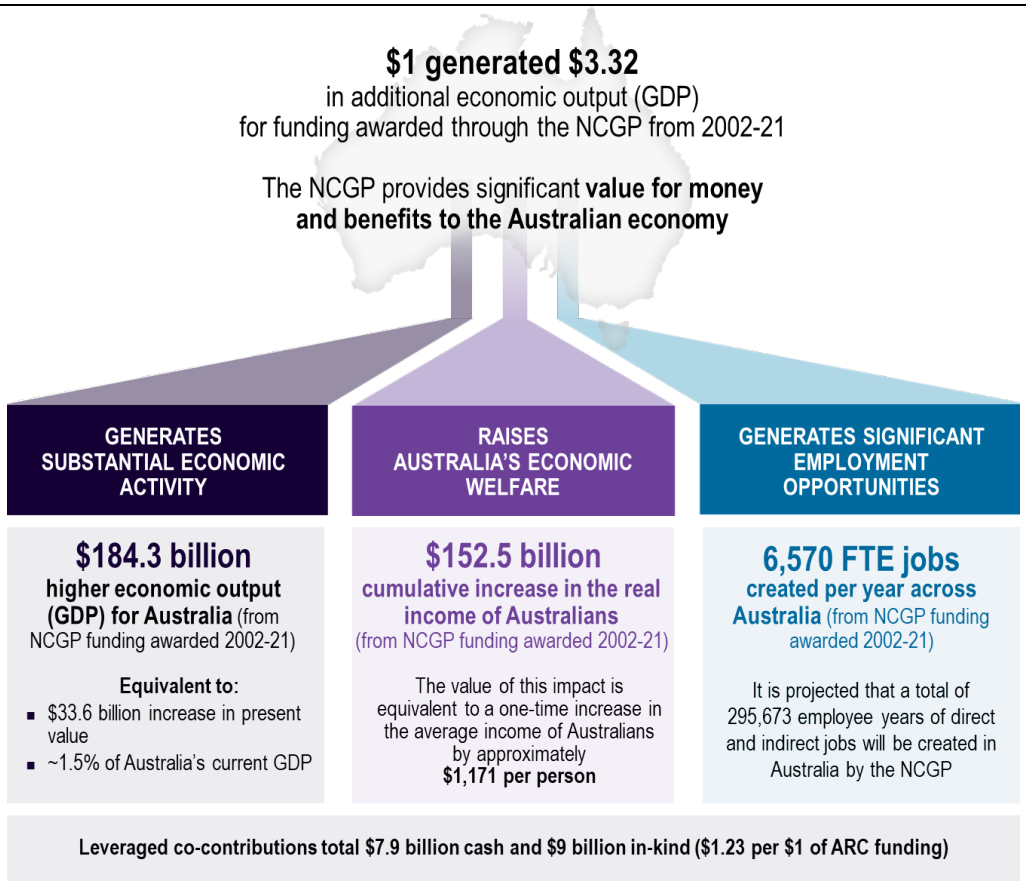
Economic impacts of NCGP-funded research

The impact of ARC-funded research from 2002-21 was estimated using a model of the Australian economy (Tasman Global). This model is a high-level representation of the Australian economy that enables measurement of the wider effects of changes in economic activity in key industries and regions due to ARC-funded research. Economy-wide models like Tasman Global are widely known and have been used by the Productivity Commission, the Commonwealth Treasury and other government agencies to evaluate economy-wide impacts of industry and policy changes.

Research funded by the ARC is varied and has a range of **economic, social, environmental, cultural and research capacity impacts**. Some of these impacts are very difficult to quantify and monetise. The **economic analysis only captures the direct and indirect economic impacts** of ARC-funded research. Research capacity, social, environmental and cultural impacts associated with research projects funded by the ARC have been qualitatively assessed. Once these (and other) non-quantified impacts of ARC-funded research are considered, **the value of the NCGP is likely much higher than the estimates provided in this section**.

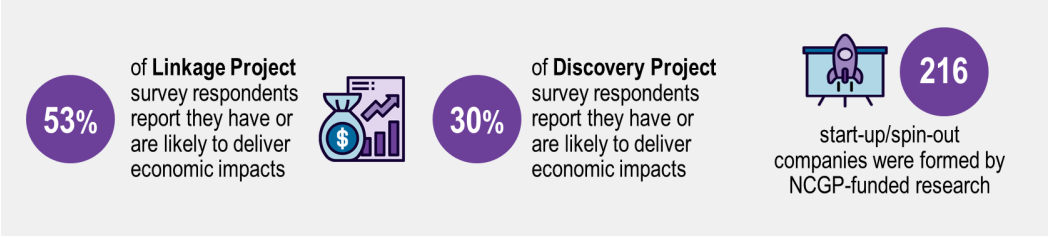
The key findings of the economic modelling are shown in Figure ES 2 and more details of the methodology used to estimate the impact of ARC-funded research are provided in chapters 1 and 2.

Figure ES 2 ARC-funded research: large gains for the Australian economy



Source: ACIL Allen

Figure ES 3 Researcher perspectives on economic impact



Source: ACIL Allen

Building research capacity and capability

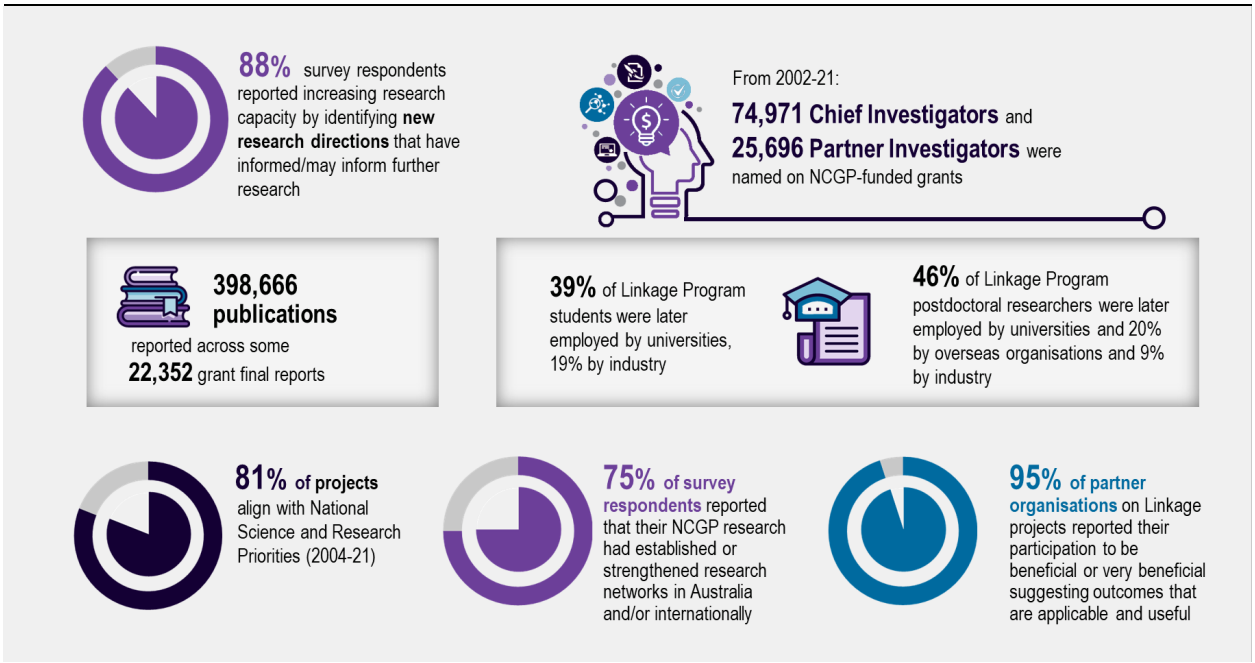
Contribution to the stock of knowledge and the longer-term research capability of Australia are core purposes of the NCGP. This evaluation found that the Discovery and Linkage Programs have improved research capacity by enabling new research directions, research training (e.g. researchers and graduates) and new partnerships (in Australia and internationally), which in turn leads to improved understanding and new knowledge. NCGP-funded research projects across a number of publication types produced almost 400,000 outputs. This is exemplified by the case studies in terms of publications, monitoring indicators and training materials.

NCGP-funded research has increased Australia's research capacity and capability by enabling **new research directions, research training** (e.g. researchers and graduates) and **new partnerships** (in Australia and internationally). This is helping to inform further excellent research, support a strong and sustainable research workforce and promote the adoption and translation of research by industry and others.

ARC grants increase research capacity by **supporting students and researchers** to participate in excellent projects with world-class research leaders. These researchers go on to be employed in different sectors, boosting the capacity of Australia's innovation system. The *Quantum Computation and Communication Technology* case study (page vi) shows that hundreds of students and researchers have gained important skills for emerging industries through participation in ARC-supported quantum Centres of Excellence.

The case studies (pages vi to xiv) highlight examples of ARC grants promoting collaboration between universities, industry and other research users, thus supporting the delivery of impact. The *Return, reconcile, renew (RRR): Indigenous remains repatriation* case study involved major multi-sector global partnerships between researchers, institutions, governments and community that expedited repatriation activities.

Figure ES 4 NCGP delivers strong research capacity and capability



Source: ACIL Allen

Social, cultural and environmental impacts

Contribution to society, culture and the environment is a core purpose of the NCGP and aligns with the intended outcome of enhancing the quality of life in Australia. NCGP-funded research has produced a broad range of impacts that have benefited many across Australia, including government, academic, industry, business and non-profit sectors as well as the general public, schools, hospitals and others.

Data on social, cultural and environmental impact

It is challenging to quantify the aggregate social, cultural, environmental and other impacts of ARC-funded research, which have been delivered to a wide range of beneficiaries and end-users. However, the data collected in this evaluation illustrates the **important role of ARC funding in the innovation ecosystem** in terms of delivering impact. Over 80% of survey respondents considered that the impacts delivered by their research would be unlikely or very unlikely to have occurred without the ARC's support. The proportion of researchers surveyed for this evaluation who report delivering social, cultural and environmental impact is shown in Figure C.2.

Both Discovery and Linkage Program projects commonly reported **social impacts**, including contributing to improved health and wellbeing, informed decision-making, improved safety and security, and reduced social problems.

NCGP-funded research has also **improved cultural understanding and preservation**, leading to improved social cohesion within and beyond Australia.

Environmental impacts included contributing to **better natural resource management and reduced environmental damage**.

Information on the broader impacts of ARC-funded research is more meaningful at the individual project level, as evidenced by the insights from the case studies on the following pages.

Case studies of impact

To illustrate the diverse nature of the impact delivered by NCGP-funded research, 7 examples of exceptional impact were chosen for deeper analysis in the form of case studies. These case studies show major benefits for Australia. They are overviewed below and presented in chapters 7 to 13.

— The ***Quantum Computation and Communication Technology*** case study shows how Australia is delivering world-leading quantum research to develop full-scale quantum systems – encompassing ultra-fast computation and secure communication. Quantum technologies work by controlling the world at its smallest scale using principles of quantum mechanics. While the ARC has funded several quantum programs, this study focuses on the Centre of Excellence for Quantum Computation and Communications Technology (CQC2T). This has fundamentally shaped quantum research in Australia and internationally and will continue to deliver broad impacts across most economic sectors.

— *The* ***Aquifer Reinjection*** project led to Australia's first full-scale groundwater replenishment scheme. The project demonstrated that treated wastewater can be reinjected into Perth's aquifers (underground layers of groundwater-bearing, permeable rock). This water can then be extracted further downstream, creating additional safe water supplies that are essential for Perth's communities, wetlands and lakes.

— The ***Irrigation automation*** case study focuses on a partnership developed between Rubicon Water Ltd and the University of Melbourne over 20 years, which involves research on irrigation automation and the efficiency of large-scale gravity-fed irrigation systems. This research has enabled the delivery of significant annual water savings to Victoria through the Goulburn-Murray Irrigation District Connections Project.

— The ***Onshore Lobster Aquaculture*** research project demonstrated that it was possible to close the complex and protracted life cycle of spiny lobsters in captivity. The lobster aquaculture project developed and demonstrated the technology for hatching, raising and growing out lobsters in captivity. This technology is being commercialised through a start-up company to create a new and more sustainable onshore lobster aquaculture industry.

- *The following case study presents a body of research focused on domestic and family violence (DFV). Some information may be sensitive and confronting to some readers, caution is advised.*
  The ***Changing the law to protect survivors of DFV*** case study focuses on women experiencing DFV and the legal and justice system responses to DFV. The research has significantly influenced state laws and culture around DFV across Australia, which aims to improve legal system responsiveness and efficiency, and outcomes for women.
- The ***Indigenous persistence in formal learning*** case study focuses on better understanding how Indigenous students persist in higher education and developing models to support retention and graduation rates. This has had a profound impact on student engagement and completion rates at selected universities, which has the potential to be scaled across Australian universities, schools and other student cohorts.
- *First Nations readers should be aware that the following case study contains information about the theft and return of ancestral remains that can be confronting and distressing.*
  The ***Return, reconcile, renew (RRR): Indigenous remains repatriation*** case study focuses on developing and implementing a centralised archive of repatriation information to support repatriation of Indigenous remains. Repatriation is a declaration of respect for ancestors and cultural beliefs. This research has benefited Australian Indigenous Communities, First Nations Peoples in other countries, and supported a global network of repatriation practitioners and researchers.

The case studies demonstrate how the **NCGP's support for curiosity-led,** excellent research, across the spectrum of **basic to applied research**, can generate new knowledge that over time delivers substantial impacts. The case studies highlight how researchers have used different ARC schemes across their careers to progress research and deliver impact to a broad range of end-users and beneficiaries. They also exemplify excellent research that delivers on Australia's Science and Research Priorities and other government priorities such as ending domestic and family violence and Closing the Gap.

Where possible and appropriate, the economic impact of the case studies has been assessed by calculating the costs and benefits (present value, PV), along with the net present and anticipated economic impacts (NPV) and benefit cost-ratio (BCR).

Future considerations

Our analysis shows there is no 'silver bullet' solution to research impact analysis, as many countries around the world struggle to systematically understand all impacts generated by their research funding programs. However, international practices for supporting, monitoring and reporting on research impact could be explored, noting that consultation with the Australian sector to determine appropriateness is critical.

Stakeholders consulted for this evaluation have expressed a desire for improved communication of impact, noting this is a shared responsibility across the sector (including ARC, universities and researchers). Further, most survey respondents reported that it was somewhat or very important that the ARC monitor and communicate the impact of funded research (71%), with a view to justifying the use of public funds and promoting the value of the investment.

Opportunities to better support and assess the impact of NCGP-funded research

As part of this evaluation, ACIL Allen was asked to assess the effectiveness with which the ARC is supporting, monitoring and reporting on NCGP research impact and identify opportunities for how these activities could be improved in the future.

The ARC's approach to improving NCGP impact assessment and communication needs to be carefully considered and tailored to **reflect the purpose** of the impact assessment, **reduce the burden** on the sector and **employ the best available tools and techniques** to capture an understanding of the breadth of impact. Given **there is no one-size-fits-all solution** to impact assessment, ACIL Allen has identified a range of opportunities to enhance how the ARC supports, monitors and reports on the impact of the research it funds, which are summarised in Table ES 1. These opportunities are based on stakeholder feedback gained through this evaluation that there is a benefit in improving the assessment of impact in the future and an appetite to capture this benefit.

The opportunities provide flexibility for ARC to design an NCGP impact assessment framework in consultation with the research community. They will need to be considered within the broader context of the independent review of the ARC and its enabling legislation, refresh of the National Science and Research Priorities and National Science Statement, the policy review of NCGP programs, the Excellence in Research for Australia (ERA) transition plan, and data analytics capability building within the ARC.

Table ES 1 Opportunities to better support and assess the impact of NCGP-funded research

Opportunity	Potential benefits
1. Develop an NCGP impact evaluation framework – Develop agreed metrics with stakeholders, drawing on existing research and innovation metrics – Align with the national research evaluations (such as ERA and Engagement and Impact)	– Greater clarity and consistency on impact reporting requirements for the research sector
2. Strengthen NCGP impact data collection and reporting – Capture case-studies of the impact of major projects – Capture impact data that can highlight trends for the ARC, researchers and the sector	– Improved evidence base that can better support the delivery of impact across the spectrum of basic to applied research – Improved data and narratives for communicating research impact – Greater ability for universities and government to demonstrate the value of research funding for both basic and applied research
3. Explore data-driven approaches to impact assessment – Connect to external data sources and metrics to supplement ARC impact data collection – Adapt approaches over time as metrics and data sources improve	– Improved capabilities to develop deep insights into the impact delivered by ARC-funded research – Reduced burden on the research sector of manual data assembly associated with impact assessment
4. Enhance the communication and understanding of research impact – Regularly communicate the impact of research in an engaging, and targeted way for audiences using data and case studies	– Improved understanding of the value of research among all stakeholders, increasing social license for government investment – Improved early-stage extension, translation and adoption of excellent research, leading to increased collaboration and impact

Source: ACIL Allen

1 Introduction

1.1 The Australian Research Council

The Australian Research Council (ARC) has a key role in Australia's innovation and research system in supporting universities to produce high-quality and impactful research through the delivery of the National Competitive Grants Program (NCGP). ARC funding for blue-sky research and for practical research that links universities, industry and other research end-users helps ensure Australia can maximise the benefits of having a strong and vibrant research sector.

The ARC also has the national responsibility for assessing the quality, engagement and impact of university research, providing grant services to other agencies, and working in partnership with the sector to safeguard research integrity.[1]

The ARC was founded in 1988, became an independent statutory authority in 2001 under the *Australian Research Council Act 2001* and is directly descended from the Australian Research Grants Committee (1965-1987).

1.1.1 The National Competitive Grants Program

The NCGP is the focus of this evaluation. The NCGP awards research grant funding based on a competitive peer review process through 2 main programs, the Discovery Program and the Linkage Program, described below. Under these programs, the ARC funds a range of complementary schemes to support researchers at different stages of their careers, build Australia's research capability and infrastructure, expand and enhance research networks and collaborations, and develop centres of research excellence.

The Discovery Program

The ARC currently delivers 5 schemes[2] under the Discovery Program, which play a crucial role in funding blue-sky (basic) research in Australia. The Discovery Program benefits Australia by supporting research training and career opportunities for the best Australian and international researchers. It builds the nation's research capacity, supports the production of internationally competitive research, and encourages international collaboration. The Discovery Program also funds research in priority areas.

[1] Australian Research Council (2022a). *Australian Research Council Strategy 2022-2025*. Canberra: Commonwealth of Australia.

[2] The 5 funding schemes are: Discovery Projects (DP), Discovery Early Career Researcher Award (DE), Future Fellowships (FT), Australian Laureate Fellowships (FL), and Discovery Indigenous (DI).

The intended outcome of the Discovery Program is to contribute to the growth of Australia's research and innovation capacity. This generates new knowledge, technologies, products and ideas, the creation of jobs, economic growth, and an enhanced quality of life in Australia.[3]

The Linkage Program

The ARC currently delivers 8 schemes[4] under the Linkage Program. The objectives of the Linkage Program are to deliver outcomes of benefit to Australia and build Australia's research and innovation capacity. This is achieved by supporting collaborative research between university-based researchers and researchers in other sectors in Australia and internationally, and funding training and career opportunities that enable researchers and students to work with industry and other end-users. The Linkage Program also funds research in priority areas. By supporting collaboration, the ARC encourages the transfer of skills, knowledge and ideas to secure commercial and other benefits from research.

The intended outcomes of the Linkage Program are to increase Australia's research and innovation capacity to generate new knowledge and result in the development of new technologies, products and ideas, the creation of jobs, economic growth and an enhanced quality of life in Australia. This includes developing commercial products, licences and revenue; new companies; and new programs and policies.[5]

1.1.2 Australian Government Science and Research Priorities

The Commonwealth Government is responsible for setting research priorities to establish a national vision and coordinate national science policy.[6] Australia has had 3 sets of national science and research priorities. The first priorities were the National Research Priorities (2003-12), followed by Strategic Research Priorities (2012-15) and National Science and Research Priorities (2015-present).[7,8]

The priorities, developed in consultation with industry and research, focus Australian Government support for science and research on Australia's most important challenges.[9]

The ARC's role regarding the National Science and Research Priorities is to support the highest-quality research and research training across all disciplines, including research outside the priority areas. Funding applicants are asked to identify whether their proposed research relates to the

[3] Australian Research Council (2022b). *Grant Guidelines for schemes under the Discovery Program (2021 edition)*. Accessed 1 August 2022: https://www.grants.gov.au/Fo/Show?FoUuid=a7f42e2b-c84c-44b6-8577-798b33ff3d67.

[4] The 8 schemes are: ARC Centres of Excellence (CE), Industrial Transformation Research Program (IH), Linkage Infrastructure, Equipment and Facilities (LE), Linkage Learned Academies Special Projects (LA), Linkage Projects (LP), Special Research Initiatives (SR), Supporting Responses to Commonwealth Science Council Priorities (CS), and Industry Fellowships (new and not included in this report).

[5] Australian Research Council (2020b). Op. cit.

[6] Federation of Australian Scientific and Technological Societies (2002). *Australian Science: Investing in the Future*. Canberra: Federation of Australian Scientific and Technological Societies.

[7] STIP Compass, OECD (2021). *National science and research priorities*. Accessed February 2023: https://stip.oecd.org/stip/interactive-dashboards/policy-initiatives/2021%2Fdata%2FpolicyInitiatives%2F13921.

[8] The current priorities are Food, Soil and Water, Transport, Cybersecurity, Energy, Resources, Advanced Manufacturing, Environmental Change, and Health.

[9] Australian Research Council (2022d). *Science and Research Priorities*. Accessed February 2023: https://www.arc.gov.au/funding-research/apply-funding/grant-application/science-and-research-priorities.

priorities and, where relevant, grant assessors assess the potential of the research to contribute to the priorities.[10]

The Australian Government announced plans to refresh the National Science and Research Priorities and National Science Statement (published in 2017) on 27 September 2022.[11]

1.1.3 Independent review into the ARC and its enabling legislation

The Minister for Education announced a review of the ARC and its enabling legislation, the *Australian Research Council Act 2001*, on 30 August 2022. The review will run from 5 September 2022 to 31 March 2023.[12] While the review is critical to ARC's future operations, it is distinct from ACIL Allen's evaluation, which focuses on the impact of NCGP-funded research.

1.2 Australian Government research funding

The Australian Government's science, research and innovation funding is distributed across multiple portfolios. In 2021-22, the Australian Government invested an estimated $11.8 billion in science, research and innovation,[13] with an estimated $830 million delivered by the ARC.[14] In 2020-21, the ARC's investment represented around 7% of the total Australian Government investment in R&D and 0.04% of Australia's Gross Domestic Product (GDP).

From 2002 to 2021, the ARC awarded $13.7 billion in funding. $8.37 billion (61%) was awarded through the Discovery Program and $5.35 billion (39%) through the Linkage Program (see Figure D.1, funding amounts are for the funding allocated in the award year).[15]

Across the individual schemes, most funding ($5.26 billion) and grants (16,638) were awarded to DP (see Figure 1.1), followed by LP ($1.96 billion and 6,762 grants) and CE ($1.91 billion and 74 grants). The amount of funding and grants awarded varies across years due mainly to the periodic funding awarded for CE (see Figure D.1).

The ARC does not prescribe the amount of funding awarded to research disciplines. Applications are assessed based on relevant criteria, for example, investigator capability, project quality and innovation, benefit and feasibility.[16] The largest funding by primary Field of Research (FoR) was awarded to Engineering ($2 billion) and then Biological Sciences ($1.96 billion). By primary Socio-Economic Objective (SEOs), the largest value of funding aligned with Expanding Knowledge, at $5.32 billion (see Figure D.2). The most common participating organisation type is Australian universities, which contribute most cash and in-kind contributions to projects (see Figure D.3).

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[10] Ibid.

[11] Australian Government (2022). *Australian Government to revitalise our science priorities*. Accessed 29 September 2022: https://www.industry.gov.au/news/australian-government-revitalise-our-science-priorities.

[12] Department of Education (2022). *Review of the Australian Research Council Act 2001*. Accessed 28 September 2022: https://www.education.gov.au/higher-education/review-australian-research-council-act-2001.

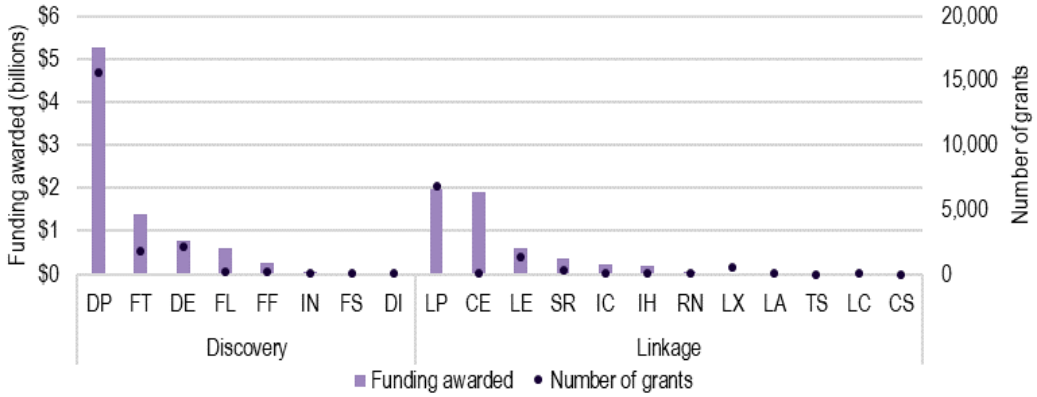
[13] Parliament of Australia (2022). *Science and Research Budget Review 2022–23 Index*. Accessed March 2023: https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/BudgetReview202223/ScienceResearch.

[14] Australian Research Council (2022). *Entity resources and planned performance*. Accessed March 2023: https://www.arc.gov.au/sites/default/files/2022-11/2022-23%20ARC%20Budget%20Oct.docx#:~:text=The%202022%E2%80%9323%20figure%20includes,during%202022%2D23%20March%20budget.

[15] Australian Government (2021). *Science, research and innovation (SRI) budget tables*. Accessed February 2023: https://www.industry.gov.au/publications/science-research-and-innovation-sri-budget-tables.

[16] Australian Research Council (2022e). *Selection Report: Discovery Projects 2022*. Accessed February 2023: https://www.arc.gov.au/funding-research/funding-outcome/selection-outcome-reports/selection-report-discovery-projects-2022.

Figure 1.1 Funding data on funding awarded and number of grants by scheme



N=29,303 projects. Note: funding amounts are in current dollars (i.e. the value of the funding allocated in the award year. Not all of these schemes are still in operation, and some have not been active over the entire analysis period (2002-21).

Source: ACIL Allen's analysis of ARC funding data for grants awarded between 2002 and 2021.

1.3 This evaluation

This evaluation provides an independent assessment of the outcomes and impact of NCGP-funded research over the past 2 decades. It also considers the potential future benefits of the Linkage and Discovery Programs. The terms of reference for this evaluation are provided in Box 1.1.

This evaluation is important because the impact of research funding programs in Australia is poorly understood, and an independent whole-of-program impact assessment of the NCGP has not been completed for 20 years.

Box 1.1 Terms of reference

The evaluation is required to:

1. assess the outcomes of NCGP-funded research, including those relevant to the Government's broad strategic priorities.[17]
2. assess the economic impact of NCGP-funded research
3. assess the broader impacts of NCGP-funded research, including environmental, social and other impacts
4. assess the effectiveness with which the ARC is supporting, monitoring and reporting on NCGP research impact
5. identify lessons and recommendations on how the impact of ARC-funded research could be better supported, monitored and communicated in the future.

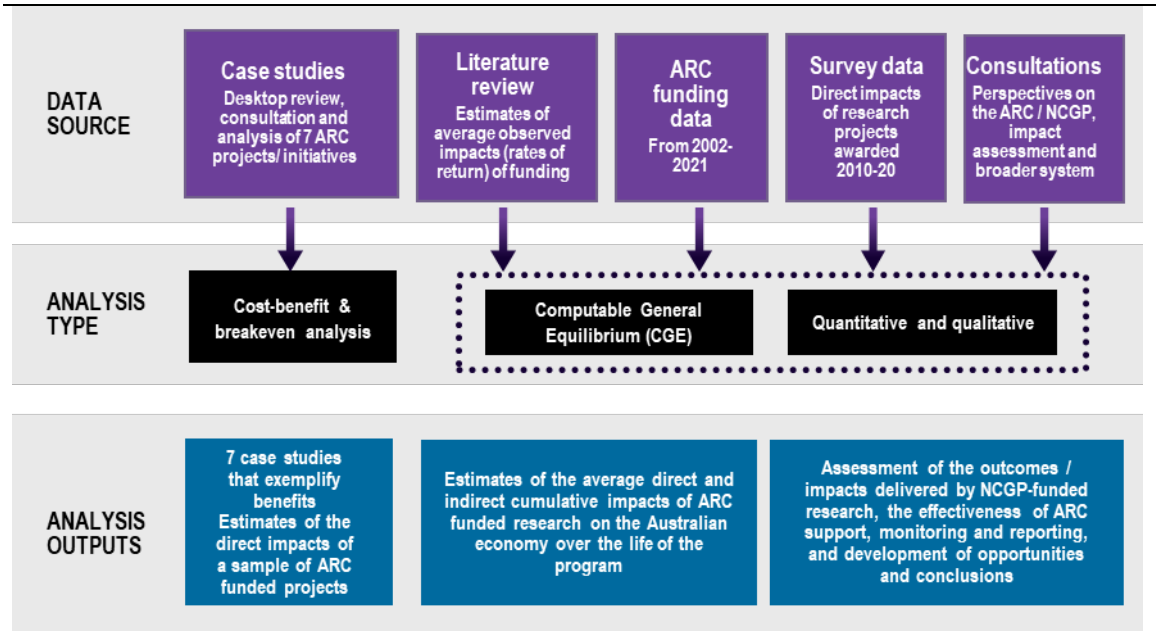
Source: ARC's 2022 RFQ

[17] Noting that reference to Government's broad strategic priorities includes priorities beyond the National Science and Research Priorities, as agreed with the ARC.

1.3.1 Evaluation approach and data sources

The evaluation used a mixed methods approach to gather and analyse qualitative and quantitative data (see Figure 1.2). Core analytical components of the method are described below, along with data limitations. These analytical components have informed an assessment of the pathway to impact for NCGP-funded research. The report (and case studies) maps the relationship between inputs, activities, outputs, outcomes and impacts (which are economic, research capacity, social, environmental and cultural in nature). In doing so, it considers the benefits that are distributed (for the Computable General Equilibrium (CGE) modelling this is benefits delivered to each industry and for the case studies this is benefits delivered to beneficiaries), attribution issues, and the counterfactual. See the appendices in Part III for more detail, as well as chapters 2 (rates of return on research literature review), 3 (CGE modelling approach), and 4 (*Tasman Global*) of the technical supplement to this report.

Figure 1.2 Impact assessment approach



Source: ACIL Allen

Computable General Equilibrium (CGE) modelling

CGE modelling estimates the average direct and indirect cumulative impacts of ARC-funded research on the Australian economy over the NCGP's life. This generates figures on the contribution of ARC-funded research to the economy, incomes, and employment. The CGE modelling draws on funding data provided by the ARC (described below).

Case studies

The case studies involved desktop research, analysis and consultation with researchers, research partners and end-users on a sample of 7 projects/key initiatives. 7 examples of exceptional impact were chosen to demonstrate the diversity of impact types, beneficiaries, disciplines, participating organisations and NCGP schemes, noting that 7 case studies cannot illustrate the full diversity of ARC-funded research and its impacts. 7 case studies were also a manageable number within the available timeframes. These illustrate the pathways to impact and highlight the diversity of impact delivered by NCGP-funded research. This includes impact on society, culture, environment and research capacity, which may not be as readily quantified nor generate a market return. The case studies are provided in full in Part II and overviewed below:

- *Quantum Computation and Communication Technology* focuses on delivering world-leading quantum research to develop full-scale quantum systems – encompassing ultra-fast computation, secure communication and distributed information processing.
- *Aquifer Reinjection, Australia's first full-scale groundwater replenishment scheme* focuses on developing an approach to reinject treated wastewater into Perth's aquifers.
- *Irrigation Automation* focuses on a partnership developed between Rubicon Water Ltd and the University of Melbourne over 20 years, which involves research on irrigation automation and the efficiency of large-scale gravity-fed irrigation systems.
- *Onshore Lobster Aquaculture* focuses on closing the complex and protracted life cycle of spiny lobsters in captivity to enable a sustainable supply of lobsters.
- *Changing the Law to Protect Survivors of Domestic and Family Violence (DFV)* focuses on women experiencing DFV and the legal and justice system responses to DFV.
- *Indigenous Persistence in Formal Learning* focuses on better understanding how Indigenous students persist in higher education and developing models to support retention and graduation rates.
- *Return, Reconcile, Renew (RRR): Indigenous Remains Repatriation* focuses on developing and implementing a centralised archive of repatriation information to support the repatriation of Indigenous remains.

Consultation with system leaders in Australia

Stakeholders were consulted from the following Australian organisations: Australian Technology Network of Universities (ATN), Universities Australia (UA), Regional Universities Network (RUN), Group of Eight (Go8), Australian Council of Learned Academies (ACOLA) and the Commonwealth Department of Education.

Consultation and comparison with international comparator programs

Four international organisations were selected for comparison with the NCGP and ARC. This focused on the structure and logic of the funding; research impacts; and efforts to monitor, measure and report on impact. This comparison aimed to identify lessons that could be applied to the ARC.

Stakeholders were consulted from Horizon Europe, European Commission (Horizon Europe), Science Foundation Ireland (SFI), United Kingdom Research and Innovation (UKRI) and the New Zealand Ministry of Business, Innovation and Employment (MBIE).

Grant final report data and funding data

ARC provided 22,352 grant final reports for grants awarded between 2002 and 2021 that had been approved by 30 June 2022. These contained information on the number and value of grants, co-contributions, outputs, outcomes and impacts.

Funding data was provided for 29,303 projects. This included funding commencement year and project duration, announced funding value, allocation to FoRs, SEOs, government priorities, number of and funding provided by participating and partner organisations, and the number of Chief Investigators (CIs) and Partner Investigators (PIs).

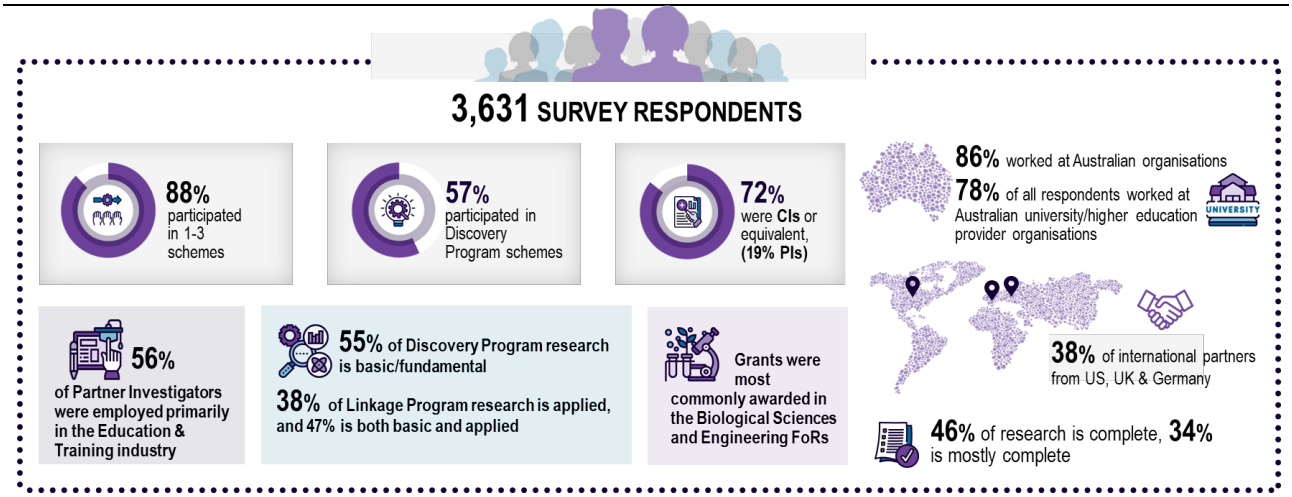
Survey of researchers

A survey was distributed to 25,707 CIs and PIs awarded NCGP grants from 2010-20. 3,361 responses were received, approximately 13% of the potential respondents. This is a sample of the population and is not necessarily representative. The final report data does not fully address all of the issues considered by the evaluation, and the data is limited to information available up to 1 year

following the completion of the grant. The survey aimed to address these gaps and provide an updated summary of the impacts delivered from NCGP-funded research following an extended lag time for impacts to emerge. It asked questions about involvement in NCGP-funded research, the nature of the research, the nature and extent of impacts delivered/likely to be delivered, the lag time to and duration of impact, beneficiaries, other funding sources, and the way the ARC monitors and communicates about impact. The survey population is overviewed in Figure 1.3.

Free text questions were qualitatively analysed using software (Python[18]) and manual processes. Python was used to analyse the frequency of individual and groups of words and themes. Additional sentiment analysis was conducted using Python, which assessed the polarity (degree of positive or negative sentiment) and subjectivity (degree of personal opinion expressed).

Figure 1.3 Overview of the survey population



Source: ACIL Allen survey of ARC funding recipients

1.4 How to read and use this report

This report is an impact assessment exercise based on the whole of economy modelling and case study analysis using assumptions and the best available data. Its results should be interpreted as an illustration of the types and nature of the impacts delivered over a long period of time. As modelled and analysed, the results are not strictly comparable to other modelling undertaken for the research sector or even other sectors that receive public funding. This is because the assumptions and data (based on best practice and best available information) used in this report are unique to the evaluation. The assumptions and data sources are overviewed in section 2.1.

Moreover, the following data limitations were encountered during the evaluation. These should be considered throughout the report when referencing or using the relevant data/analyses.

The CGE modelling findings presented in this report provide valuable evidence of the economic impacts of ARC-funded research on the Australian economy. Nonetheless, as with any modelling exercise, there are some limitations in the analysis, as follows:

— The social, cultural, environmental and other impacts associated with research projects funded by the ARC have not been monetised or included in the economic modelling. As a result, the economic impacts described in this report understate the overall impacts of the NCGP.

[18] Python is a programming language that is used for data analysis of qualitative and quantitative analysis.

- The economic modelling assumes that the economic returns from ARC-funded research projects are, on average, similar to those found in the literature (provided in chapter 2 of the technical supplement to this report, with the assumptions at chapter 3). Potentially, these may be higher or lower for some projects. Accurate estimation of rates of return for ARC-funded projects would require analysis of each of the 29,000 plus projects funded by the ARC.
- The findings in this report are subject to unavoidable statistical variation. While all care has been taken to ensure that the statistical variation is kept to a minimum, care should be taken whenever using this information. This report considers information provided by the ARC up to the end of 2021. The findings may be affected by new information.
- A small sample of 7 case studies was selected. This is not representative of the breadth of research funded under the NCGP. Due to the nature of the impacts generated by some projects, it was not appropriate or possible to quantity some benefits. Where this occurs, impacts have been discussed qualitatively.
- Domestic stakeholders had limited visibility or capacity to articulate the breadth and depth of the impact delivered by the NCGP and limited visibility of ARC's support mechanisms and communications. Many stakeholders are peak bodies with members (e.g. universities, learned academies) that are at varying levels of maturity in assessing their impact., and as such there was no consistent view on impact measurement. A full report of stakeholder feedback is provided in chapter 6 of the technical supplement to this report. Consultation methodology is provided in chapter 5.
- International stakeholders represented schemes of varying comparability to the NCGP and ARC and were at varying levels of impact measurement maturity. A full report of stakeholder feedback is provided in chapter 7 of the technical supplement to this report.
- Final report data has changed over time as questions, data types, response options and collection approaches have varied over time and across schemes. Outputs and outcomes may be underestimated because not all final reports were submitted at the time of data extraction, and they do not capture benefits realised after final reports were submitted (no later than 12 months post grant completion).
- Survey respondents were a sample of approximately 13% of grant recipients and may not be representative. Some grants were ongoing at the time of the survey, and impacts had not necessarily emerged. Survey methodology, respondent demographics and additional analysis are provided in chapter 8 of the technical supplement to this report.

1.5 Report structure

ACIL Allen's report addresses the terms of reference and Key Evaluation Questions (KEQs), as outlined in Table A.1. ACIL KEQs have been identified in the margin of the report, where relevant.

The remainder of this report is structured as follows:

- Part I: Impact report
  - Chapter 2: Economic impacts of NCGP-funded research
  - Chapter 3: Broader impacts of NCGP-funded research
  - Chapter 4: Supporting, measuring and communicating impact
  - Chapter 5: Challenges, opportunities and future impact assessment
  - Chapter 6: Concluding remarks

- Part II: Case studies
  - Quantum Computation and Communication Technology
  - Aquifer Reinjection
  - Irrigation Automation
  - Onshore Lobster Aquaculture
  - Changing the Law to Protect Survivors of DFV
  - Indigenous Persistence in Formal Learning
  - RRR: Indigenous Remains Repatriation
- Part III: Appendices
  - A: Evaluation framing and terms of reference
  - B: Beneficiaries of NCGP-funded research
  - C: Stakeholder survey additional information
  - D: Program and other data methodology and evidence.

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Impact report

Economic impacts of NCGP-funded research 2

This chapter details the modelled and other economic impacts generated by the NCGP over the past 2 decades.

KEQ 1. What are the short-, medium- and long-term outcomes and impacts of ARC-funded research? Is the NCGP achieving its intended outcomes?
KEQ 3. What is the Government's return on investment for the NCGP?

2.1 NCGP's return on investment: modelled impacts

Key Finding 1 Modelled economic impacts

The NCGP is projected to provide significant benefits to the Australian economy by:

- **Generating substantial economic activity**, particularly for a single research program. For grants awarded between 2002 and 2021, it will boost Australia's economic output (GDP) by $184.3 billion over the lifetime of the research benefits. The present value of this change ($33.6 billion) is equivalent to approximately 1.5% of Australia's current GDP.
- **Raising economic welfare across Australia**. In particular, it is projected that the NCGP (for grants awarded 2002-21) will increase the real income of Australians by a cumulative total of $152.5 billion. The value today of this whole of life impact[19] is equivalent to a one-time increase in the average income of *all* Australians by approximately $1,171 per person.
- **Generating significant employment opportunities**. For grants awarded between 2002 and 2021, the NCGP will increase total employment, creating around 6,570 FTE jobs per year across Australia.
- **Providing significant value for money**. For every dollar the Australian Government awarded through the NCGP from 2002-2021, funded projects generated $3.32 in additional economic output (GDP).

These estimated economic impacts understate the overall benefits of the NCGP as they do not account for the social and environmental impacts associated with research projects funded by the ARC.

This section characterises the economic impact of ARC-funded research.

2.1.1 Economic impacts

Research funded by the ARC is varied and can have various impacts. Impacts can be:

- economic: impacts that can be given a measurable and specific asset value captured by economic actors (e.g. changes in gross domestic product or employment)
- research capacity: impacts on the contribution to knowledge, training and collaboration

[19] That is, the discounted present value using a 7% discount rate.

— social: impacts on the wellbeing of the wider community (e.g. changes in community resilience)

— environmental: impacts on natural systems, including ecosystems, land, air and water

— cultural: impacts on cultural understanding, preservation and creativity.

Examples of impacts across these categories are provided in Figure 2.1. Importantly, it is not always possible to quantify or monetise all of these impacts (e.g. impacts on community resilience as a result of a research project would be challenging to quantify and monetise). However, as noted by the Department of the Prime Minister and Cabinet's Guide to Cost-Benefit Analysis (CBA), 'The fact that some impacts may be very difficult to quantify in dollar terms does not invalidate the CBA approach. In such cases, a detailed qualitative analysis will often be most appropriate in place of dollar values'..[20] Qualitative consideration of impacts is important for recognising that those impacts exist and have value.

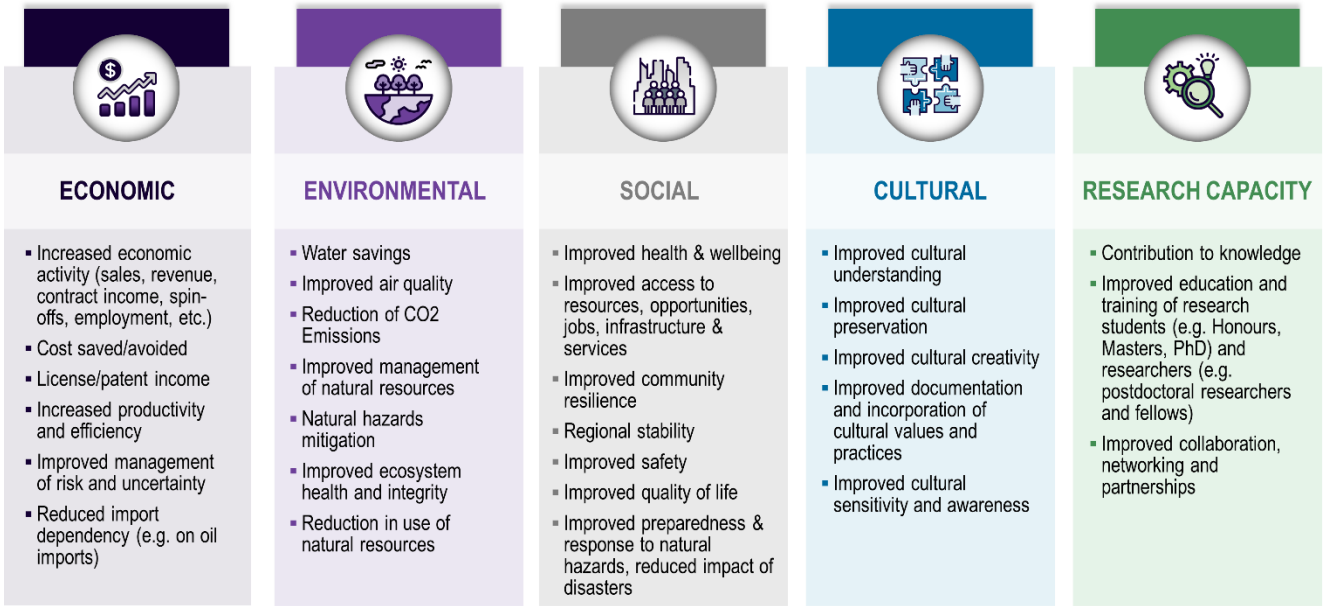
In this analysis, research capacity, social, environmental and cultural impacts associated with research projects funded by the ARC have not been monetised. As a result, the economic impacts reported in this chapter understate the overall benefits of the NCGP.

The economic impacts measured in this report can be divided into 2 categories:

— Direct impacts of ARC-funded research, which refer to changes directly attributed to the research outputs (for instance, cost saved due to the use of a new production method).

— Economy-wide impacts, which refer to the indirect impacts of ARC-funded research on the economy. As the direct impacts of research are propagated throughout the economy, this stimulates investment, jobs and further economic growth.

Figure 2.1 Examples of research project impacts



Source: ACIL Allen.

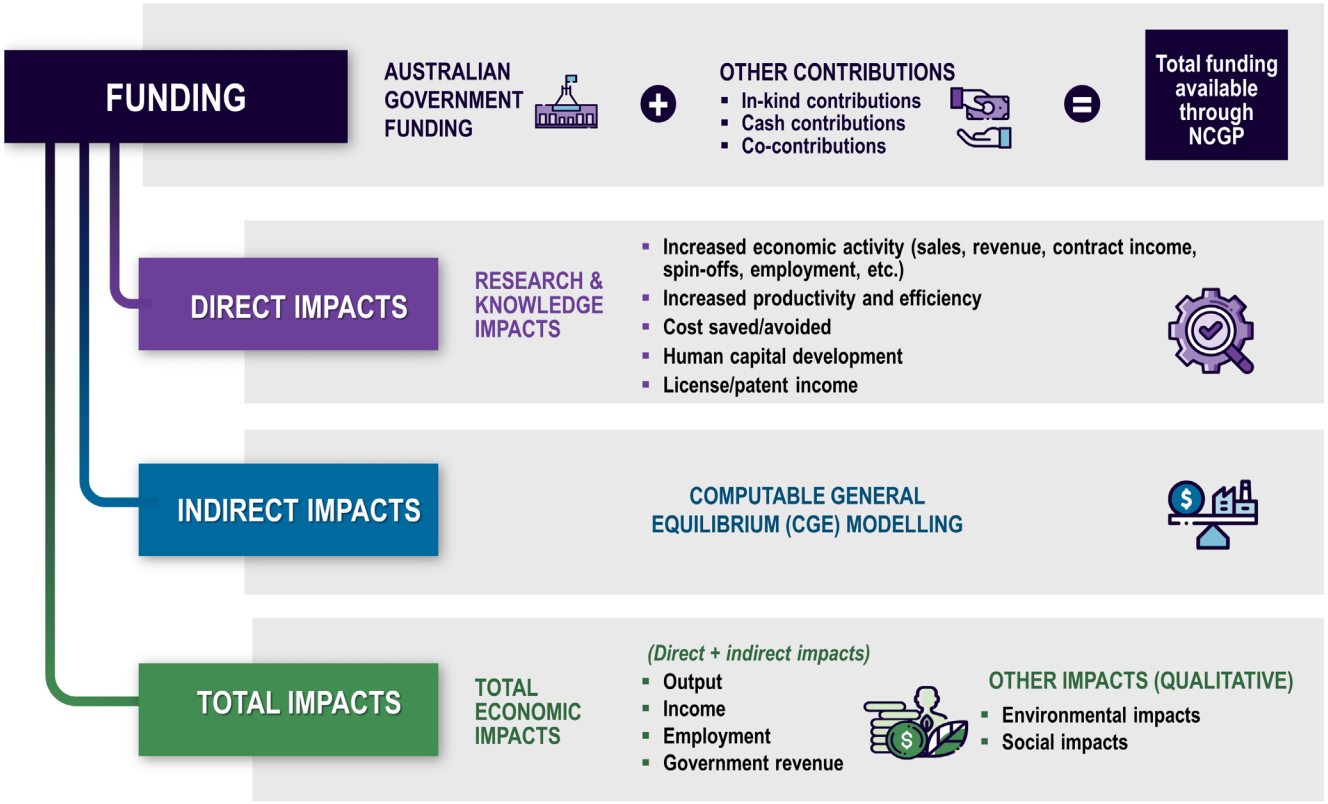
[20] Department of the Prime Minister and Cabinet (2023). *Cost–benefit analysis*. Canberra: Australian Government.

2.1.2 Analytical framework for economic impact analysis

The analytical framework used to assess the impact of ARC-funded research on the Australian economy is summarised in Table 2.2. This framework shows the main channels through which ARC-funded projects impact the Australian economy. It has been successfully used in many similar studies of research impact undertaken by ACIL Allen over the past decades.

The total (economy-wide) impacts of ARC-funded research were estimated using ACIL Allen's CGE model of the Australian economy, the *Tasman Global* model (detail is provided in chapter 4 of the technical supplement to this report.).

Figure 2.2 Analytical framework



Source: ACIL Allen.

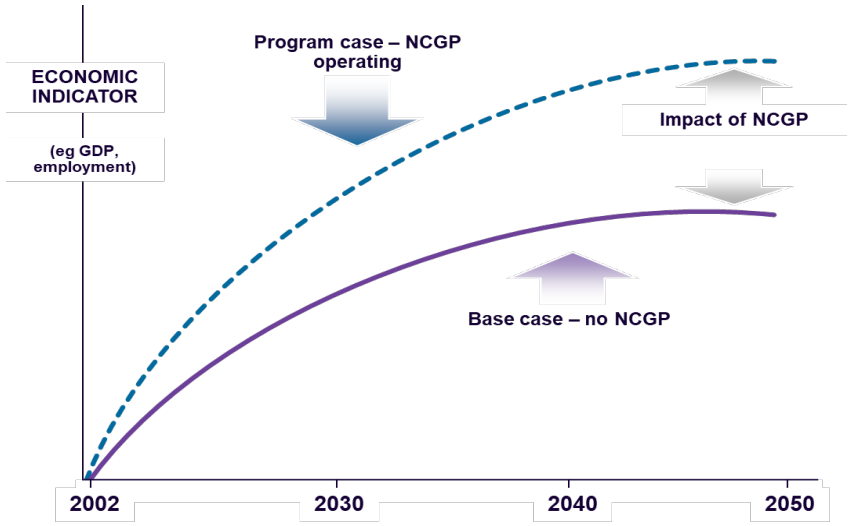
Tasman Global

Tasman Global is a large-scale, dynamic CGE model of the world economy developed in-house by ACIL Allen and allows for economic analysis to be conducted at the regional, state, national and global levels. Detail on Tasman Global is provided in chapter 4 of the technical supplement to this report.

CGE models mimic the workings of the economy through a system of interdependent behavioural and accounting equations linked to an input-output database. These models provide a representation of the whole economy, set in a national and international trading context, starting with individual markets, producers and consumers and building up the system via demand and production from each component. When an economic shock or disturbance is applied to the model, each of the markets adjusts according to the set of behavioural parameters, which are underpinned by economic theory.

In applications of the *Tasman Global* model, a reference case simulation forms a 'business-as-usual' basis with which to compare the results of various simulations (herein referred to as the Base Case). The Base Case provides projections of growth in the absence of the program being analysed (such as GDP, population, labour supply, industry output, etc.) and provides projections of endogenous variables such as productivity changes and consumer preferences. The program case assumes all productivity improvements, tax rates, and consumer preferences change as per the Base Case projections but also includes the program being evaluated (in this case, the NCGP). The 2 scenarios give projections of the economy, and the net impact of the program is then calculated as deviations from the reference case (see Figure 2.3).

Figure 2.3 Illustrative scenario analysis using *Tasman Global*



Note: In reality impacts could be negative, positive, neutral or a mixture.
Source: ACIL Allen.

2.1.3 Simulation design and key inputs used in the economic modelling

This report analyses the economic impact of grants awarded by the ARC from 2002 to 2021 (i.e. it illustrates the economic impact of the NCGP in Australia over its life). To estimate this impact, the following scenarios were simulated in the *Tasman Global* model:

— *Base Case scenario* — where it is assumed that the NCGP does not exist. This was used as a benchmark with which to compare the results of simulating the NCGP scenario.

— *NCGP scenario* — this scenario refers to a case where the NCGP has been established and grants have been awarded by the ARC over the period 2002 to 2021. This scenario includes the funding provided by ARC and the co-contributions from different parties. In practice, the historical period (2002-2022) reflects the actual historical path of the Australian economy in terms of changes in GDP, population, employment, trade, etc., while the Base Case scenario estimates what the Australian economy could have looked like if the NCGP had not been established.

Differences in economic outcomes between the NCGP scenario and the Base Case scenario are calculated to determine the economic benefits stemming from the NCGP over its lifetime.

Two sets of shocks were applied to *Tasman Global* in the NCGP simulation. One set of shocks is related to the direct benefits of the ARC-funded research activity, and the other to its costs.

The benefits of ARC-funded research are estimated using ARC project data, the ROR on public research investments obtained from the national and international literature (see chapter 2 in the technical supplement to this report), and a number of assumptions (further detail is provided in chapter 3 of the technical supplement). The internal ROR used to calculate the benefits range from 5-70% per annum, depending on the sector and type of research. Based on this information, ACIL Allen estimated the productivity gains in each industry that are introduced into *Tasman Global*. Importantly, while the modelling only covers the ARC grants awarded from 2002 to 2021 (with the last year of actual annual funding provided in 2026 for grants awarded in 2020 which have a duration of 7 years), the benefits of ARC-funded research are not experienced until a few years after the research projects have been completed and are likely to last for many years. Considering these factors, the timeframe covered by the economic modelling spans from 2002 to 2046, when the last year of direct benefits from research projects awarded in 2021 (and completed in 2025) finish. These timeframes are explained in more detail in Figure 2.4.

In terms of NCGP's costs, it has been assumed that if the Government had not funded the NCGP, the grant funding would have been allocated across other Government expenditures (potentially having positive impacts elsewhere). An alternative counterfactual assumption could be that taxes could have been lowered by the amount of NCGP funding. However, given the scale of NCGP funding in the overall Australian Government budget, it is more likely that the funds would have been differently allocated out of consolidated government revenue.

Table 2.1 provides a summary of the assumptions used to derive the modelling inputs for the NCGP scenario. More detail is provided in chapter 3 of the technical supplement to this report.

Table 2.1 Summary of assumptions used to derive modelling inputs

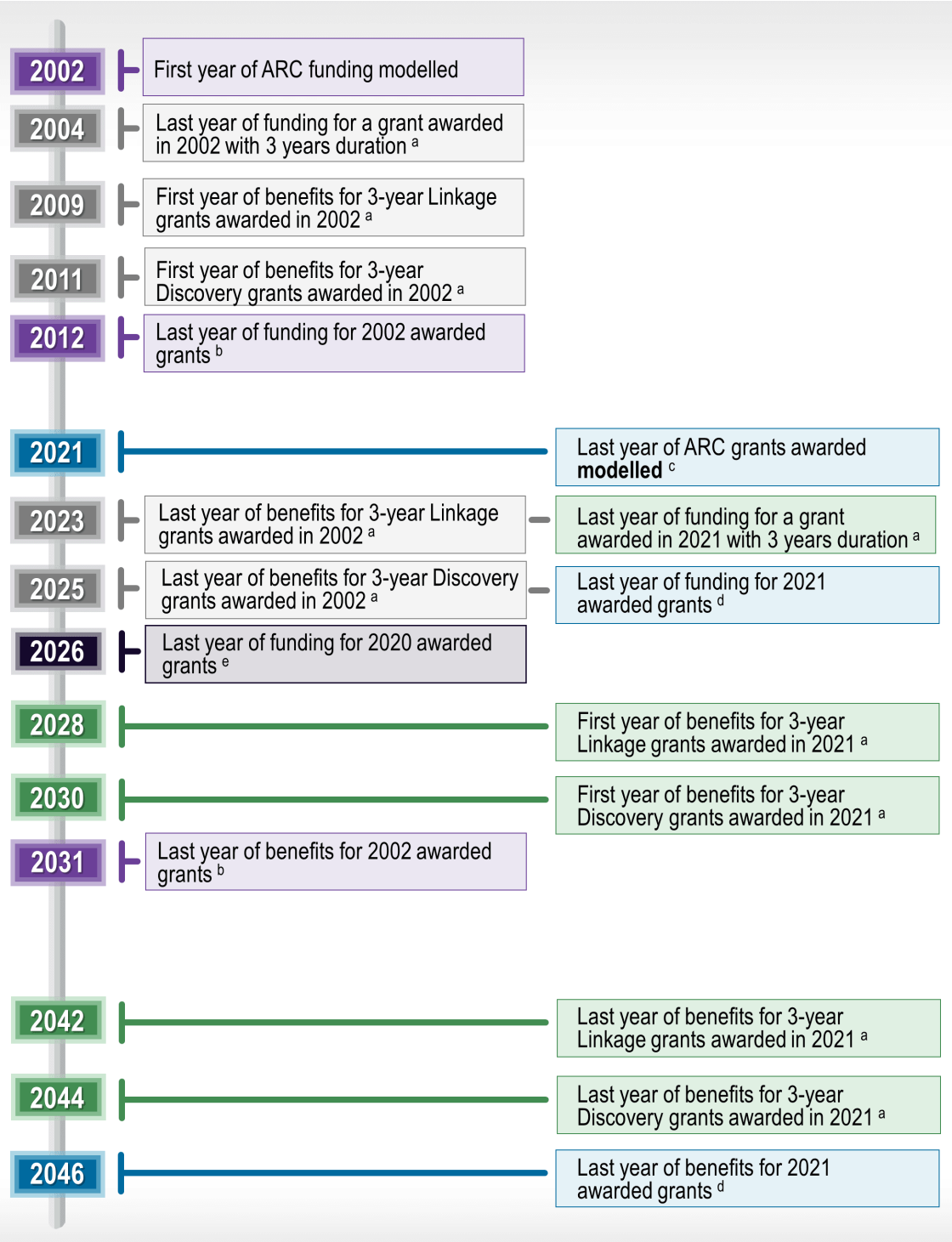
<table>
<tr><th>Input/assumption</th><th>Value</th></tr>
<tr><td>Level of investment in research activities</td><td>The total amount of research funds provided by the ARC from 2002-26 (for grants awarded from 2002-21, noting there are some grants awarded in 2020 with a duration of 7 years) is $13.7 billion (in nominal dollars, equivalent to $17.6 billion in 2022 dollars). This funding was extended by $14.3 billion in co-contributions from other Australian sources and $2.6 billion in co-contributions from international sources.

Around 72% of the ARC funds awarded from 2002-2021 ($9.9 billion in nominal dollars) and their corresponding co-contributions (approximately $12.9 billion in nominal dollars) were assumed to get an economic return. The proportion of projects (funds) generating a market return has been drawn from the survey responses. This includes responses reporting that projects ‘have produced’, are ‘likely to result in’ and ‘may result in’ economic impact by FoR (see Figure C.2).</td></tr>
<tr><td>Rate of return on investment</td><td>The direct benefits of ARC-funded research were estimated by applying average ROR to research investments based on their SEO, as proposed by the ARC. The RORs applied to research investments in scientific fields were sourced from national and international literature. No estimates of RORs on research in social sciences, arts and humanities were found in the literature, and a ROR was assumed.

The RORs the economic modelling by SEO assumed are provided directly below.
<table>
<tr><th>SEO</th><th>Assumed type of R&D</th><th>Rate of return</th></tr>
<tr><td>Defence</td><td>Public R&D (literature estimates)</td><td>35%</td></tr>
<tr><td>Plant Production and Plant Primary Products</td><td>Agricultural R&D (literature estimates)</td><td>40%</td></tr>
<tr><td>Animal Production and Animal Primary Products</td><td>Agricultural R&D (literature estimates)</td><td>40%</td></tr>
<tr><td>Mineral Resources (excl. Energy Resources)</td><td>Mining R&D (literature estimates)</td><td>70%</td></tr>
<tr><td>Energy</td><td>Public R&D (literature estimates)</td><td>35%</td></tr>
<tr><td>Manufacturing</td><td>Manufacturing/industrial research (literature estimates)</td><td>20%</td></tr>
<tr><td>Construction</td><td>Public R&D (literature estimates)</td><td>35%</td></tr>
<tr><td>Transport</td><td>Public R&D (literature estimates)</td><td>35%</td></tr>
<tr><td>Information and Communication Services</td><td>Public R&D (literature estimates)</td><td>35%</td></tr>
<tr><td>Commercial Services and Tourism</td><td>Public R&D (literature estimates)</td><td>35%</td></tr>
<tr><td>Economic Framework</td><td>Public R&D (assumption)</td><td>10%</td></tr>
<tr><td>Health</td><td>Health/medical R&D</td><td>45%</td></tr>
<tr><td>Education and Training</td><td>Public R&D (assumption)</td><td>15%</td></tr>
<tr><td>Law, Politics and Community Services</td><td>Public R&D (assumption)</td><td>10%</td></tr>
<tr><td>Cultural Understanding</td><td>Public R&D (assumption)</td><td>5%</td></tr>
<tr><td>Environment</td><td>Public R&D (literature estimates)</td><td>35%</td></tr>
<tr><td>Expanding Knowledge</td><td>Public R&D (literature estimates)</td><td>35%</td></tr>
</table>
Notes: The category named ‘Public R&D (literature estimates)’ is based on estimated ROR to overall public R&D in scientific fields (including basic & applied). No estimates of ROR in non-scientific fields (research in social sciences, arts and humanities) were found in the literature. Hence, assumptions were developed in discussions with the ARC about a potential ROR to research in these areas (noted in the table above as ‘Public R&D (assumption)’).</td></tr>
<tr><td>Industry sectors receiving the returns from research</td><td>Benefits from the research were allocated between subdivisional structures of the Australian and New Zealand Standard Industrial Classification (ANZSIC). Allocation was made based on analysis of the SEOs codes and FoR codes of the research projects.</td></tr>
<tr><td>Time lags for accrual of benefits</td><td>Assumed to be 6 years for Discovery Projects and 4 years for Linkage Projects based on survey results (see Table C.1) and consultation with sector leaders (see section 4.2.1).</td></tr>
<tr><td>Useful life of research</td><td>It is assumed that the useful economic life of outcomes generated or enabled through ARC-funded research activities is, on average, 15 years.</td></tr>
<tr><td>Geographic boundaries of returns from research</td><td>Given the national nature of the ARC, the modelling assumes that all Australians enjoy all research benefits stemming from ARC funding.</td></tr>
</table>

Source: ACIL Allen and ARC.

Figure 2.4 Economic modelling timeframes



[a] For illustrative projects with a duration of 3 years. The actual duration varies by project. [b] The maximum duration of grants awarded in 2002 is 11 years. [c] In reality, ARC grants have continued to be awarded after this date. [d] The maximum duration of grants awarded in 2021 is 5 years. [e] The maximum duration of grants awarded in 2020 is 7 years, so the last year of actual funding provided by ARC will be 2026 for these projects.

Source: ACIL Allen.

2.1.4 Measured economic impacts

When assessing the impacts of research activities on the economy, a range of key macroeconomic variables are commonly evaluated (and have been included in other economy-wide studies of research impacts), including the following.[21]

- *GDP* — measures Australia's economic activity (output), and is described as 'economic output' throughout the report.
- *Real income* — indicates changes in economic welfare (wellbeing) of the residents of Australia. This indicator measures the ability to purchase goods and services (adjusted by inflation).
- *Employment* — shows how job numbers change across the Australian economy at large.
- *Government revenue* — measures the distribution of impacts of ARC-funded research on Commonwealth and State Government revenues.

The sections below discuss the impacts of the ARC-funded research on these key macroeconomic variables for the Australian economy.

All of the economic impacts in this section are reported in Australian dollars (in 2022 dollars unless noted) and the net present valuations (NPV) are calculated using a central 7% real discount rate[22] (with sensitivity analysis for a lower 3% rate and higher 10% discount rate presented in tables).

Total economic output

Figure 2.5 shows the impact of ARC-funded research on Australia's real economic output (GDP). This has been measured as the change between actual economic outcomes delivered by the NCGP compared to the Base Case. Figure 2.5 reflects the economic impacts resulting from ARC funding and co-contributions for grants awarded between 2002 and 2021,[23] which last until 2046, as explained in Figure 2.4. However, if the continuation of ARC funding were modelled at its current rate into the future, the changes in the economy due to the spending would not decrease, as illustrated in this figure.

As shown in Figure 2.5, the benefits of ARC-funded research take time to translate into additional economic activity.[24] However, after the initial years of the modelling period, the benefits of the ARC-funded research ramp-up substantially, with the impact on GDP peaking in 2031 at $9.05 billion above that of the Base Case scenario. This occurs as the investment in research begins to generate increased productive capacity in the economy. Consequentially, GDP begins to increase above that of the Base Case scenario due to the flow of activities generated by the ARC-funded research. In the long run, the effect of higher productivity in industries is passed on to consumers in the form of lower prices for consumer goods and services, with scarce resources freed up for use elsewhere in the economy, allowing an increase in total production. Lower consumer prices and the increased productive potential of the Australian economy arising from the productivity gains translate into higher real private consumption and higher economic activity.

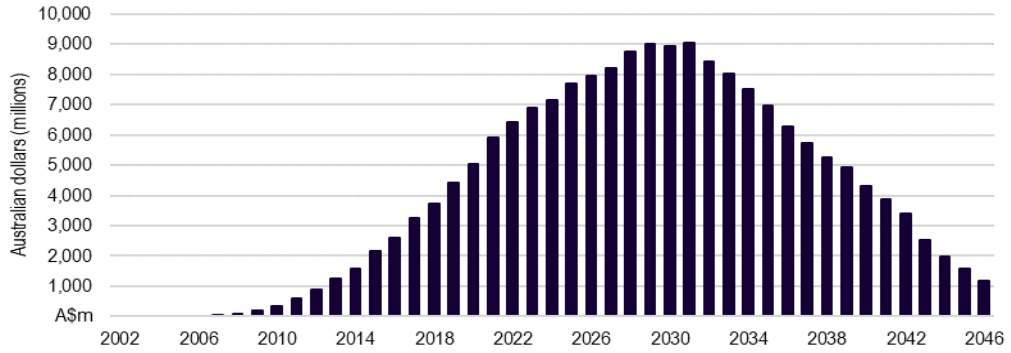
[21] Additional explanation about these economic terms is provided in the appendices in Part III.

[22] A 7%real discount rate is based on the Commonwealth Office of Impact Analysis Guidelines on evaluation of projects.

[23] Notably, while the last round of grants modelled are those awarded in 2021, there are projects awarded in 2020 which will receive funding over 7 years (until 2026) and hence the costs to the Australian Government extend over the period 2002-2026.

[24] See **Table 2.1** for an overview of the modelling inputs and assumptions affecting the profile of these impacts.

Figure 2.5 Estimated change in Australian real GDP from 2002–2046 associated with ARC grants awarded between 2002 and 2021, relative to the Base Case (2022 dollars)



Source: ACIL Allen.

Table 2.2 summarises the estimated change in real economic output because of ARC-funded research in cumulative and NPV terms. This table also compares the investment by the Australian Government in the NCGP with the projected increase in economic output. As shown in this table, NCGP-funded research awarded between 2002 and 2021 is estimated to increase the real economic output of Australia (i.e. real GDP) by a cumulative total of $184.3 billion relative to the Base Case over the life of the benefits. This is equivalent to a one-off increase of $33.6 billion (in 2022 dollars, using a 7% real discount rate).

To place these estimated changes in economic output in perspective, the discounted present value of the change in Australian output is equivalent to the following significant changes arising from a research program:

— around 1.5% of Australia's current GDP

— almost the size of the Tasmanian economy — in 2021-22 Tasmania's GSP was $38.5 billion

— more than 8% of Western Australia's current Gross State Product (GSP, in 2021-22 WA's GSP was $40.4 billion).

The economic modelling also shows that the benefits generated by ARC-funded research are substantially higher than the costs to the Australian Government of NCGP grants awarded between 2002 and 2021.

— NCGP funding awarded between 2002 and 2021 totals $17.6 billion in 2022 dollars ($10.1 billion in present value at a 7% discount rate).

— Therefore, it is estimated that for every $1 spent by the Australian Government on the NCGP research investments awarded between 2002 and 2021, GDP is cumulatively $3.32 higher (on a 7% real discounted basis) than it would have been had that $1 instead been allocated to general government expenditure, noting that any return on investment higher than $1 is positive. While other sources of funding contributed to achieving this result, these funds were only leveraged as a result of ARC funding. As such, the ratio of GDP to funding is only presented in relation to the Australian Government funding provided through the NCGP.

— The payback period for the Australian Government investment in the NCGP in terms of economic output (GDP) is 17 years.[25]

Importantly, as discussed in chapter 4, ARC-funded research delivers a range of benefits that go beyond the direct monetised impacts included in this modelling. Examples of benefits that could not

[25] Number of years until the total accumulated GDP benefits associated with the NCGP equal the total accumulated costs to society. Any benefits that continue to accrue after this point represent a net benefit to society in the long run.

be quantified in this way include increasing the stock of useful knowledge, training skilled post-graduates (many of whom will work outside academia), developing new methodologies and forming networks for knowledge exchange. Once these (and other) non-quantified benefits of ARC-funded research are considered, it is clear that the value of the NCGP is much higher than these estimates.

Table 2.2 Estimated change in Australian real GDP from 2002–2046 associated with ARC grants awarded between 2002 and 2021 (relative to Base Case, 2022 A$m)

	Annual average	Total (2002-2046)	Net Present Value		
			3%	7%	10%
Real GDP	4,096	184,299	84,703	33,567	18,063
Australian Government funding to the ARC	706[a]	17,645[b]	13,581	10,097	8,367
Ratio of increase in GDP to government funding	5.80	10.44	6.24	**3.32**	2.16

[a] Annual average ARC funding over 2002-2026 (while the last round of grants modelled are those awarded in 2021, there are projects awarded in 2020 which will receive funding over 7 years – until 2026 – and hence the costs to the Australian Government extend from 2002-2026).

[b] Refers to ARC funding over 2002-2026 (while the last round of grants modelled are those awarded in 2021, there are projects awarded in 2020 which will receive funding over 7 years – until 2026 – and hence the costs to the Australian Government extend from 2002-2026).

Source: ACIL Allen.

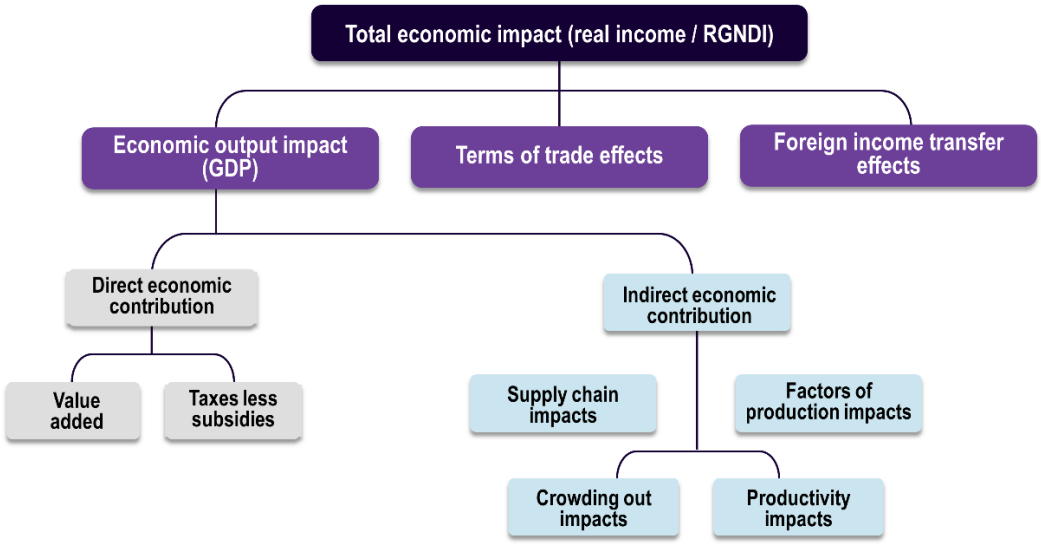
Real income impacts

Measuring the impact of a program using just real economic output (GDP) may disguise investments that are not beneficial in the overall economic welfare sense. This is because it is possible for real economic output to increase (that is, for GDP to rise) while at the same time consumers may be worse off when measured in terms of real income. In such circumstances, people and households would be worse off despite economic growth.

This leads to a preference for considering real income effects. Real income measures the ability to purchase goods and services, adjusted for inflation. A rise in real income indicates a rise in current consumption capacity and an increased ability to accumulate wealth in the form of financial and other assets. The change in real income is equal to the change in real economic output (real GDP) plus the change in international income transfers, plus the change in the nation's terms of trade (which measures the purchasing power of the nation's exports relative to its imports) (see Figure 2.6).

In global CGE models such as *Tasman Global*, the change in real income is equivalent to the change in consumer welfare using the equivalent variation measure of welfare change resulting from exogenous shocks. Hence, it is valid to say that the projected change in real income (from *Tasman Global*) is also the projected change in consumer welfare.

Figure 2.6 Macroeconomic impact of a program or policy



Source: ACIL Allen

The projected changes in real income associated with the ARC's research investments are shown in Figure 2.7 and Table 2.3. Overall, as shown in Figure 2.7, the pattern of changes in income is similar to the pattern of changes in output, but income gains are slightly lower than the change in economic output. As shown in Table 2.3, from 2021-2046, ARC-funded research is projected to increase the real income of Australia as a whole by a cumulative total of $152.5 billion relative to the Base Case.[26] This is equivalent to a one off increase in real income of $30.3 billion (in 2022 dollars, using a 7% real discount rate).

Therefore, it is estimated that for every $1 spent by the Australian Government on the NCGP research investments awarded between 2002 and 2021, real income is cumulatively $3.00 higher (on a 7% real discounted basis) than it would have been had that $1 instead been allocated to general government expenditure. While other sources of funding contributed to achieving this result, these funds were only leveraged as a result of ARC funding. As such, the ratio of GDP to funding is only presented in relation to the Australian Government funding provided through the NCGP.

To place these projected changes in income in perspective, the value today of this whole-of-life impact[27] is equivalent to a one-time increase in the average income of all current residents of Australia by approximately $1,171 per person.[28]

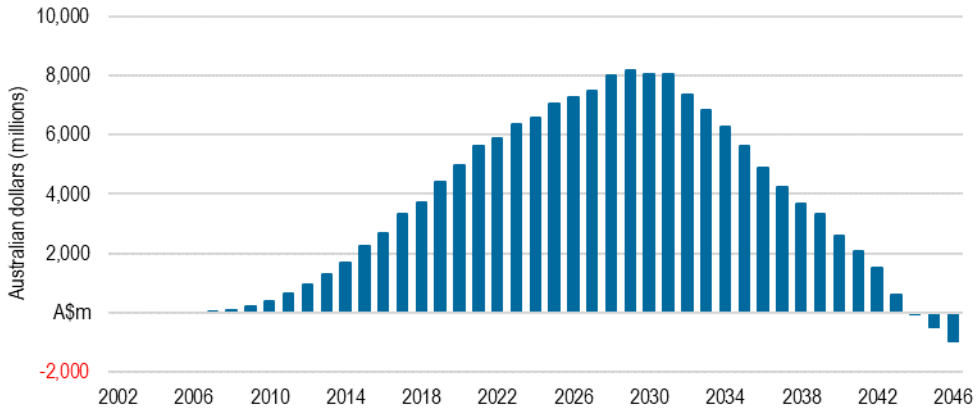
This is a sizeable increase in consumer welfare in the context of a research program.

[26] The small negatives at the end of the projection period reflect the inertia of the structural adjustments in the Australian and world economies in the previous year's driven particularly changes in capital accumulation and net foreign debt. This effect would be expected to return to zero if the simulations were continued into the future.

[27] That is, the discounted present values of the projected changes in real income using a 7% real discount rate.

[28] Figure has been calculated as NPV of real income at 7% discount ($30,327 million) divided by the total Australian population (25,890,773 persons).

Figure 2.7 Estimated change in Australian real income from 2002–2046 associated with ARC grants awarded between 2002 and 2021, relative to the Base Case (2022 dollars)



Source: ACIL Allen.

Table 2.3 Estimated change in Australian real income from 2002–2046 associated with ARC grants awarded between 2002 and 2021 (relative to the Base Case, 2022 A$m)

	Annual average	Total (2002-2046)	Net Present Value		
			3%	7%	10%
Real income	3,390	152,528	73,237	30,327	16,729
Australian Government funding to the ARC	706[a]	17,645[b]	13,581	10,097	8,367
Ratio of increase in income to government funding	4.80	8.64	5.39	**3.00**	2.00

[a] and [b] as for *Table 2.2*.

Source: ACIL Allen.

Estimated employment impacts

Employment is closely linked with economic activity and investment: as demand for a firm's goods increases, it can expand its operations and increase levels of capital and, in turn, requirements for labour change. Hence, changes in employment mirror changes in economic output.

A key issue when estimating the impact of a program is determining how the labour market will clear.[29] Increases in the demand for labour from the productivity gains enabled by ARC-funded research can be met by 3 mechanisms: increasing migration; increasing participation rates and/or average hours worked; and reducing the unemployment rate. In the model framework, the first 2 mechanisms are driven by changes in the real wages paid to workers while the third is a function of the additional labour demand relative to the Base Case. Given the moderate unemployment rate assumed throughout the projection period, changes in the real wage rate accounts for the majority of the additional labour supply in the NCGP scenario relative to the Base Case.

[29] 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 time 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, non-CGE methods tend to overestimate the impacts of a project or policy.

It should be noted that this analysis does not assume any changes in net foreign migration because of the productivity benefits generated by the ARC-funded research.[30]

The economic modelling projects that the productivity benefits generated by ARC-funded research will result in a net increase in jobs across Australia. Indeed, from 2002 to 2046, it is projected that 295,673 employee years[31] of full-time equivalent employment (FTE) direct and indirect jobs will be created in Australia under the NCGP scenario (equivalent to an annual average of 6,571 FTE jobs a year, see Table 2.4).

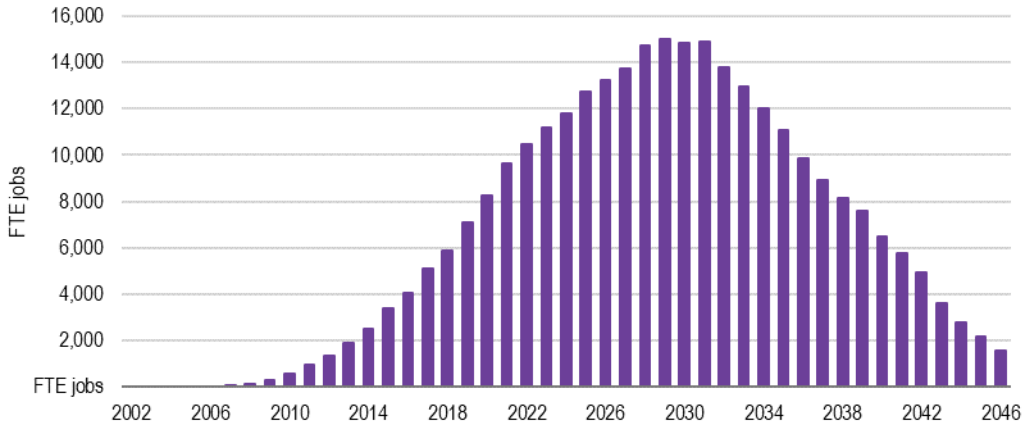
Table 2.4 Estimated change in Australian employment from 2002–2046 associated with ARC research investments from 2002 to 2021 (relative to the Base Case)

	Annual average	Total (2002-2046)
	FTE	Employee years
Australia	6,571	295,673

Source: ACIL Allen.

Figure 2.8 illustrates the profile of total additional employment in Australia under the NCGP scenario. As shown in this figure, employment associated with ARC-funded grants awarded between 2002 and 2021 is projected to peak in 2029 at around 15,000 FTE jobs.[32]

Figure 2.8 Projected change in total (direct and indirect) employment from 2002–2046 associated with ARC research investments made from 2002 and 2021 (relative to the Base Case, FTE jobs)



Source: ACIL Allen.

[30] The underlying logic for this assumption is that the NCGP does not have any significant effect on the Australian Government's immigration policy.

[31] An employee year is employment of one full time equivalent (FTE) person for one year or one 0.5 FTE person for 2 years.

[32] Final report data supports this, showing that researchers deliver economic impacts, such as increases in productivity, human capital build-up and employment. Linkage Program project researchers were more likely to report broad economic impacts compared with Discovery Program (see Figure C.2). Survey recipients report a higher proportion of projects likely to result in economic impacts, likely a result of the longer time allowed for impacts to emerge following submission of final reports.

Government revenues

Government revenues are projected to rise because of the NCGP. It is likely that some of the additional revenue will be returned to private households through slightly lower effective tax rates compared to the Base Case, while the rest will be used to provide public goods and services.

Table 2.5 summarises the anticipated total additional tax revenues projected to be generated because of the productivity gains generated through ARC-funded research. As shown in this table, the Australian Government is projected to benefit from higher revenues of around $34.3 billion from 2002-2046 relative to the Base Case. This is equivalent to a one-off increase of $6.5 billion (in 2022 dollars, using a 7% real discount rate). This includes:

— payroll taxes of around $2.2 billion

— federal personal income taxes of around $21.1 billion

— federal company income taxes of around $2 billion

— GST of around $4.4 billion.

Table 2.5 Projected change in real government tax revenues from 2002–2046 associated with ARC grants awarded between 2002 and 2021 (relative to the Base Case)

	Total (2002-2046)	Net present value		
		3%	7%	10%
State and Territory payroll taxes	2,176	1,020	416	229
Federal personal income taxes	21,059	9,776	3,920	2,125
Federal company income taxes	2,033	991	422	238
GST	4,436	2,111	865	473
Other State and Federal Government taxes	4,616	2,103	836	454
Total Australia	**34,319**	**16,003**	**6,458**	**3,520**

Note: Other State and Federal Government taxes include stamp duties, motor vehicles, gambling, insurances, excises and duties, tariffs, etc.

Source: ACIL Allen modelling.

KEQ 1. What are the short-, medium- and long-term outcomes and impacts of ARC-funded research? Is the NCGP achieving its intended outcomes?

2.2 Other economic impacts

Key Finding 2 Other economic impacts

The NCGP is delivering broad economic impacts, including commercial outcomes such as invention disclosures, patents filed, training and spin-out/spin-off companies. These directly support the intended outcomes of the Discovery and Linkage Programs. Outcomes are most likely to be experienced by the Education and Training, and Professional, Scientific and Technical Services sectors.

The case studies evidence the breadth of commercial and innovation outcomes, including commercialising and licensing technology, building innovative approaches and infrastructure, launching start-up and spin-off companies, and generating intellectual property (IP) and patents.

A range of other economic impacts associated with NCGP-funded research have been identified by survey recipients and are evident in the program data collected by ARC.

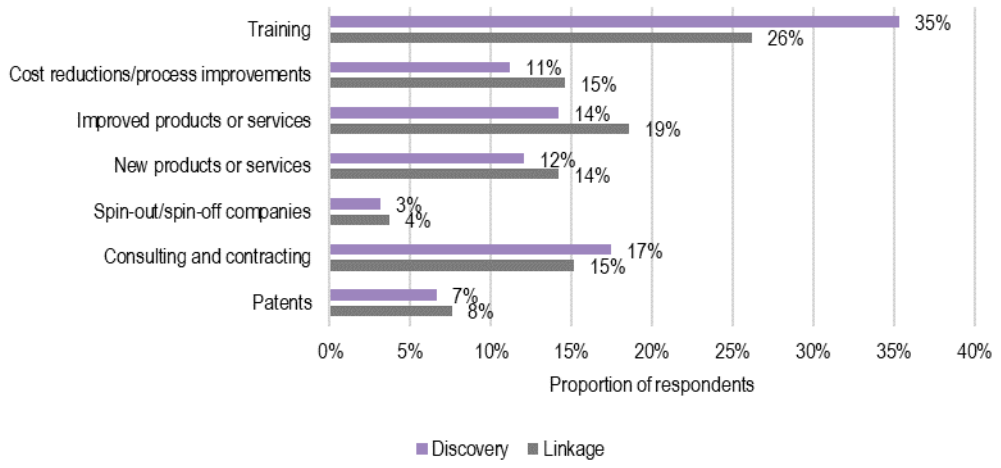
The survey results and final report data show evidence of significant commercial outcomes from NCGP research. The survey data show a higher proportion of projects reporting commercial outcomes than for final report data, likely due to the longer lag time allowed for impact to emerge (see Figure D.6 and Figure D.7). These commonly related to training, with 35% of Discovery and 26% of Linkage Program respondents reporting training outcomes (see Figure 2.9). Discovery Program projects were next most likely to report consulting and contracting (17%), and Linkage Program projects to report improved products or services (19%).

The program data shows that 216 unique start-up/spin-out companies were formed by NCGP-funded research. This equates to approximately 0.230 start-up/spin-out companies per $1 million of funding invested specifically in the projects that spun out these companies, or 0.0188 compared to the total value of ARC funding invested. This is in line with an international comparator, with SFI funding resulting in 13 start-ups in 2021, with funding of AU$362 million awarded, or 0.036 companies per $1 million of funding invested. For UKRI, 1,027 start-ups were created between 2017-21, with AU$52.3 billion of funding invested, or 0.0196 companies per $1 million of funding invested. Although this is an approximation, it shows that the ARC-funded research is leading to start-ups at a similar rate as international comparators.

Survey data also shows that 2-3 times more projects report spin-out/spin-off companies than in final report data (see Figure D.6). A total of 169 start-up/spin-off companies were formed across the survey respondents. While this may be influenced in part by the sample of researchers responding to the survey, this likely highlights the time taken for these impacts to emerge and the importance of capturing data at an appropriate time to ensure outcomes and impacts have had time to emerge.

These outcomes are most likely to be experienced by the Education and Training sector for both Discovery (22% of respondents) and Linkage (18%) Program projects, followed by Professional, Scientific and Technical Services (both 12%, see Figure B.5).

Figure 2.9 Survey results on commercial outcomes from ARC-supported projects



N= 829 Discovery Program and 640 Linkage Program respondents.

Source: ACIL Allen survey of ARC funding recipients

The case studies (see chapters 7 to 13) provide detailed narratives for how examples of excellent and innovative ARC-funded research contributes to a wide range of commercial and innovation impacts. Some examples are provided below. These examples illustrate how research funded by the NCGP delivers the intended outcomes to generate new knowledge, technologies, products and ideas (see section 1.1.1).

2.2.1 Commercialising and licensing technology

The technology developed by UTAS in the *Onshore Lobster Aquaculture* (see chapter 10) case study was licenced to Ornatas in 2018. This firm was specifically established to commercialise and use the technology to operate a commercial lobster aquaculture facility. 4 patents for feed composition and uses, and larval culture and grow-out tank design and operation have been granted or are pending.

The research described in the *Indigenous persistence in formal learning* case study (see chapter 12) leveraged student information systems and analytics to develop a bespoke platform, WillowSoft Student Success,[33] for managing student learning. Prof Nakata helped develop the platform in 2018 with industry partner WillowSoft Pty Ltd. This commercial application now supports universities in applying the TAPS (Transitional, Academic, Pastoral, Support) Strategy. A subscription license can be purchased for just over $120,000 per year. As noted on the WillowSoft website:

> *WillowSoft is the only software platform in the world to incorporate over 20 years of Australian academic research in identifying and managing the levers for Indigenous student success. This knowledge is encapsulated in the design of the assessment tools and prescriptive case plan activities.*

Quantum Computation and Communication Technology (see chapter 7) has contributed immensely to the field of quantum computing and communications in Australia and globally. CQC^{2}T's vision was to lead the world in discovering and developing quantum information technologies and ensure long-term economic and strategic benefits for Australia. With this in mind, the Centre has implemented strong policies for IP protection and commercialisation. There have been over 100 granted patents over 43 patent families in the centre-related portfolio with an additional 50 patents pending or at the Patent Cooperation Treaty phase. Furthermore, the ongoing success of CQC^{2}T has led to the development of 4 Australian quantum information companies: QuintessenceLabs, Silicon Quantum Computing, Diraq, and Aqacia.

The *Irrigation Automation* case study (see chapter 9) describes the impact of the Total Channel Control (TCC), which leverages intelligent control devices, software and communications to accurately measure and control the flow of water from the source (such as a river or reservoir) to the farm in real-time, and thus optimise performance monitoring of controllers and demand-driven network control. TCC was introduced to the market in 2002 with the initial pilot project. The solution is used by all major irrigation authorities in Australia, as well as in India, Italy, Central Asia and the United States, with site management solutions in countries such as Chile, Spain, France, New Zealand and Rwanda. The University of Melbourne jointly owns the intellectual property (IP) of many patents with Rubicon Water, including the patents associated with TCC.

2.2.2 Launching start-up and spin-off companies

Quantum Computation and Communication Technology (see chapter 7) and the ongoing success of CQC^{2}T has led to 4 Australian quantum information companies. For example, QuintessenceLabs (2007), produces encryption key and policy management products, a hardware quantum random number generator, a quantum key distribution system, and other encryption solutions. The company provides these security products to companies in Australia and the United States. Silicon Quantum Computing Pty. Ltd (SQC, 2017): Australia's first quantum computing company, focuses on atom-based quantum computing in silicon. The cross-sector start-up established with $83.7 million in funding from the Commonwealth Government, the Commonwealth Bank, Telstra, UNSW and the NSW Government. SQC is spearheading the manufacture of silicon processors at the atomic-scale and is a global leader in the race to manufacture the world's first commercial

[33] WillowSoft (2019). *WillowSoft Student Success*. Accessed February 2023: https://www.willowsoft.com.au/.

quantum computer. It has a world-class team of approximately 50 quantum scientists, engineers and technicians, and specialist equipment and globally unique laboratories at UNSW.

The *Onshore Lobster Aquaculture* case study led to the development of Ornatas Pty. Ltd. in 2018. Ornatas was specifically established to commercialise and use research to commercialise research developed by the University of Tasmania, and technology developed to operate a commercial lobster aquaculture facility. Ornatas would not exist today without the research supported by the 2 ARC grants provided under the project.

2.2.3 IP and patents

The Centre from the *Quantum Computation and Communication Technology* case study (see chapter 7) implemented strong IP protection and commercialisation policies to capture future impacts from research identified in the *Quantum Computation and Communication Technology* case study. In 2017 SQC developed the Centre's IP in silicon-based quantum computing in a commercial context. IP developed by the team at UNSW will continue to be patented and licenced to SQC. More broadly, across all nodes, the Centre continues to actively protect its IP, with 7 provisional patents supported by Centre work at University Melbourne, RMIT, Griffith University, University of Technology Sydney and ANU. The Centre has been granted over 100 patents in over 43 patent families, including techniques for developing globally unique technologies to manufacture qubits at the atomic-scale to realise the fastest two-qubit gate in silicon; lowest noise silicon devices; and highest fidelity qubits in the solid state.

Irrigation Automation (see chapter 9) demonstrates the comprehensive portfolio of 218 patents developed by Rubicon Water and the University of Melbourne, which focus on agricultural water management from dams right through to the application of water to crops.

2.2.4 Building capacity through innovative approaches

The *Aquifer Reinjection* (see chapter 8) research was the first of its kind in Australia. It was integral to the decision by the Water Corporation to develop the Groundwater Replenishment Trial (see section 3.2 for more detail). While aquifer recharge for indirect potable reuse had been undertaken overseas, this was the first application in Australia. Innovative 'marker' chemicals were also identified that could establish the effectiveness of the trial in removing contaminants: Recycled Water Quality Indicators and the Recycled Water Quality Parameters. This research also led to the construction of Australia's first full-scale Groundwater Replenishment Scheme plant, completed in July 2016 and creating more than 180 jobs. It can recharge up to 14 gigalitres of recycled water annually into groundwater supplies. It has been so successful that an additional plant was constructed in August 2022 to double the capacity to 28 gigalitres per year. When announcing the second plant, the Water Minister, Dave Kelly, stated that:

> *[WA] Water Corporation's Groundwater Replenishment Scheme is an innovative and sustainable way to recycle large volumes of water. By recharging our precious groundwater supplies through the scheme, we are able to abstract equivalent groundwater in later years, adding to Perth's drinking water supply, while reducing impacts to the environment and other water users..*[34]

[34] Water Corporation (2022). *$320m investment doubles Perth's rainfall-independent water source*. Accessed March 2023: https://www.watercorporation.com.au/About-us/Media-releases/2022/August-2022/Stage-Two-Groundwater-Replenishment-Scheme.

KEQ 1. What are the short-, medium- and long-term outcomes and impacts of ARC-funded research? Is the NCGP achieving its intended outcomes?

2.3 Case studies of excellent research that delivers quantifiable impact

Key Finding 3 Case studies of economic impact

The case studies exemplify the breadth of economic impacts delivered by NCGP-funded research. The economic impacts have and are continuing to be delivered to a range of sectors and partner types.

Economic impacts include:

- positive Benefit-Cost Ratios (BCRs) from 2.49 to 5.76
- additional income generated by Indigenous students that graduate at a higher rate as a result of the research
- quantum opportunity in Australia
- avoided costs associated with using desalination rather than groundwater recharge
- value of future lobster production
- value of water savings from reduced spills, more precise delivery of water to farmers, and the reduced operational expenditure for the water distributor from automating a previously manual system.

The absence of easily quantifiable economic impacts for some case studies demonstrates the breadth of research conducted and the need to consider and measure the full suite of research impact.

The case studies highlight the economic impact delivered by examples of excellent ARC-funded research. This impact complements the economy-wide modelling detailed in section 2.1 by illustrating how individual projects or work programs can potentially provide economic impacts that, in some instances, far outweigh the costs of funding research.

These examples directly contribute to the intended outcomes of the Discovery and Linkage Program to support the creation of jobs and economic growth (see section 1.1.1).

As part of this study, CBA was undertaken for 5 case studies. CBA was used to estimate the NPV and BCR of individual or multiple projects funded by a mixture of the Discovery and Linkage Program schemes.

The results of these CBAs are summarised in Table 2.6. The CBA results show that in all cases, NPV is positive, and the BCRs are well above one. They also show how broad support for excellent research by individuals, small teams, Centres, and partner organisations (across academic disciplines) can benefit the Australian economy. They are just a small snapshot of the types of impacts that some ARC-funded projects have delivered over the past 2 decades.

A brief discussion of the costs and benefits underpinning these estimates is provided in Table 2.6. Further discussion on the methodology and assumptions of the case studies are provided in each case study in Part II.

Table 2.6 Summary of case study CBAs (NPV and BCR at the 7% discount rate)

Case study	Grants	Present Value Costs	Present Value Benefits	Estimated NPV (million)	BCR
Indigenous Persistence in Formal Learning	DP, DI, 2xCE, LE (only DI modelled)	$71.3 million ARC-funded research costs, and the higher education expenses of the Indigenous students supported by the program	$176.5 million Additional income generated by the Indigenous students who graduated as a result of the program and experienced higher income	**$105.2**	**2.48**
Quantum Computation and Communication Technology	3xCE, 4xFL, LE (all modelled)	$4637.7 million ARC-funded research costs	$2.9 billion Quantum computing, quantum communications and quantum sensing and measurement opportunity in Australia that can be attributed to the ARC-funded research	**$2,231.3**	**4.50**
Aquifer Reinjection	LE, 2xLP (all modelled)	$13.6 million ARC-funded research costs	$78.1 million Costs avoided by Water Corporation that would have been associated with utilising desalination over aquifer reinjection	**$64.5**	**5.76**
Onshore Lobster Aquaculture	2xIH (all modelled)	$96.7 million ARC-funded research costs, Ornatas' capital and operational expenditure involved in lobster production	$297.7 million Value of future lobster production	**$201.1**	**3.08**
Irrigation Automation	5xLP (all modelled)	$4.9 billion (not attributed)[1] ARC-funded research costs, and Golden Murray Water Connections Project capital expenditure costs to upgrade the irrigation network (VIC and Australian Government funded)	$14.6 billion (not attributed)[1] Value of the water savings and reduced operational expenditure for the water distributor from automating a previously manual system	**$9,659.0** (not attributed)[1]	**2.94**

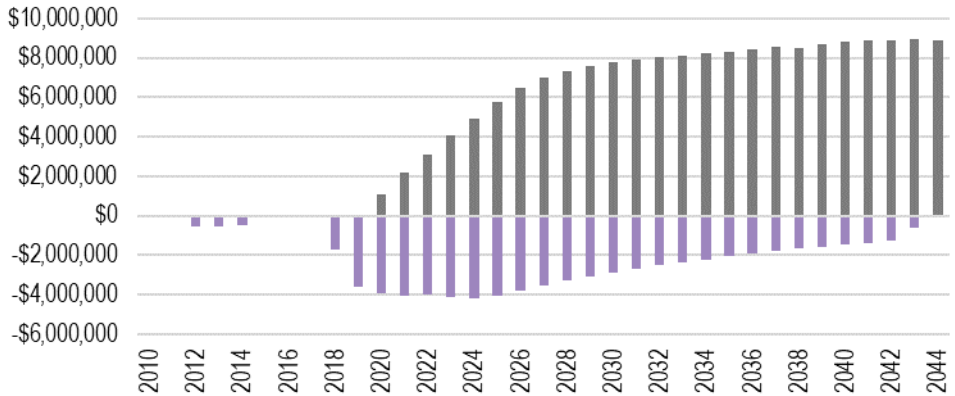
[1]Note that the Irrigation Automation CBA is not attributed to the ARC due to commercial sensitivities. See case study in Part II for further information.

Source: ACIL Allen

The case studies also identify a range of potential economic and financial impacts associated with different types of research funded by the ARC. These impacts have been analysed qualitatively and are described in detail in Part II of this report.

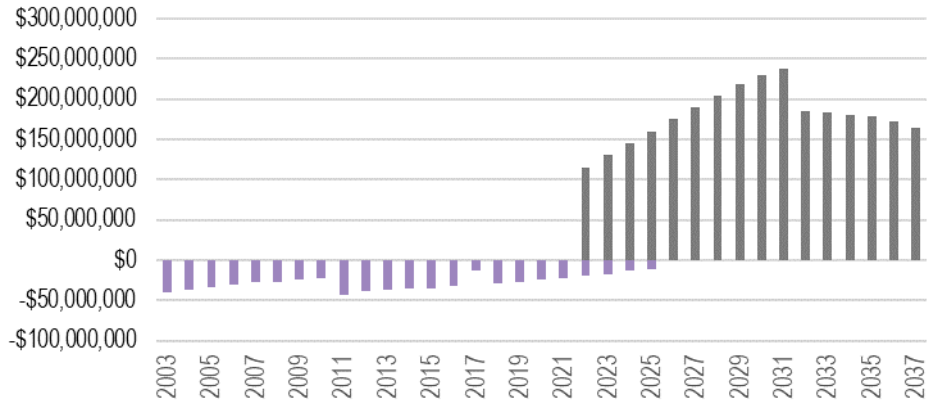
Figure 2.10 Present value costs and benefits by year (7% DR) Legend: PV costs PV benefits

Indigenous Persistence in Formal Learning



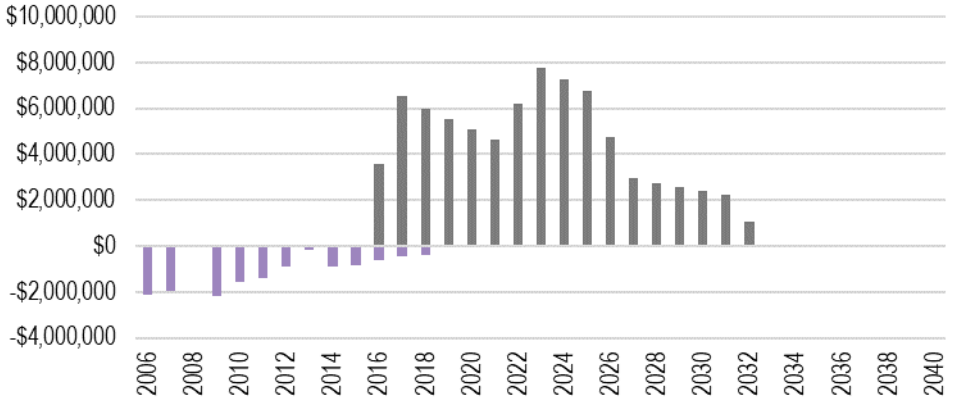
The analysis period (2010 to 2044), with ARC funding between 2012-14 and the bulk of costs from educational expenses, from 2018-43. The benefits of additional income to the university graduates begin to flow in 2020 and steadily increase each year as their income increases over their career and more indigenous learners graduate from university.

Quantum Computation and Communication



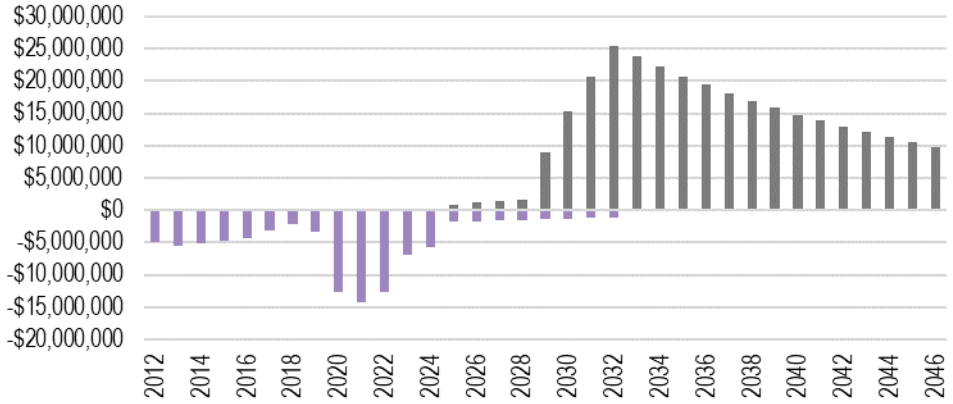
The analysis period (2003 to 2037), with ARC funding between 2003-025. The benefits of the estimated quantum opportunity to Australia attributable to ARC begin to flow from 2022 and are reduced from 2032, noting that this is when benefits have been assumed to start flowing under the counterfactual case (i.e. in the scenario where ARC did not provide funding).

Aquifer Reinjection



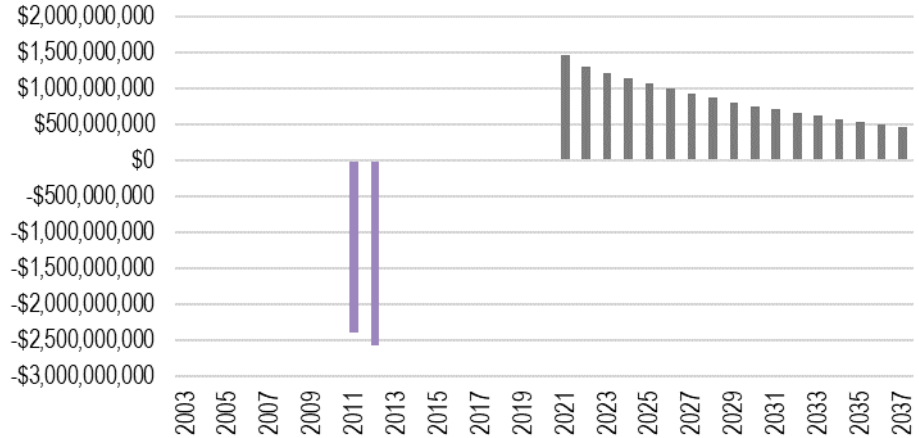
The analysis period (2006 to 2040), with ARC funding between 2006-18. The benefits from using aquifer reinjection over desalination begin to flow from 2016 (7GL treated in 2016, 14GL from 2017-2021, 21GL in 2022 and 28GL from 2023-25). Benefits begin to fall from 2026, noting that this is when benefits have been assumed to start flowing under the counterfactual case. Benefits that can be counted in the analysis are reduced from 2026 until they reach zero in 2032.

Lobster Aquaculture



The analysis period (2012 to 2046), with ARC funding between 2012-24 and Ornatas's costs occurring between 2020-32. The benefits of the value of lobster production begin to flow in 2025 and steadily ramp up with production capacity to 2032. Benefits begin to fall in 2033 because the production peaks at 1000 tonnes of lobster, and future benefits erode over time due to discounting.

Irrigation Automation



The analysis period (2003 to 2037), with ARC funding for the Total Channel Control algorithm research between 2003-24 (not visible in the chart due to the magnitude of other costs and benefits). The bulk of costs from the capital expenditure on the Connections Project, from 2011-12. The benefits of the reduced operational expenditure began in 2013 following installation of initial automated infrastructure. The benefits of water savings begin in 2021, following the release of audited water savings amounts of 433 gigalitres per annum. The benefits flow until the end of the analysis period and decrease over this time due to discounting.

Source: ACIL Allen, various Legend: PV costs PV benefits

Broader impacts of NCGP-funded research 3

This chapter presents the impacts delivered to research capacity and capability, society, the environment and culture.

Contribution to the stock of knowledge and the longer-term research capability of Australia as well as to society, culture and the environment are core purposes of the NCGP. The NCGP-funded research impacts below have been delivered to a broad range of beneficiaries and end-users, which vary based on the nature of the research and include government, research, industry, business and non-profit sectors. Further detail is provided in Appendix B. It is challenging to articulate at an aggregate level the impacts delivered to specific sectors and end-users, the involvement of end-users, and how this involvement has influenced research impacts. This information is more meaningful at the individual project level, as evidenced by the insights from the case studies throughout this chapter.

KEQ 1. What are the short-, medium- and long-term outcomes and impacts of ARC-funded research? Is the NCGP achieving its intended outcomes?

3.1 Contribution to knowledge, research and research capability

Key Finding 4 Contribution to research capacity and capability

NCGP-funded research projects contributed to the stock of knowledge, producing almost 400,000 outputs across a number of publication types. This is exemplified by the case studies in terms of publications, monitoring indicators and training materials. While beyond the scope of this project, a citation impact analysis of ARC supported publications would support an understanding of the impact delivered through these publications.

The Discovery and Linkage Programs have delivered research capacity impacts by enabling new research directions, research training (e.g. researchers and graduates) and new partnerships (in Australia and internationally). This is helping to inform further excellent research, support a strong and sustainable research workforce and promote the adoption and translation of research by industry and others.

Overall, the NCGP supports significant collaboration across research, industry, government and community sectors. Linkage Program projects have more CIs and PIs on average, in line with the requirement for end-user engagement in some schemes.

From 2002-21, participating organisations made a total of $7.9 billion cash and $9 billion in-kind contributions to NCGP-funded projects ($1.23 per $1 of ARC funding), demonstrating significant leveraging of additional resources to support Australian research. The largest contributions were made to projects in the Biological Sciences, Engineering and Physical Sciences FoRs, and by participating organisations in Australia.

ARC grants increase research capacity by supporting students and researchers to participate in excellent projects with world-class research leaders. A proportion of these researchers go on to be employed in different sectors, boosting the capacity of Australia's innovation system.

The case studies demonstrate the breadth of collaboration, education, and training stimulated by NCGP-funded research. This includes:

- 253 honours, 398 PhD students, 87 Masters and 52 postdoctoral fellows that were/will be trained
- working with communities and community organisations to engage with research beneficiaries, partnering with peak bodies and training providers to translate research, collaborating with researchers in Australia and internationally to broaden the scope of the research, and working with government and industry to focus the research outputs on critical issues.

Contribution to the stock of knowledge and the longer-term research capability of Australia are core purposes of the NCGP. Most survey respondents agreed or strongly agreed that NCGP's primary roles were to generate new knowledge (95%), and foster new technologies, products and ideas (86%), which is consistent (see Figure C.1) with qualitative analysis of survey free text responses highlighting the importance of NCGP-funded research in generating ***knowledge*** and ***understanding***. The words ***new*** (23), ***fundamental*** (14), and ***scientific*** (9) frequently preceded "knowledge", and education and training of scientists, researchers, and students in survey responses.

As the evidence shows below, both the Discovery and Linkage programs play a key role in supporting these types of impact.

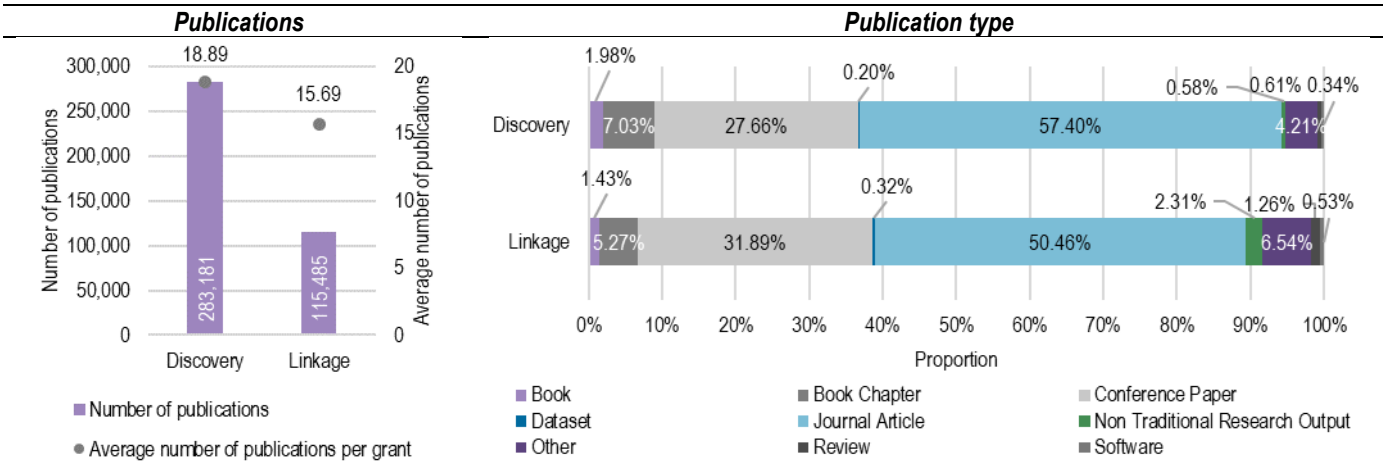
3.1.1 Contribution to the stock of knowledge

Figure 3.1 shows the total and average number of publications reported in final reports (left chart) and the type of publication (right chart). Discovery Program projects reported a higher total (283,181) and average (18.89 per project) number of publications compared with Linkage Program projects (115,485 and 15.69, respectively). This is likely an underestimate of the total publications produced by NCGP-funded research, as not all final reports for grants between 2002-2021 have been completed and publications may have been made after final reports were submitted.

The distribution of publication type reported was similar between the 2 Programs, with most publications reported to be journal articles (57% of publications for Discovery and 50% for Linkage Program), followed by conference papers (28% and 32%).

While beyond the scope of this project, a citation impact analysis of ARC supported publications would support an understanding of the impact delivered through these publications.

Figure 3.1 Final report data on the total and average number of publications by Discovery and Linkage Programs



N=22,350 final reports

2 reports were excluded (LP0219732 – 620,307 total outputs and LP0561117 – 3,131,390 total outputs) due to a possible data error.

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

The case studies provide examples of the outputs produced by excellent NCGP-funded research.

Quantum Computation and Communication Technology (see chapter 7) track record of publications exemplifies its contribution to the field and the breadth of its contribution to the academic sector. Since 2000, the Centre has published more than 2,133 papers. In the past 12 years, the Centre published 176 papers in the Nature and Science suite of journals, averaging 15 papers per year with more than one article a month for over a decade.

Aquifer Reinjection (see chapter 8) developed indicators for the monitoring of trial water recycling plants, which continue to be used by the Water Corporation.

Both *Changing the law to protect survivors of DFV* (see chapter 11) and *RRR: Indigenous Remains Repatriation* (see chapter 13) led to the development of education and training materials. A key output of *Changing the law to protect survivors of DFV* was the National DFV Bench Book, a centralised resource that aims to harmonise the treatment of DFV issues across jurisdictions, guide legal professionals through the sensitivities and complexities of DFV and assist with decision-making and judgement writing processes.[35] The DFV Bench Book has been used as a resource for first-year law students at the Australian National University (ANU), the University of Melbourne, the University of Southern Queensland and University of Technology Sydney.

RRR: Indigenous Remains Repatriation (see chapter 13) led to a masters and professional development course at ANU. *Indigenous persistence in formal learning* (see chapter 12) led to the development of WillowSoft software, which aids in identifying and managing the levers for Indigenous student success.

The case studies also produced several commercial outputs, as discussed in section 2.2.

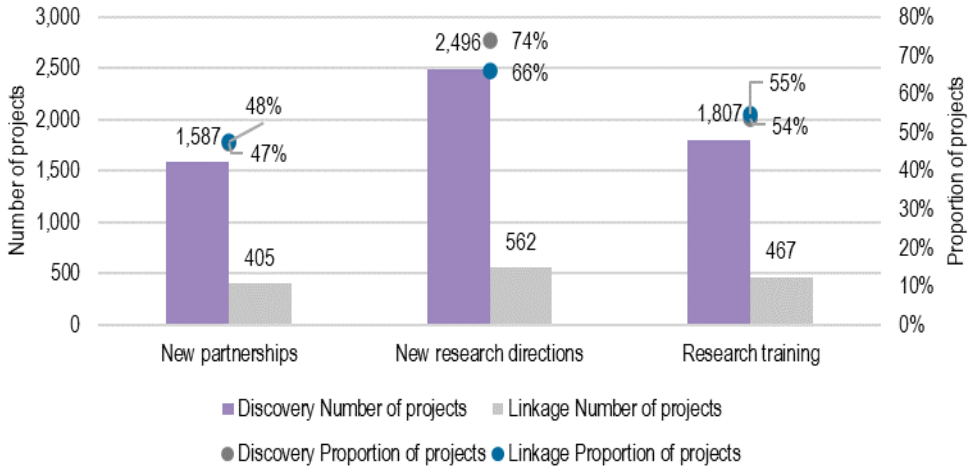
3.1.2 Contribution to research capacity and capability

Research capability focuses on workforce development, such as educating and training students and upskilling researchers, as well as researcher collaboration and network development. These capability improvements support the development of a more highly skilled workforce, create jobs, enable knowledge transfer, and foster innovation. This directly aligns with the intended outcomes of the Discovery and Linkage Programs (see section 1.1.1).

Final report data shows that the proportion of projects that reported delivering research capacity impacts is comparable for Discovery (81%) and Linkage (77%) Programs (see Figure C.2). Figure 3.2 shows that most Discovery and Linkage Program projects delivered research capacity impact by enabling new research directions (74% and 66%, respectively), followed by research training (55% and 54%) and new partnerships (48% and 47%).

[35] National Domestic and Family Violence Bench Book (2022). *Understanding domestic and family violence*. Accessed January 2023: https://dfvbenchbook.aija.org.au/contents.

Figure 3.2 Final report data on research capacity impacts by Discovery and Linkage Programs



N=4,221 final reports

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

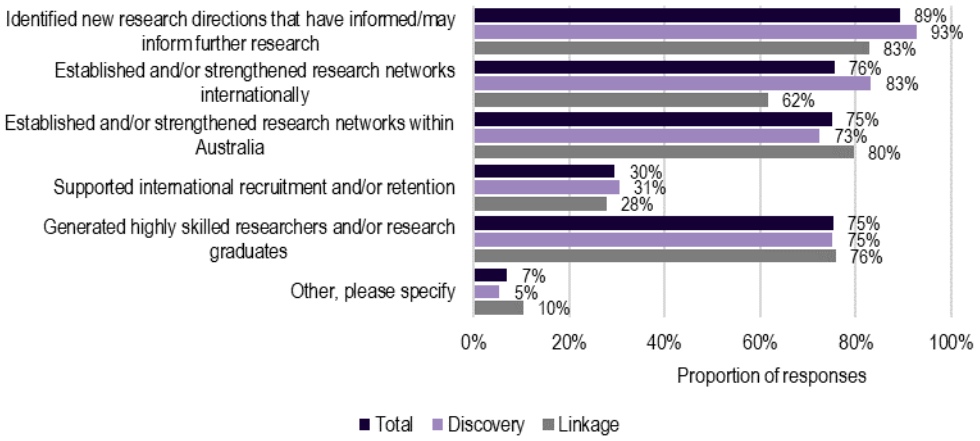
These findings are supported by the survey results, which, unsurprisingly, show higher proportions of projects leading to these impacts, likely due to the lag time for these to emerge (see Figure 3.3).

Survey respondents commonly reported that their projects increased research capacity by identifying new research directions that have informed/may inform further research (89% on average, 93% of Discovery and 83% of Linkage program respondents, see Figure 3.3). This may suggest that researchers consider their impacts are indirect and are more likely to deliver impact by contributing to knowledge or progressing their research towards a pathway to impact, rather than (or in addition to) delivering direct impacts.

Overall, survey respondents most commonly reported that their research had established and/or strengthened research networks internationally (76%) and within Australia (75%), and generated highly skilled researchers and/or research graduates (75%). Discovery Program respondents were more likely to report that their research had established and/or strengthened research networks internationally than Linkage Program respondents (83% and 62%, respectively). While Linkage Program respondents more commonly reported having established and/or strengthened research networks in Australia compared with Discovery Program respondents (80% and 73%, respectively). Respondents from both Programs commonly reported that their research generated highly skilled researchers and/or research graduates.

In free text responses, few respondents identified other ways their research had increased research capacity, including ***building Indigenous research capacity*** and ***supporting Indigenous communities*** (18), ***influencing policy*** (13), ***improving industry partner networks*** (12), ***increasing industry research capacity*** (12), ***building new and improved research infrastructure*** (11), ***improving industry standards*** (7), and ***advancing Australia's position in the FoR*** (4), noting that some of these themes are more related to social impact.

Figure 3.3 Survey results on the likelihood of research resulting in increased research capacity



N=3,849

Source: ACIL Allen survey of ARC funding recipients

Qualitative analysis of survey free text responses on the most significant impacts resulting from research projects highlights the importance of NCGP-funded research in delivering research capacity impacts. Improved ***understanding*** (411) and ***new knowledge*** (62) were frequently identified (see Table C.2), as well as support provided for ***PhD students*** (37) and ***early career researchers*** (10).

3.1.3 Increased collaboration and networking

There is a breadth of collaboration occurring on NCGP-funded research. This collaboration enables knowledge generation and transfer and builds workforce capability.

One measure of collaboration is the breadth and diversity of researchers involved in the projects. From 2002-21, a total of 74,971 CIs and 25,696 PIs were involved in NCGP-funded research projects (see Figure 3.4, left chart). The Linkage Program, compared with the Discovery Program, had the largest number of CIs (39,002 and 35,969, respectively) and PIs (16,126 and 9,570, respectively) and the largest average number of CIs (4.2 and 1.8, respectively) and PIs (1.8 and 0.5, respectively) per grant. This aligns with end-user engagement requirements in some Linkage Program schemes (see Table D.1) and the breadth and diversity of skills required to progress research toward an end-user and market-ready stage.

Another measure of collaboration is the number and diversity of participating organisations involved in NCGP projects. There have been 63,515 organisation participations on NCGP grants awarded between 2002-21 (see Figure D.3). 60% of participations were from Higher Education Funding Act Organisations (primarily Australian universities), the most common participating organisation type, followed by international higher education organisations (10%), Australian companies (7%), and State and Local Government (7%).

Information from a selection of Linkage Program schemes shows the value delivered to partners, with 95% finding the schemes to be very beneficial or beneficial (see Figure D.8).

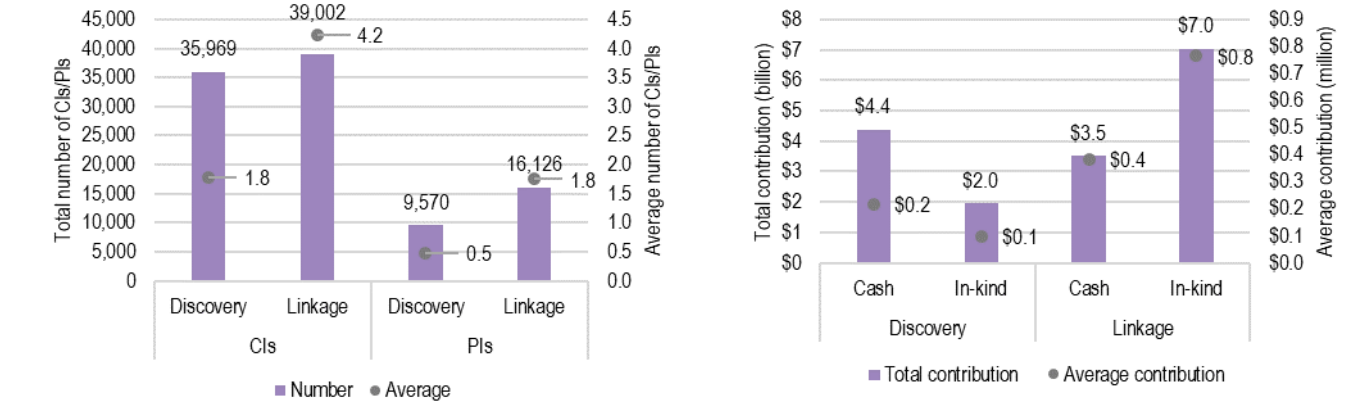
From 2002-21, $4.4 billion in cash and $2.0 billion in-kind contributions from participating organisations were made to Discovery Program projects. $3.5 billion in cash and $7.0 billion in-kind contributions were made to Linkage Program projects (see Figure 3.4, right chart). The average value of cash contributions is higher for Linkage compared with Discovery Program projects ($0.4 million and $0.2 million, respectively), but the value of in-kind is higher for the Linkage

Program compared with the Discovery Program ($0.8 million and $0.1 million, respectively).[36] The NCGP overall leveraged $0.76 in cash and in-kind contributions per $1 of ARC funding for Discovery Program, and $1.97 in cash and in-kind contributions per $1 of ARC funding for Linkage Program. Overall, the ratio was $1.23 per $1 of ARC funding.

These co-contributions have varied slightly over time (see Figure D.9), which has broadly aligned with the quantum of funding provided by the ARC (as discussed in section 1.2). In-kind contributions to Discovery Program projects were negligible before 2015. This reflects that in-kind contributions were not recorded for most Discovery Program scheme applications (i.e. DE, FT, and FL), while DP and IN only began recording in-kind contributions since 2015.

When examined by FoR, as for the distribution of ARC funding, the largest cash and in-kind contributions to both Discovery and Linkage Program projects were made to research in the Biological Sciences, Engineering and Physical Sciences FoRs (see Figure D.10). This likely reflects the requirement for co-contributions across a range of ARC schemes (see Table D.1), and that more ARC funding is likely to leverage more co-contributions for the same project (in its FoR).

Figure 3.4 Funding data on the total and average number of CIs and PIs, and value of cash and in-kind contributions made by participating organisations, by Discovery and Linkage Program



N=29,303 projects

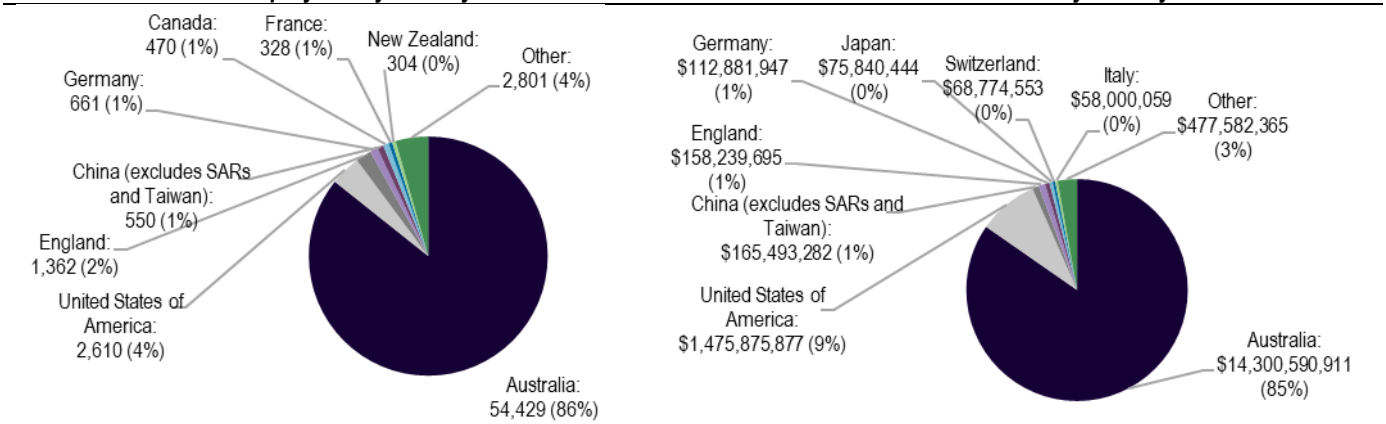
Contributions are from participating organisations. CE11 data is not available. For DE, FL (except FL10) and FT only cash contributions (no in-kind) can be entered into the application form for Administering Organisations. In-kind contributions were not recorded for most Discovery Program scheme applications. DE, FT, and FL do not record in-kind contribution, DP and IN only record in-kind contributions since 2015. Therefore, in-kind funding is not recorded for these schemes.

Source: ACIL Allen's analysis of ARC funding data for grants awarded between 2002 and 2021.

Figure 3.5 shows the top 10 countries where participating organisations were most commonly headquartered by number (left chart) and value of co-contribution (cash and in-kind) (right chart). Australia accounted for most projects (86%, 54,429) and co-contributions (85%, $14.3 billion). The United States (4%, 2,610) and England (2%, 1,362) had the second-highest number of projects. The next largest co-contributors were in the United States (9%, $1.47 billion).

[36] In-kind contributions were not recorded for most Discovery Program scheme applications. DE, FT, and FL do not record in-kind contributions, DP and IN only began recording in-kind contributions since 2015.

Figure 3.5 Final report data on the location of and total contribution (cash and in-kind) made by participating organisations



N=22,352 final reports

Note: funding amounts are in current dollars (i.e. the value of the funding allocated in the award year, as reported in the final report).

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

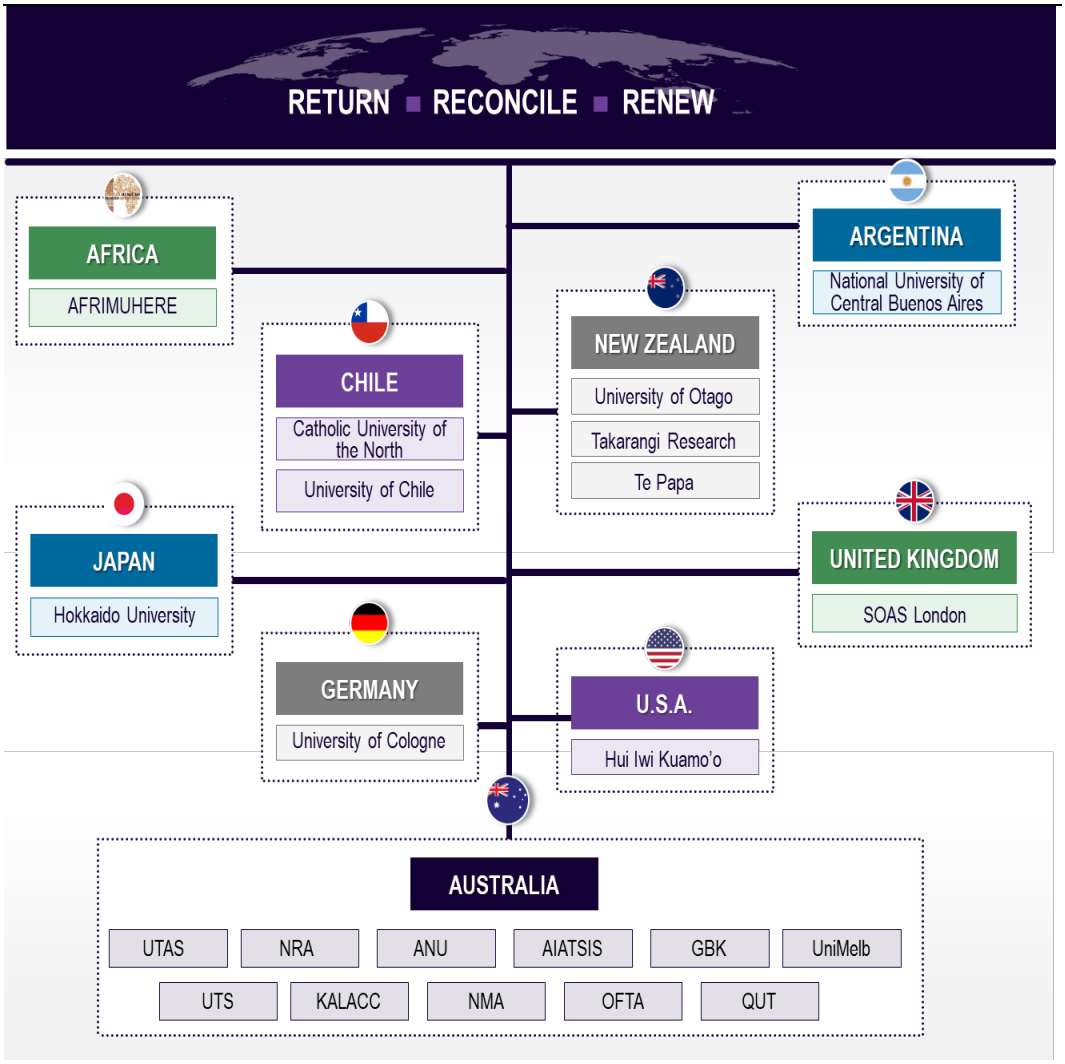
Examples of excellent research delivering collaboration

The case studies highlight examples of excellent NCGP-funded research contributing to collaboration and research capability impacts.

Changing the law to protect survivors of DFV (see chapter 11) involved collaboration with a broad range of researchers working in related fields in Australia and internationally. DFV support services were close partners in supporting connections with women experiencing DFV and ensuring they were supported throughout the research. This also involved a partnership with the AIJA and NJC to develop and extend the research into end-user-focused products. For example, the DFV Bench Book was developed with AIJA (see section 3.1). Training courses for judges, magistrates and tribunal members were developed with NJC based on the Bench Book.

RRR: Indigenous Remains Repatriation (see chapter 13) involved major multi-sector collaborative partnerships between researchers, institutions, governments and community, in Australia and internationally. The research involved significant collaboration through the Indigenous community partners, including founding partners Ngarrindjeri Regional Authority (NRA), Kimberley Aboriginal Law and Culture Centre (KALACC) and the Gur A Baradharaw Kod Sea and Land Council Torres Strait Islander Corporation (GBK). Figure 3.6 is a visual representation of the core RRR network, which is comprised of more than 30 researchers and collaborators across 22 universities and organisations. This network spans more than 10 countries around the world. Since the original Linkage Project for this body of research in 2013, repatriation activity has grown, and partnerships in the sector have strengthened.

Figure 3.6 Core network of professionals, practitioners and communities connected to RRR



Source: ANU

Quantum Computation and Communication Technology's (see chapter 7) Centre for Quantum Computing Technology was started in 2000 when researchers across the globe established a program in silicon quantum computing that combined with the nascent optical quantum computing programs led by Gerard Milburn and Michael Nielsen at the University of Queensland. The highly successful research results and rapid development of the technology and a series of CEs in quantum physics across Australia (CQC^{2}T, Engineered Quantum Systems (EQUS), Exciton Science, Future Low-Energy Electronics Technologies (FLEET), Quantum Biotechnology and Gravitational Wave Discovery) demonstrating Australian strength in this field. Prof Simmons (Director of CQC^{2}T) established a unique corporate-Government-University consortium to help quantum computing technologies cross the well-known "Valley of Death". The Centre is one of the key reasons for Australia's strong capability in quantum science and technology.

Onshore Lobster Aquaculture (see chapter 10) strengthened collaboration between UTAS, PFG Australia and Ornatas. This ongoing collaboration focuses on commercialising earlier research results. UTAS also collaborated with other universities. For example, the University of the Sunshine Coast researched lobster genetics to develop ways of producing sterile stock and developing all-male populations (male lobsters grow faster and are quicker to market).

3.1.4 Supporting research training

Education and training are essential to research capability development. NCGP-funded research specifically aims to build research capability by training researchers at various career stages, thus contributing to new jobs and increased research and innovation capacity (see section 1.1.1).

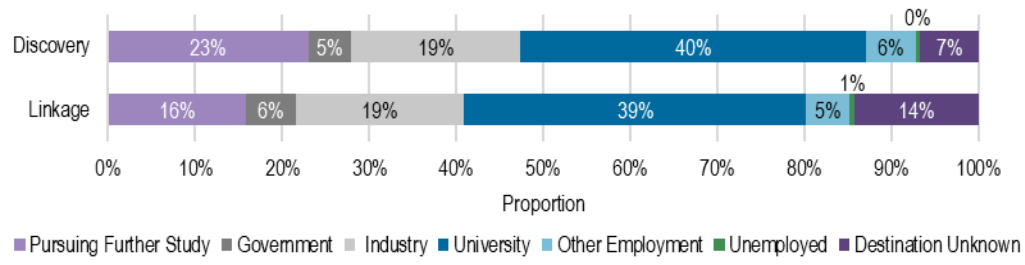
Figure 3.7 shows the destinations of students (top chart) and postdoctoral researchers and fellows (bottom chart) involved in NCGP-funded research. Most capacity development for students leads to their employment in the university sector. Most students from Discovery Program projects were employed at universities (40%) or pursued further study (23%). Students from Linkage Program projects were most employed by universities (39%) then industry (19%).

Among postdoctoral researchers involved in NCGP-funded projects with available employment destination data, most went on to be employed by other universities (28%), overseas organisations (20%) and administering organisations (18%), noting that data were only recorded for some Linkage Program schemes, and does not include LP, which has the largest number of grants. Fellows were most commonly employed by the administering organisation (75%). This highlights the broader diversity of employment outcomes for Linkage Program postdoctoral researchers, potentially due to more engagement with Participating Organisations. While the NCGP plays a clear role in training for academic and university sector, there is an opportunity to enhance the contribution of researchers to private industry, government and NGOs.

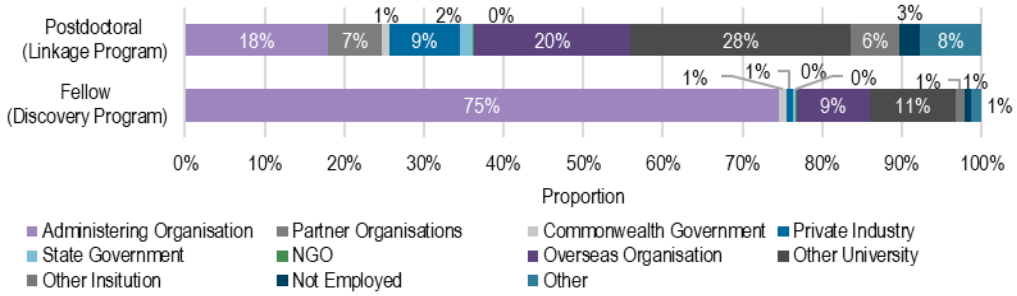
In addition to commenting on economic, societal, cultural and environmental impacts, survey respondents were asked to identify other impacts that had or were likely to be delivered by the projects. Most Discovery (61% of respondents) and Linkage (70%) Program respondents reported that the projects will not or are unlikely to result in other impacts (see Figure C.2). Among the respondents that reported their research may, is likely to or had produced other impacts, these related to education and training (11), policy and law (5), and capacity increase within industry (5).

Figure 3.7 Final report data on student (Masters and PhD) and postdoctoral and fellow destinations

Student destination



Postdoctoral and Fellow destination



N=4,221 for students, N=46 for postdoctoral researchers, and N=1,108 for fellows. Note all postdocs were involved in Linkage Program projects (CE, IC, IH and SR), all fellows were involved in Discovery Program projects (DE, FL, FT and IN).

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

Examples of excellent research delivering innovation system capacity

The case studies highlight examples of excellent NCGP-funded research contributing to education and training impacts. In total, 253 honours, 398 PhD students, 87 Masters and 52 postdoctoral fellows were and will be trained across the 7 case studies. The case studies also demonstrate an ongoing commitment to educate and train the next generation of researchers and support students in research careers. This includes:

— *Quantum Computation and Communication Technology* (see chapter 7) has had a significant impact on research capability. Since 2000, 275 PhD, 65 Master students and 229 Honours have graduated or worked with various CEs. Many students obtain a first-Class Honours degree or win the University Medal. 8 researchers have won the Bragg Medal for the best PhD in physics since 1995. Each year the Centre holds a full-day workshop at UNSW, attracting approximately 200 primary and high school students to tour the facilities and see research in action. The Centre focuses on increasing the number of girls and women in STEM, engaging with them from primary through secondary school and through to our research leaders.

— *Onshore Lobster Aquaculture* (see chapter 10) has trained 26 PhD students.

— *Aquifer Reinjection* (see chapter 8) trained 2 PhD students who specifically worked on the water recycling research, and both are currently writing their theses and working full-time in industry. Of the other PhD graduates from the Curtin Water Quality Research Centre, 2 are employed by the Water Corporation, 2 by consulting engineering firms, 3 by commercial analytical laboratories, and 5 in postdoctoral fellowships/academia. The Centre has provided a steady supply of graduates contributing their expertise to the operations of different businesses and carrying out further research..[37]

KEQ 1. What are the short-, medium- and long-term outcomes and impacts of ARC-funded research? Is the NCGP achieving its intended outcomes?

3.2 Social impacts

Key Finding 5 Contribution to society

NCGP-funded research has produced broad social impacts, including improved health and wellbeing, informed decision-making, improved safety and security, and reduced social problems.

The Linkage Program has been reported to deliver more social impacts, likely due to the more applied nature of the research.

Case studies highlight significant contributions to social impacts, including supporting stronger community engagement and entitlements, improving wellbeing and quality of life, improving the accuracy, responsiveness and efficiency of the legal and justice system, reducing pain and suffering, and enhancing community wellbeing and advancing reconciliation.

Contribution to society is a core purpose of the NCGP and aligns with the intended outcomes of developing new technologies, products and ideas, creating jobs, growing the economy and enhancing the quality of life in Australia (see section 1.1.1). As overviewed in Figure 2.1, this includes, for example, improved health and wellbeing; access to resources, opportunities, jobs, infrastructure and services; community resilience; and safety (see case studies from page 158 onwards).

[37] In addition, many Honours and Bachelor Chemistry graduates have been employed at WAWC over the years.

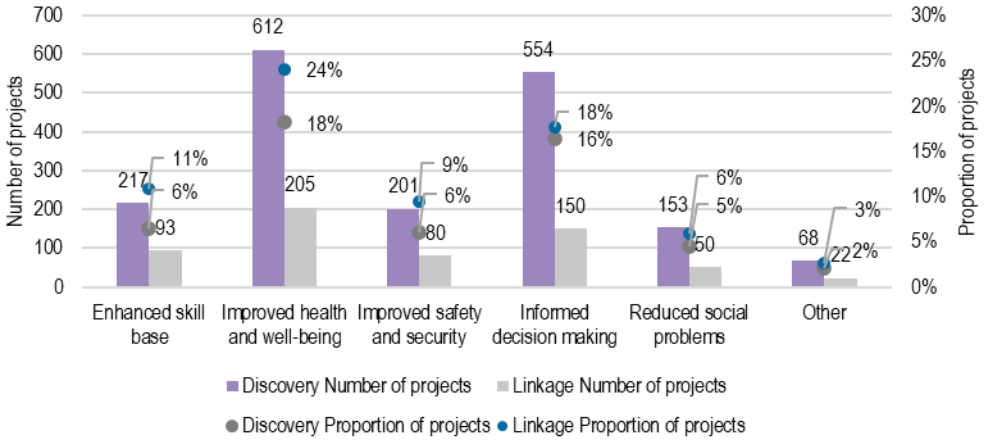
As the evidence shows below, both the Discovery and Linkage programs play a key role in supporting these types of impact, noting that this is only a small proportion of the potential impact delivered by the NCGP. This could be documented with additional evidence and a systematic assessment framework (see chapter 5).

3.2.1 Evidence of social impact

Most survey respondents from the Linkage (79%) and Discovery (72%) programs reported that their projects may, will likely or had already produced social impacts (see Figure C.2). As expected, more Linkage Program respondents reported societal impacts, likely due to the more applied nature of the research.

This is also the case for more detailed social impacts (see Figure 3.8), with both Discovery and Linkage Program projects commonly reporting contributing to improved health and wellbeing and informed decision-making. Other impacts included an enhanced skill base, improved safety and security, reduced social problems and others. The proportion of projects reporting detailed social impacts was similar across the Discovery and Linkage Programs for most impact types. However, Linkage Program projects more commonly led to improved health and wellbeing than Discovery Program grants (24% and 18%, respectively). Again, this is to be expected due to the more applied nature of the research.

Figure 3.8 Final report data on social impacts by Discovery and Linkage Programs



N=4,221

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

3.2.2 Examples of excellent research delivering social impacts

The case studies highlight examples of how excellent NCGP-funded research contributes to society and delivers a social impact that is far-reaching. This is directly enhancing the quality of life in Australia a key purpose of the NCGP.

The *Irrigation Automation* case study (see chapter 9) led to the successful recovery of over 429 gigalitres through Australia's largest irrigation modernisation project to date, the Connections Project.[38] Under the project, water allocation was committed to irrigators, the environment, the Melbourne retail water corporations, and Traditional Owners. This was the first time that Traditional Owners in northern Victoria received a water entitlement as part of the Government's commitment

[38] The Hon Lisa Neville MP (2022). *Successful Connections Project Delivers Extra Water*. Available online at: https://www.premier.vic.gov.au/successful-connections-project-delivers-extra-water.

to Indigenous values and aspirations for water. By reducing the time required for manual watering and improving farmer's capability and capacity, the irrigation technology provides peace of mind, a better lifestyle, and longevity for farmers on their properties. This has led to improved farmer wellbeing and quality of life.

Changing the law to protect survivors of DFV (see chapter 11) has supported fundamental changes in the way government, the legal and justice systems, and society understand and respond to DFV. This research ultimately aims to improve the accuracy, responsiveness and efficiency of the legal system in the context of DFV. This research significantly influenced the introduction of a non-fatal strangulation law in Queensland in 2016, the first in Australia. In 2019, a similar law was introduced in South Australia, which had clear parallels to and was modelled from the Queensland law. As noted in section 3.1.1, the research resulted in the development of the DFV Bench Book, which has been highly impactful in informing and guiding legal professionals through the complexities of DFV.

RRR: Indigenous Remains Repatriation (see chapter 13) established the RRR Archive, website and global network of repatriation scholars, practitioners and communities. The RRR Archive is a web-accessible, centralised digital database of repatriation knowledge that can be shared sensitively and appropriately. The research has been particularly impactful for the community partners involved in the research, the NRA, KALACC and GBK. The removal of ancestors has caused significant and lasting pain to these communities. Repatriation represents a declaration of respect for their ancestors and cultural beliefs, and combines a number of factors that are integral to healing and wellbeing, including nation building, cultural governance, identity and knowledge building.[39] Informing and enabling future repatriation, and reducing the time taken to repatriate remains has reduced the associated pain, suffering and trauma for individuals and communities involved in repatriation. With continued support and expansion, RRR has the potential to influence the healing and wellbeing of other communities in Australia and overseas. The RRR Archive may also become a critical evidence base and an important underpinning digital infrastructure that supports a future 'National Resting Place' in Canberra. This would house and provide long-term care for remains that are returned from overseas with limited-provenance and thus cannot be specifically repatriated to Indigenous lands within Australia or require further research before they can be returned to Country.

The *Aquifer Reinjection* case study (see chapter 8) aimed to secure water supplies for Perth and address the reduced streamflows in the southwest of Western Australia resulting from lower winter rainfall and hotter summers. This led to the introduction of aquifer reinjection to Western Australia's water supply. Water Corporation and university partners went through several years of testing and established a trial plant to prove the effectiveness of aquifer reinjection. Part of the trial was a customer perception program run by Water Corporation, which involved working with the local community (e.g. tours with the public and school groups, open days) to improve awareness of the effectiveness of the chemical treatment and the process of aquifer reinjection. More than 7,300 community members toured the water recycling facility during the trial. Rigorous testing, including assurance that 62,300 water quality samples met the required health and safety guidelines, declared the trial a success. The public outreach helped ensure that 76% of the public supported the construction of a full-scale scheme. By 2030, it is estimated that up to 8% of Perth's water supply may be from aquifer reinjection.[40] This has helped diversify Perth's water resources, contributed to future regional stability and enabled the public to enjoy the wetlands and lakes.

[39] Australian National University (2021). *Repatriation, healing and wellbeing: understanding success for repatriation policy and practice*. Accessed March 2023: https://chms.cass.anu.edu.au/research/projects/repatriation-healing-and-wellbeing-understanding-success-repatriation-policy-and.

[40] Ibid.

The *Indigenous Persistence in Formal Learning* case study (see chapter 12) aimed to address the lower educational outcomes (and interconnected life outcomes, like health and wellbeing)[41] encountered by Indigenous students. The research resulted in the development of the TAPS strategy, a wrap-around supportive approach to building learner identity, self-efficacy in learners and academic performance. This model has been applied at Edith Cowan, James Cook and Griffith Universities and UNSW, where it has almost doubled the graduation rate of Indigenous students. TAPS has improved Indigenous student's stress levels, satisfaction, proactive support-seeking behaviours, success rates and retention rates, and is helping close the gap on student education objectives. It is also being applied across other priority cohorts and is showing strong signs of success, including students with disabilities and those in remote high schools in Queensland.

Quantum computing has the potential to bring about significant impacts in many facets of our society. The *Quantum Computation and Communication Technology* case study (see chapter 7) demonstrates a few examples of the sectors that may be affected by quantum technology:

— Materials science: by optimising and discovering new materials (e.g. more efficient solar cells and battery technology).
— Drug discovery: by expediting the discovery and development of new drugs by simulating complex molecular interactions.
— Financial modelling: by helping financial organisations better model and understand complex financial systems and make more accurate financial predictions.
— Supply chain optimisation: by helping to optimise supply chain networks, reducing waste and increasing efficiency in areas such as transportation and logistics.
— Artificial Intelligence: by significantly enhancing the performance and capabilities of artificial intelligence systems, enabling the development of more advanced and intelligent systems.
— Cryptography: by improving the security of sensitive data.

KEQ 1. What are the short-, medium- and long-term outcomes and impacts of ARC-funded research? Is the NCGP achieving its intended outcomes?

3.3 Environmental impacts

Key Finding 6 Contribution to the environment

About half of the projects have or may contribute to environmental outcomes in the future. These impacts include contributing to better natural resource management and reduced environmental damage. Again, this was more commonly reported among Linkage Program projects.

The case studies highlight the significant impact of the research on the environment, including supporting the environmental sustainability of Australia's emerging lobster aquaculture industry; modernising irrigation to save water and support water quality and ecological outcomes, mitigate some drought impacts and protect key refuges for endangered species; developing more efficient clean energy technologies; reducing energy consumption and emissions; and enabling injection of water into aquifers to protect important wetlands and lakes, and, in turn, helping ensure the protection of flora and fauna that depend on those wetlands.

Contribution to environmental impact is a core purpose of the NCGP and aligns with the intended outcomes of developing new technologies, products and ideas, creating jobs, growing the economy and enhancing the quality of life in Australia (see section 1.1.1). As overviewed in Figure 2.1, this includes, for example, water savings and improved reliability, improved air quality and management

[41] OECD (2022). *Education GPS: Economic and Social Outcomes*. Accessed February 2023: https://gpseducation.oecd.org/revieweducationpolicies/#!node=41761&filter=all.

of natural resources, reduced CO_2 emissions, improved ecosystem health and integrity and reduced use of natural resources.

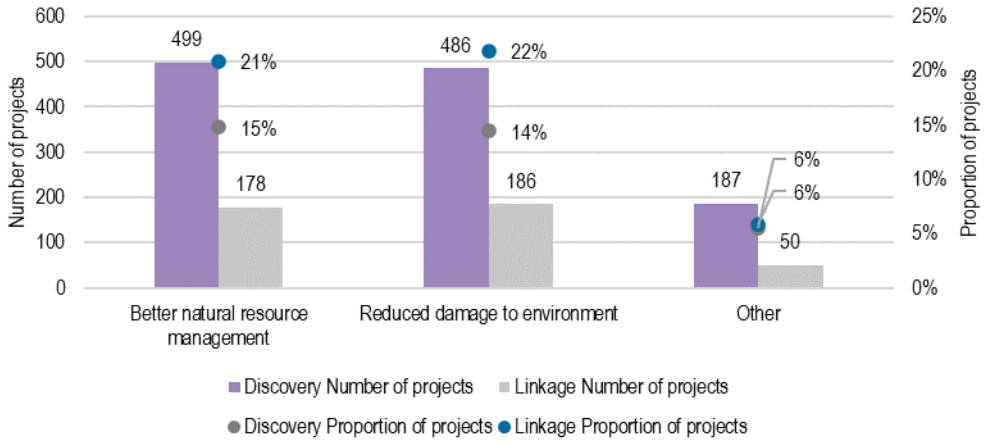
As the evidence shows below, both the Discovery and Linkage programs play a key role in supporting these types of impact, noting that this is only a small proportion of the potential impact delivered by the NCGP. This could be documented with additional evidence and a systematic assessment framework (see chapter 5).

3.3.1 Evidence of environmental impact

Final report data shows a higher proportion of Linkage Program projects reported delivering environmental impacts (39%) than Discovery Program projects (28%, see Figure D.4).

Analysis of detailed environmental impacts (see Figure 3.9) shows that both Discovery and Linkage Program respondents commonly reported that their projects contributed to better natural resource management (15% and 21%, respectively) and reduced environmental damage (14% and 22%, respectively). Again, this is to be expected due to the more applied nature of the research.

Figure 3.9 Final report data on environmental impacts by Discovery and Linkage Programs



N=4,221 final reports

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

Survey respondents were asked to report on whether they had or were likely to deliver environmental impacts (see Figure C.2). As expected, a higher proportion of projects reported delivering environmental impacts due to the lag time allowed for these impacts to emerge since final reporting (see Figure D.4). 44% of Discovery and 54% of Linkage Program respondents reported that their projects may, were likely to or had produced environmental impacts. The remaining respondents considered that this was unlikely to or would not occur.

As discussed in section 3.1.2, survey respondents were asked to identify the most significant impacts resulting from research projects (see Table C.2). Qualitative analysis identified terms such as ***climate change*** (56), reduction in ***carbon emissions*** (17) and ***rising sea levels*** (6) were frequently mentioned. Given this question was not specifically targeted toward environmental impacts, the nature of the responses shows the important impact of NCGP-funded research on the environment and achieving outcomes for significant environmental challenges.

> *"My research has trained countless scientists in the environmental sciences, and has contributed to the development of new ways of managing and conserving biodiversity under climate change." – Survey respondent*

3.3.2 Examples of excellent research delivering environmental impacts

The case studies highlight examples of excellent NCGP-funded research that has and will continue to deliver environmental impacts. This is enhancing the quality of life in Australia by improving Australian's engagement with the environment.

Onshore Lobster Aquaculture (see chapter 10) research will help ensure the environmental sustainability of Australia's emerging lobster aquaculture industry, in particular, by ensuring that lobster feed is environmentally sustainable. Less reliance on the live catch will help maintain wild populations. This is increasingly important as climate change impacts wild lobsters, which become severely stressed by sustained, hostile environmental conditions and above-average water temperatures.[42]

The *Irrigation Automation* case study (see chapter 9) demonstrates the impact of Rubicon Water's technology on the environment. Irrigation accounts for more than 70% of the global demand for fresh water. However, less than 70% of distributed irrigation water reaches farms due to a range of water losses, most commonly from 'spills' (20-46% of all losses),[43] an operational problem when water is not precisely controlled in manually operated canal systems.

Rubicon's modernised irrigation automation system addresses many of these issues through accurate measurement and accounting, eliminating spills, improving the reliability and timeliness of water supply, and enabling precise crop application. This has led to significant water savings. For example, the Goulburn Murray Water Connections Project enabled the recovery of 279 gigalitres of water for the environment.[44] To put this into perspective, the municipality of Melbourne uses 18.5 gigalitres of mains water per year.[45] Over the 10-year period from 2021-31, the Project is expected to return over 3,000 gigalitres to the environment. This water will maintain the long-term health of Victoria's rivers and groundwater ecosystems, and the plants and animals that depend on them.[46] A study by the Productivity Commission shows early evidence of improved water quality and ecological outcomes at the local level, including mitigation of some of the most severe impacts of drought through the protection of key refuges and prevention of some species' extinctions.[47]

In addition to the many impacts described in section 3.2 *Quantum Computation and Communication Technology* (see chapter 7) is also expected to deliver environmental and sustainability impacts, for example, by improving our understanding of weather patterns and developing more efficient clean energy technologies.

Aquifer Reinjection (see chapter 8) research has enabled the Water Corporation to source an estimated total of 100 gigalitres of groundwater from Perth's aquifers. This has enabled the Water Corporation to significantly reduce its energy consumption and help it meet its emissions reduction targets. The injection of water into Perth's aquifers is helping protect important wetlands and lakes, and, in turn, ensure the protection of flora and fauna dependent on those wetlands.

[42] Refer: https://www.climate.gov/news-features/climate-and/climate-lobsters

[43] Marsden Jacob Associates, 2003, *Improving water-use efficiency in irrigation conveyance systems*, available online at http://www.insidecotton.com/jspui/bitstream/1/1756/2/pr030516.pdf

[44] The Hon Lisa Neville MP, 2022, Successful Connections Project Delivers Extra Water, available online at: https://www.premier.vic.gov.au/successful-connections-project-delivers-extra-water.

[45] Refer: https://urbanwater.melbourne.vic.gov.au/melbournes-water-story/water-use-facts/.

[46] Refer: https://www.melbournewater.com.au/water-and-environment/water-management/allocating-melbournes-water-resources/water-environment.

[47] Australian Government Productivity Commission, 2017, National Water Reform: PC Inquiry Report, available online at: https://www.pc.gov.au/__data/assets/pdf_file/0009/228177/water-reform-overview.pdf

KEQ 1. What are the short-, medium- and long-term outcomes and impacts of ARC-funded research? Is the NCGP achieving its intended outcomes?

3.4 Cultural impacts

Key Finding 7 Contribution to culture

About half of NCGP-funded researchers reported delivering cultural impacts. Projects reported contributing to cultural impacts by improving cultural understanding and preservation.

The case studies highlight the significant impacts of the research on culture, including supporting a culture change movement on DFV, and enabling deeper cultural connections, understanding and engagement across 3 community partners and other end-users globally.

Contribution to cultural impact is a core purpose of the NCGP and aligns with the intended outcomes of enhancing the quality of life in Australia (see section 1.1.1). As overviewed in Figure 2.1, this includes, for example, improved cultural understanding, preservation and creativity, improved documentation and incorporation of cultural values and practices, and improved cultural sensitivity and awareness. Cultural impacts are closely tied with social impacts (see section 3.2) as improved understanding and preservation of culture leads to improved social cohesion within and beyond Australia and benefits a broad range of community members.

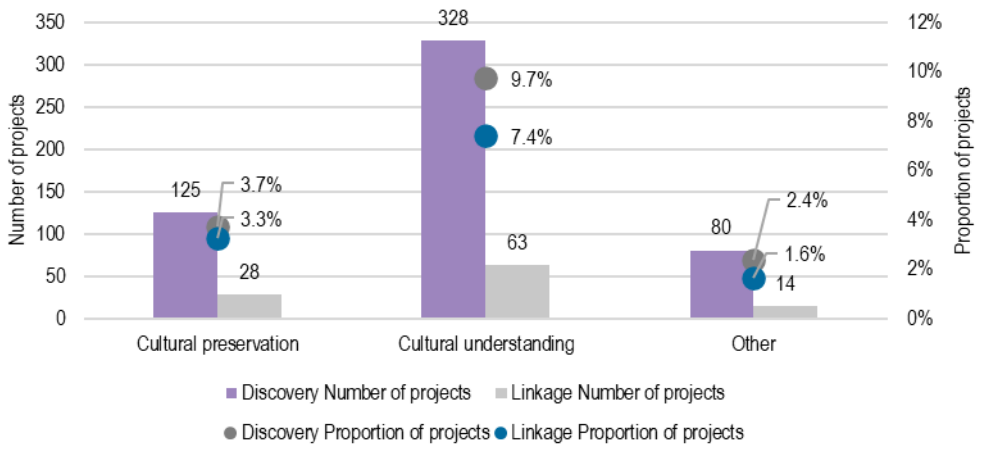
The Discovery and Linkage programs play a key role in supporting cultural impacts, noting that the evidence below is a small proportion of the potential impact delivered by the NCGP. This could be documented with additional evidence and a systematic assessment framework (see chapter 5).

3.4.1 Evidence of cultural impact

Final report data (see Figure D.4) shows that Discovery and Linkage Program projects reported a similar proportion of projects delivering cultural impacts (13% and 11%, respectively). This was the least commonly reported impact type.

More detailed cultural impacts (see Figure 3.10) were slightly more likely to be delivered by Discovery Program projects, particularly for improved cultural understanding, where 9.7% of Discovery and 7.4% of Linkage Program projects reported this impact. Both Programs were most likely to improve cultural understanding, followed by cultural preservation.

Figure 3.10 Final report data on cultural impacts by Discovery and Linkage Programs



N=4,221 final reports

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

This is supported by survey data, which shows that Discovery and Linkage Program projects were equally likely to deliver cultural impacts (may, likely to or has produced, 52% and 50%, respectively) (see Figure C.2). Similar to the findings for other impacts presented above, survey data identifies a higher proportion of projects reporting cultural impacts.

Qualitative analysis of survey free text responses to the question on unintended impacts achieved by the research shows that respondents awarded Linkage Program grants frequently reference ***culture*** (10) and ***collaboration*** (8).

> *"Improved cultural understanding for Indigenous communities on K'gari, with possible tourism implications." – Survey respondent*

3.4.2 Examples of excellent research delivering cultural impacts

The case studies highlight excellent NCGP-funded research that contributes to cultural impacts across Australia and internationally. This directly enhances the quality of life in Australia and internationally by impacting communities and cultures.

Changing the law to protect survivors of DFV (see chapter 11) provided an evidence base to inform and raise awareness of a wider culture change movement in the way society considers and responds to DFV. This has in part been driven by recent high-profile DFV cases, the me too Movement, government policy responses and growing investment in the space.

RRR: Indigenous Remains Repatriation (see chapter 13) significantly contributed to understanding the history of removal and return of ancestral remains, the relationship between heritage and reconciliation, and the economics and valuation mechanisms of the modern commercial trade in Indigenous remains. The research has been particularly culturally impactful for the 3 community partners. Before the RRR Archive, no centralised resource was available to provide the NRA with information on the ancestors in their Keeping Place or in domestic and international museums, while KALACC had only limited and paper-based information about the ancestral remains in its care. The GBK does not yet have a Resting Place but had similarly poor access to information about their ancestors held in domestic and international institutions.

The RRR Community Partner Extension compiled information relating to the ancestral remains of the NRA, KALACC and GBK, synthesising and organising the information into a manageable form. The information relating to each group is stored in its own private section of the RRR Archive for access by each group. This information provided the NRA, KALACC and GBK with a greater understanding of the history and whereabouts of their ancestral remains and served as a tool to guide future repatriation processes. This information has been of significant cultural importance to each community partner. Access to such information can contribute to healing and wellbeing for Indigenous communities by supporting nation-building, self-determination, knowledge transmission, cultural governance and identity.[48]

[48] Australian National University (2021). *Repatriation, healing and wellbeing: understanding success for repatriation policy and practice*. Accessed February 2023: https://chms.cass.anu.edu.au/research/projects/repatriation-healing-and-wellbeing-understanding-success-repatriation-policy-and.

KEQ 2. Do the outcomes and impacts delivered by the NCGP align with the Government's strategic priorities?

3.5 Alignment with Government priorities

Key Finding 8 Alignment of NCGP outcomes and impacts with Government's strategic priorities

The government has a strategic role in identifying areas of focus and critical needs. This enables universities and industries to plan for future activity and investment. The case studies exemplify excellent research that delivers on Australia's National Science and Research Priorities and other government priorities. This highlights the role of NCGP-funded research in contributing to a range of government priorities, including those outside the National Science and Research Priorities.

To effectively drive research in the future, the priorities should balance currency with stability and consistency. More consideration needs to be given to the role of strategic priorities in applied, mission-based discovery research.

3.5.1 Application of priorities at a strategic level

All domestic stakeholders saw a strategic role for the Australian Government in identifying areas of focus and signalling Australia's critical needs. This was particularly important in Australia, which has a relatively small research sector and funding envelope. Government priorities were also important signals universities and industry can use to plan for future activity and investment. One domestic stakeholder noted that these priorities should align with our international strengths to generate funding and leverage our capability. One domestic stakeholder used the example of prioritising research translation as a way of investment signalling by Commonwealth, state and territory governments for greater research translation and adoption.

The National Manufacturing Priorities[49] and National Reconstruction Fund priorities[50] were identified as examples of priorities that have guided research activity. However, the National Manufacturing Priorities were considered narrow in focus relative to the breadth of research that was funded under the ARC and potentially misaligned with the core intent of basic research.

Domestic stakeholders considered that government priorities should be broad and flexible and applied only to particular types of research. Most considered that discovery research should not be required to align with national priorities, as it should be 'blue sky' and investigator-driven. This aligns with the Haldane Principle, as mentioned by a stakeholder, which states that "decisions about which research projects to fund should be made through independent evaluation by experts, based on the quality and likely impact of that research".[51] This is because discovery research outcomes are challenging to predict and can vary widely from those initially proposed and that outcomes can arise decades after the initial grant funding, when priorities may have changed.

Domestic stakeholders identified a stronger role for government priorities in guiding more applied research (i.e. higher up the TRL scale, and Linkage funding) and mission-based work (as occurs internationally). This could also extend to start-ups, industry organisations and small-medium enterprises (SMEs). As the research becomes more applied, other government and industry organisations (such as RDCs and Public Research Organisations (i.e. CSIRO)) can invest.

[49] Department of Industry, Science and Resources (2020). *Modern Manufacturing Initiative and National Manufacturing Priorities announced*. Accessed 21 December 2022: https://www.industry.gov.au/news/modern-manufacturing-initiative-and-national-manufacturing-priorities-announced.

[50] Department of Industry, Science and Resources (2020). *National Reconstruction Fund: diversifying and transforming Australia's industry and economy*. Accessed 21 December 2022: https://www.industry.gov.au/news/national-reconstruction-fund-diversifying-and-transforming-australias-industry-and-economy.

[51] UKRI (2023). *Our relationship with the government*. Accessed January 2023: https://www.ukri.org/about-us/how-we-are-governed/our-relationship-with-the-government/.

International comparators also saw a strategic role for government priorities in guiding research. The UKRI was not established to deliver on Government priorities yet supports government priorities and receives funding based on national science priorities. It seeks to shape funding direction on a portfolio level and through strategic projects. However, most funding is determined by researchers at the project level independently from government, using the Haldane principle.[52]

In contrast, Horizon Europe, SFI and MBIE all fund research aligned with the government priorities. Horizon Europe facilitates the achievement of European Union (EU) science priorities, SFI aligns with Ireland's national science priorities and supports Government ambitions outlined in the Innovation 2020 program, and MBIE funds research portfolios and mission-based research based on national science priorities.

3.5.2 Application of priorities at the project level

The ARC supports the highest-quality research, including research that is not related to priority areas. The ARC supports research under the Science and Research Priorities by asking applicants for funding to indicate whether their research proposal relates to one of the priorities and, where relevant, assessing the potential of research proposals to contribute to the priorities. From 2004, 78% of Discovery and 89% of Linkage Program projects align with government research priorities (see Figure D.11). This has varied over time (see Figure 3.11), noting that there have been several iterations of Government research priorities (see section 1.1.2).

While almost all projects aligned from 2005-16, alignment decreased from 2015-17 and remained at approximately 60-70% from 2017-21. This lower level of alignment coincides with the introduction of the National Science and Research Priorities. This is likely to reflect the nature of the priorities, which highlight specific thematic focuses. In contrast, the previous National Research Priorities and Strategic Research Priorities had greater thematic breadth and generality.

To effectively drive research, domestic stakeholders wanted a balance between current and frequently reviewed/refreshed priorities, with the need for stability and consistency. Many considered it had been too long since Australia's National Science and Research Priorities were last updated.[53] However, changing these too frequently can hinder university and industry investments.

All domestic stakeholders welcomed the current review,[54] which was considered necessary to signal the importance of the priorities, drive funding decisions, and better align with Australia's current policy and program setting. For example, one stakeholder considered that the priorities did not reflect the MRFF (introduced in 2015), a $20 billion long-term investment that has reshaped the research funding landscape.[55]

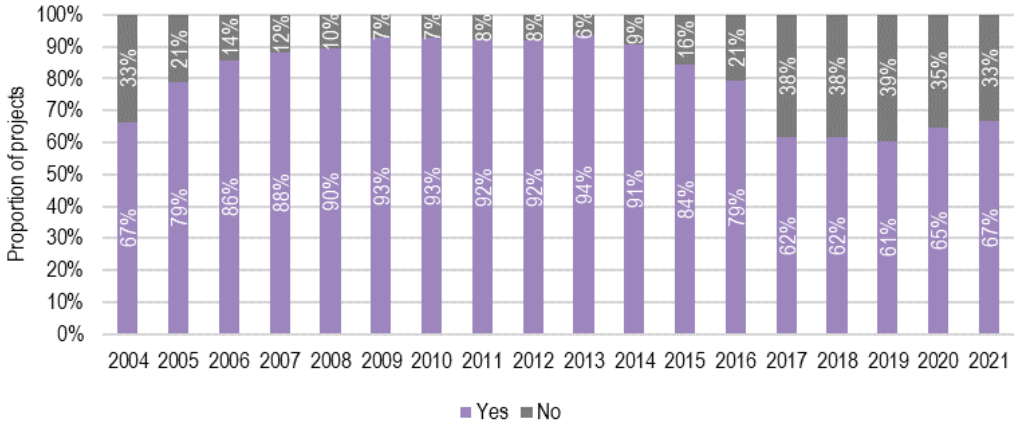
[52] Ibid.

[53] Australian Government (2022). Op. cit.

[54] Ibid.

[55] Department of Health and Aged Care (n.d.). *Medical Research Future Fund*. Accessed February 2023: https://www.health.gov.au/our-work/medical-research-future-fund.

Figure 3.11 Funding data on the proportion of projects aligning with government priorities by year



N=29,303 projects

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

Some domestic stakeholders considered Australia's National Science and Research Priorities too broad, encompassing a range of research. Therefore, priorities do not drive a strong focus for individual research projects, nor the outcomes and impacts achieved. This is because projects can generally be crafted to align with preferred priorities while avoiding contentious research. Further, one domestic stakeholder noted that some of the most impactful research they had observed arose outside the priorities. According to some, seeking to align research with Australian Government priorities does not deliver impact aligned with the priorities at the project level.

The case studies provide examples of how researchers support the National Science and Research Priorities, how other government priorities drive research and the value of designing research to meet current priorities (see Table 3.1).

Table 3.1 Government priorities that are considered through the case study research

Case study	Alignment with Government priorities
Changing the Law to Protect Survivors of DFV	Australian Government's National Plan to End Violence against Women and Children 2022-2032,[56] the Queensland Government Department of Justice and Attorney-General Not Now, Not Ever Report[57] and the Queensland Domestic and Family Violence Prevention Strategy 2016-2026.[58]
Indigenous Persistence in Formal Learning	National Agreement on Closing the Gap Goals 6 and 7.[59] Outcome 6 is focused on higher education completion rates, and outcome 7 focuses on the proportion of Indigenous people aged 15-24 engaged in employment, education or training. The research also relates to the strategic goals of Australia's peak university body, Universities Australia, which in 2022 launched a 5-year sectoral strategy for closing the gap in higher education.
Quantum Computation and Communication Technology	National Science and Research Priorities, including transport; cybersecurity; energy; resources; advanced manufacturing; environmental change, and health, as quantum computing may improve existing processes in these fields. Government has also invested in the Australian National Quantum Computing Centre and the National Quantum Technology Program, and the National Quantum Strategy will outline Australia's vision for the quantum industry.
Aquifer Reinjection	Several Science and Research Proprieties, namely soil and water, as the research has increased the resilience and sustainability of Perth's water supplies; energy, by assisting the Water Corporation to reduce the amount of energy it needs to supply Perth's drinking water; and environmental change as the reduced energy use will assist the Water Corporation to achieve its target of net zero emissions across all operations by 2035, help protect the flora and fauna that rely on Perth's aquifers, and strengthen Perth's water security in the face of climate change.
RRR: Indigenous Remains Repatriation	Science and Research Priority 9: Practical Research Challenge and its challenge, 'better health outcomes for Indigenous people'. The research also aligns with the Australian Government Office of the Arts' statement that "The Australian Government supports the repatriation of Aboriginal and Torres Strait Islander ancestral remains (ancestors) and secret sacred objects (objects) which contributes to healing and reconciliation."[60]
Irrigation Automation	Soil and Water Science and Research Priority, and the Australian Government's commitment to delivering water security. Investments in critical water infrastructure projects were a key feature of the 2022 Budget, with the Government delivering more than $2 billion for the Water for Australia Plan.
Onshore Lobster Aquaculture	Several National Science and Research Priorities: food, as the research is expected to increase Australia's ability to grow and supply lobsters; advanced manufacturing, due to the design and fabrication for lobster mass rearing systems; and environmental change by focusing on environmental sustainability of feed and lobster culture systems.

Source: ACIL Allen, various sources. See case studies, Part II

[56] Commonwealth of Australia (2022). *National Plan to End Violence against Women and Children 2022-2032.* Brisbane: Queensland Government.

[57] Queensland Government Department of Justice and Attorney-General (2021). *Not now, not ever report.* Brisbane: Queensland Government.

[58] Queensland Government (2021). *Domestic and family violence prevention strategy 2016-2026*. Accessed March 2023: https://www.publications.qld.gov.au/dataset/not-now-not-ever/resource/008db60d-06e9-4702-bb87-48be367edf93.

[59] Australian Government (2023). *Closing the gap: targets and outcomes*. Accessed February 2023: https://www.closingthegap.gov.au/national-agreement/targets.

[60] Australian Government. Department of Infrastructure, Transport, Regional Development, Communication and the Arts. 'Indigenous Repatriation'. Accessed February 2023: https://www.arts.gov.au/what-we-do/cultural-heritage/indigenous-repatriation.

Supporting, measuring and communicating impact

4

This chapter considers measuring, monitoring and communicating on impacts.

KEQ 4. What are the main factors supporting the delivery of research outcomes and impacts? How does the ARC contribute to these factors?

4.1 ARC support for research

Key Finding 9 Factors supporting the delivery of research outcomes and impacts

The ARC supports the delivery of outcomes and impacts through a variety of mechanisms, including by providing grants for basic and applied research, funding career development, and supporting the sector through outreach and engagement with universities. Most consider that the ARC is effective in this role.

International comparators encourage researchers to consider and plan for their research impact pathway. This is appropriate and helpful for supporting the delivery of research impact. SFI takes a collaborative and supportive approach to grant management, while Horizon Europe provides end-of-grant funding to support research translation.

The ARC plays an essential funding role in the innovation ecosystem, which other funding sources do not support. However, non-ARC funding sources are also essential in supporting pathways to impact for NCGP-funded research and filling gaps in the activities/research funded by the ARC.

For these reasons, a large proportion of the impact of the research considered in this evaluation is attributable to the presence of the NCGP's research funding.

As part of this evaluation, ACIL Allen was required to consider the main factors supporting the delivery of outcomes and impacts from NCGP-funded research. Consultation with domestic stakeholders identified various factors that are important in supporting or inhibiting outcomes and impacts from NCGP-funded research. These included financial support through grants for basic and applied research, funding for career development, and general support for the sector through outreach and engagement with universities. These factors were only discussed at a high-level owing to the large range of impact drivers across the NCGP.

ARC funding contributes to delivering impacts from university research within the Australian innovation system by funding basic and applied research and research capacity building through training and career development. Domestic stakeholders spoke highly of the value and necessity of ARC funding, which was seen to have a specific role and to fund specific purposes and activities not supported by other funding sources. Domestic stakeholders also spoke of the importance of the ARC allocating funding based on research and researcher excellence to support the delivery of impacts, particularly given the small relative size of the available research funding.

The ARC uses a range of mechanisms to support the delivery of research impact, as outlined in Box 4.1. Domestic stakeholders did not have strong views about the utility of these mechanisms (at an aggregate level), although most agreed that researchers perceive a need to address the Australian Government research priority areas in their research, and that this is a source of tension in the broader research system. When they were identified, some considered the mechanisms to be a mix of requirements for applicants and funded researchers and statements of purpose of ARC funding rather than supports.

However, 2 domestic stakeholders commented on the value of requiring researchers to submit a research impact statement as part of their application and including assessment criteria related to impact. This created an opportunity for researchers to identify the intended impacts of the research and enabled future reporting on the extent to which impacts were realised.

Domestic stakeholders did not express a strong view about how the ARC's different support mechanisms for delivering impact compare with other funding agencies nationally and internationally. They were clear that international practice is a useful consideration but is not sufficient grounds for implementation in Australia. They all believe that consultation with the sector is critical before any practices or supports used overseas are implemented locally.

Box 4.1 Mechanisms the NCGP uses to support research impact

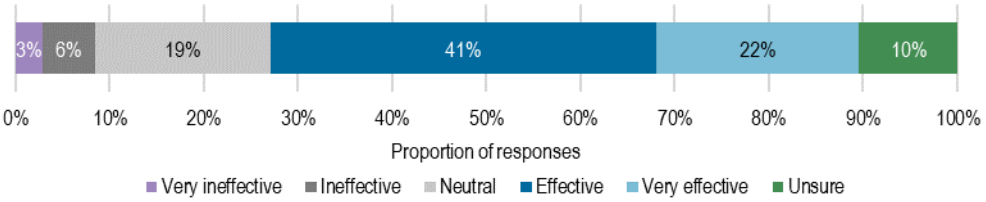
Current mechanisms used under the NCGP to support research impact include:

- support for both basic and applied research
- intended outcomes across most Discovery/Linkage Program schemes, which highlight the delivery of benefit/impact as a key long-term aim for ARC-funded research
- requiring/encouraging collaboration with end-users, particularly through the Linkage Program
- assessment criteria across most NCGP scheme Grant Guidelines relating to the delivery (or potential delivery) of economic, commercial, environmental, social and/or cultural impact
- the inclusion of research impact as a form of performance evidence under the Research Opportunity and Performance Evidence Statement
- the National Interest Test, which asks applicants to demonstrate the impacts (economic, commercial, environmental, social, or cultural) of the proposed research beyond academia
- highlighting the Australian Government's research priority areas
- reporting in Final Reports relating to: the kind of impacts delivered; the actual/expected timeframe for the delivery of impact; the stakeholders who will impact; outcomes achieved from the perspective of Partner Organisations.

Source: ARC

Survey respondents were asked to reflect on the extent to which the ARC supports research that leads to impacts beyond academia (see Figure 4.1). 63% of respondents considered the ARC to be effective or very effective. However, a notable proportion was neutral (19%), unsure (10%), or reported the ARC's support to be ineffective/very ineffective (9%).

Figure 4.1 Survey results on ARC's effectiveness in supporting research that leads to impacts beyond academia

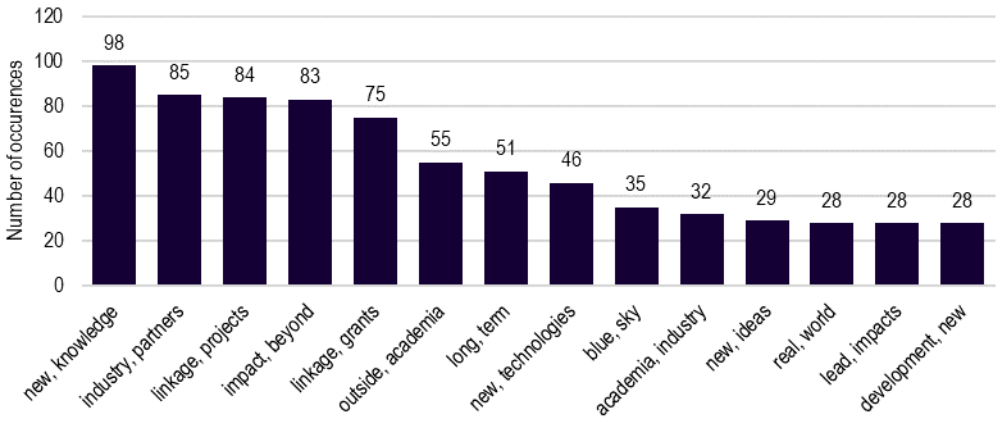


N=3,515

Source: ACIL Allen survey of ARC funding recipients

Qualitative analysis of survey free text responses on ARC support for research impact beyond academia identified a clear relationship between funding for the Linkage Program and industry. Respondents highlighted how the ***Linkage*** (459) Program supports ***industry*** (818), ***community*** (138), and ***government*** (131) agencies by creating ***partnerships*** (72) and ***collaboration*** (77) (see Figure 4.2). "Industry partners" was identified 85 times. This aligns with the Linkage Program's clearer pathway to market and end-users and highlights the program's strength in delivering impacts beyond academia.

Figure 4.2 Qualitative analysis of survey results on the ways the ARC supports research that leads to impacts beyond academia – most common bigrams



Source: ACIL Allen survey of ARC funding recipients

This question had the highest concentration of common words, with 24% of respondents referring to industry and 19% to ***Linkage***. Many respondents referred to the impacts of ***basic science*** and ***research*** (227) beyond academia and stressed the need for continued funding.

> *"Through partnership with industry and stakeholders outside academia." – Survey Respondent*
>
> *"The flexibility of ARC funding allows the ability to find creative solutions that are otherwise difficult to fund directly from industry." – Survey Respondent*
>
> *"Any science-based research will enhance knowledge, and in that way positively impacts society." – Survey Respondent*

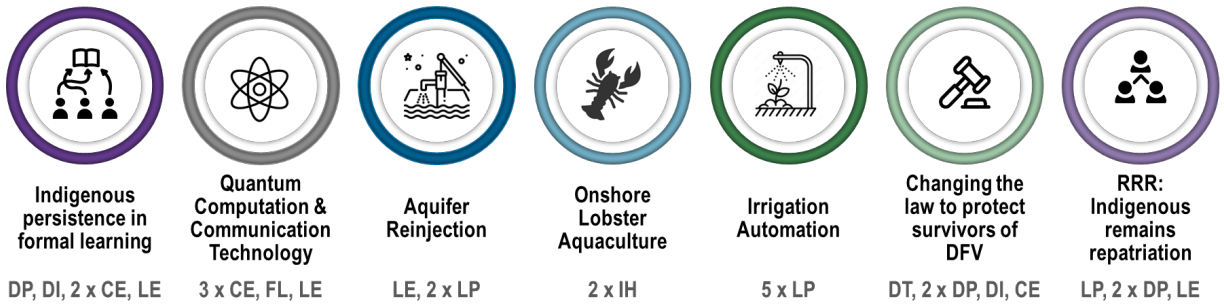
Researchers strongly valued the ARC's support for multiple ARC grants across a career. Qualitative analysis of survey free text responses on the synergies or linkages between the awarded ARC grants shows that this allowed researchers to ***build*** and ***extend a body of work***

(205). Many respondents referenced the link between ***LIEF*** (80), ***Future Fellowships*** (40) and ***DECRA*** (40), and the connections between ***Discovery grants*** (131) and ***Linkage grants*** (101).[61]

> *"I have conducted wide-ranging research that has been funded from multiple sources over the last 20 or so years, and the ARC projects have been one element of this. The ARC projects have been fundamental in contributing to, and extending, this body of work." – Survey respondent*
>
> *"In my field of biology, we have synergistically combined Discovery and Linkage projects to build on and extend a body of work in both directions, i.e. into the pure research space and into the applied space." – Survey respondent*
>
> *"The ARC funding I've received have both extended a body of work and broadened the scope of this body of work, including across disciplines." – Survey respondent*

The case studies highlight how researchers have used different ARC schemes across their careers to further their research along the pathways to impact. As shown in Figure 4.3 and detailed in Part II, the programs of research showcased in the case studies have used multiple NCGP grants to build a track record and reputation of the research and researchers, generate innovative ideas through discovery funding, progress this research along the pathway to impact using translation funding, foster the development of partnerships, trial and build research infrastructure to support many other research projects, and fund researchers at varying stages of their career. The impacts demonstrated in chapters 2 and 3 and Part II, would not have been achieved if researchers did not receive multiple grants from the ARC over their careers. This highlights the importance of funding research based on excellence and impact, and supporting research over longer time periods to enable research to progress along pathways to impact.

Figure 4.3 NCGP scheme grants awarded across the case studies



Note: Discovery Projects (DP), Future Fellowships (DT), Australian Laureate Fellowships (FL), and Discovery Indigenous (DI), ARC Centres of Excellence (CE), Industrial Transformation Research Hubs (IH), Linkage Infrastructure, Equipment and Facilities (LE), Linkage Projects (LP).

Source: ACIL Allen

Qualitative analysis of survey responses on how the ARC could better support the realisation of impacts from the research it funds show that researchers want larger funding for ***long term*** (75) and ***blue-sky*** (47) research, with a clear preference for funding to be decoupled from ***short term*** (54) gains. Support for "basic research" was mentioned 121 times, highlighting that researchers perceive that basic research is also important for delivering impact, perhaps just on a longer timescale.

[61] Note that respondents were likely referring to Discovery Projects grants and Linkages Projects grants.

"All significant research ends up going beyond academia, it just takes time. I strongly disagree with the current trend of funding research with immediate application to industry- that research is important and should be co-funded by industry- but blue-sky fundamental research should be funded." – Survey respondent

Domestic stakeholders provided a broader perspective on how the ARC could better support the sector to deliver outcomes and impacts from NCGP-funded research. These included advocating more to Government on the value of research, and guiding funding in areas where impacts are needed and likely to be delivered.

4.1.1 International experiences

Broadly, the international stakeholders found it challenging to comprehensively articulate the effectiveness of their funding programs in supporting and influencing research impact. However, SFI and Horizon Europe did identify successful supports provided by their funding programs.

For SFI, the 2011-12 financial downturn created more focus on delivering economic impacts from research. As for the ARC, SFI requires research applicants (for discovery and applied research) to consider translation and potential impact by including impact statements in grant applications, even if this is unlikely or likely to be delivered over a long time.

SFI is also taking a more collaborative and supportive approach to grant management rather than focusing on financial acquittals. SFI engages with researchers to agree on co-contribution targets for large and industry-facing grants and hires entrepreneurial officers that visit researchers to support researchers in translating their work. As a result of these supports, SFI is observing more researchers engaging and collaborating with the public and relevant sectors (e.g. health) to better understand the challenges, develop responsive research applications, and translate research. This is considered to be leading to stronger research impact.

Researchers funded under Horizon Europe are asked to identify research impact pathways, and translation and dissemination activities in their proposal. This was considered helpful in guiding researchers toward delivering impact and enabling Horizon Europe to observe impact. Horizon Europe also provides additional funding at the end of research grants to support researchers in designing a business or communication plan to disseminate their results. This was seen as critical in translating research that supports stronger end-user outcomes. As a result, Horizon Europe has been receiving higher quality proposals, from about 50% of applications being of high quality in the last Horizon program to 60% after introducing the impact element.

KEQ 4. What roles do non-ARC funding sources play in pathways to impact for ARC-funded research?

4.1.2 The contribution of non-ARC funding to pathways to impact

There is also a strong role for non-ARC funding sources in supporting pathways to impact for NCGP-funded research. Domestic stakeholders identified gaps in the type of research funded by ARC, including for non-project costs (e.g. administration, infrastructure, training), project costs not funded by ARC (i.e. where proposals are part-funded) and research translation (particularly for Technology Readiness Levels (TRLs).[62] 4-7, noting this is beyond the ARC's current remit).

Domestic stakeholders identified recent publications that showed the costs of university research as funded by universities, government and other sources. The quotes below demonstrate that research funding provided by the Australian Government is insufficient to cover the full costs of research, and as such, other funding sources are required to fill this funding gap.

[62] The TRL scale is used to assess the maturity level of a technology, from 1 (basic research technology) to 9 (system test, launch and operations).
ARENA (2014). *Technology Readiness Levels for Renewable Energy Sectors*. Canberra: Australian Renewable Energy Agency.

> *"The 2 main sources of funds for HERD [higher education expenditure on research and development] in 2018 were general university funds ($6,823 million, or 56% of HERD) and Australian Government competitive grants ($1,700 million, or 14% of HERD)."*[63]
>
> *"In 2018 (latest available figures) the Go8 spent a total of $6.5 billion on research. 36% of this was funded directly from the Commonwealth Government and 48% from General University Funds – the latter largely from international student fees."*[64]
>
> *"The support needed for completing government research projects from energy costs and building maintenance to technicians, librarians and other professional support is now only 18 cents in each dollar of external research funding earned by Australian universities."*[65]

Universities support ARC-funded and non-ARC-funded research based on the individual university's priorities, needs and/or researcher merit. Universities also fund administrative and other research-related activities or costs that are not typically covered by ARC or other funding. This creates an uneven playing field for universities and impacts the extent to which they can support priority-driven and ARC-funded research. Some called for further ARC support for unfunded costs to support the delivery of impact.

Private investment was seen as critical in supporting later-stage, applied and market-ready research. This either supports ARC funding (e.g. co-contributions for Linkage Projects) or separate funds for translation and commercialisation (e.g. taking a product or service to market). This is supported by the case studies, for example, *Changing the Law to Protect Survivors of DFV* secured additional funding from AIJA between 2015-2022 to fund the development of the DFV Bench Book and from the NJC in 2017 to develop training materials based on the Bench Book. Without this translation funding, the likelihood of the research affecting the training and professional practice of end users would be far lower.

Domestic stakeholders identified other government bodies and schemes that support the innovation ecosystem. For example, Research Block Grants fund eligible Australian higher education providers for research, training and indirect research costs,[66] the National Health and Medical Research Council (NHMRC) and Medical Research Future Fund (MRFF) support health research, Cooperative Research Centres support applied research, and the National Collaborative Research Infrastructure Strategy (NCRIS) supports research infrastructure. Other schemes have emerged recently to fill other funding gaps, including:

- Australian Government's $362.5 million (2022-23 to 2025-26) Trailblazer Universities Program, focused on building research capability, commercialisation and industry engagement[67]
- Australian Government's $1.6 billion Australia's Economic Accelerator program, focused on research discovery, translation and commercialisation aligned with national research priorities[68]

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[63] Ferguson, H. (2022). *University research funding: a quick guide*. Accessed 5 January 2023: https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp2122/Quick_Guides/UniversityResearchFunding.

[64] Ibid.

[65] Group of Eight Australia (2022). *Essential decisions for national success Supporting Australian research*. Canberra: Go8.

[66] Australian Government Department of Education (2022). *Research Block Grants*. Accessed 5 January 2023: https://www.education.gov.au/research-block-grants.

[67] Australian Government Department of Education (2022). *Trailblazer Universities Program*. Accessed 4 January 2023: https://www.education.gov.au/trailblazer-universities-program.

[68] Australian Government Department of Education (2022). *Australia's Economic Accelerator*. Accessed 4 January 2023: https://www.education.gov.au/university-research-commercialisation-package/australias-economic-accelerator.

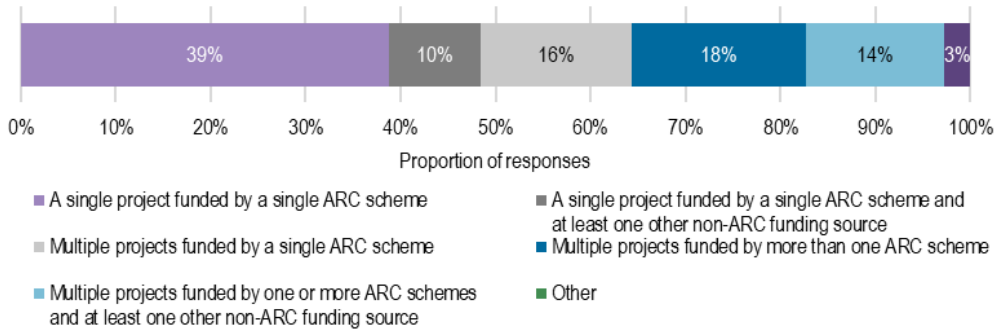
State and Territory Governments typically fund research at higher TRLs and research that focuses on State/Territory priorities, such as the NSW Innovation Research Acceleration Program and Commercialisation Pathways Program,[69] Breakthrough Victoria,[70] and the South Australian Research and Innovation Fund.[71]

The role of non-ARC funding sources can be seen in the survey of NCGP-funded researchers. Respondents most reported having a single project funded by a single ARC scheme (39%, see Figure 4.4), followed by multiple projects funded by more than one ARC scheme (18%). 24% received funding from a source other than ARC, for example, Cooperative Research Centres, NHMRC, AusAID, Australian Centre for International Agricultural Research, EU Horizons, United Nations, various Rural Research and Development Corporations (Rural RDCs), and funding from other Australian and state government, industry and philanthropic sources.

The Australian Federal Government was the most reported source of non-ARC funding, with 68% reporting receiving this funding before, in parallel, of after ARC funding (see Figure C.3). The value of funding received from other sources was most commonly $100,000-500,000 or $1-5 million (both 29%, see Figure C.4). When respondents received funding from non-ARC sources, most of their funding was still from ARC. 63% of respondents (499 of 792) received 50% or more funding from ARC (see Figure C.4).

These findings highlight the importance of the ARC in providing the majority of respondent's funding for research. Non-ARC funding sources play a smaller role in supporting impactful research programs that involved at least some NCGP-funded research.

Figure 4.4 Survey results on recipient funding sources and exposure to ARC schemes



N=3,469

Source: ACIL Allen survey of ARC funding recipients

[69] NSW Government Chief Scientist and Engineer (n.d.). *Research and Development*. Accessed 5 January 2023: https://www.chiefscientist.nsw.gov.au/funding/research-and-development.

[70] Breakthrough Victoria (2023). *Breakthrough Victoria – University Innovation Platform*. Accessed 5 January 2023: https://breakthroughvictoria.com/stories/university-innovation-platform-launch/.

[71] Government of South Australia Department for Industry, Innovation and Science (2023). *Research and Innovation Fund*. Accessed 5 January 2023: https://www.diis.sa.gov.au/innovation/entrepreneurship-and-future-industries/funding/research-and-innovation-fund.

KEQ 5. How would the capacity of Australian research to support economic, environmental, social and other impacts be affected by the absence of the NCGP?

4.1.3 Attribution of benefits to the ARC

Given the above insights into the core role of ARC funding and the use of non-ARC funding sources, it is important to consider how much of the impacts delivered by NCGP-funded research (see chapters 2 and 3) can be reasonably attributed to the ARC.

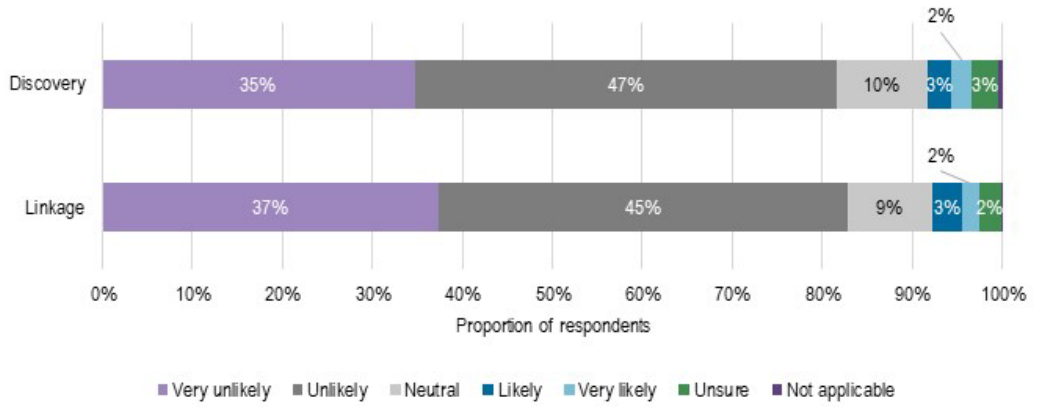
Domestic stakeholders considered the NCGP to be a significant part of the innovation ecosystem, with funding directed to activities that would be challenging to fund through other sources. It was considered so significant that some could not envisage a scenario without the NCGP.

> *"The funding is critical to the Australian research system – it is the only funding scheme of any size that funds basic research outside of health and medical research. Without this, the system would be under severe pressure and significantly diminished." – Domestic stakeholder*

> *"This would be a huge issue if it [NCGP funding] was removed, and have a big impact on universities." – Domestic stakeholder*

This is supported by survey results showing that 82% of respondents from both the Discovery and Linkage Programs considered that the impacts delivered by their research would be unlikely or very unlikely to have occurred without the ARC's support (see Figure 4.5).

Figure 4.5 Survey results on the likelihood of research impact occurring without ARC's support



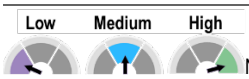
N=3,698

Source: ACIL Allen survey of ARC funding recipients

The case studies also support the central role of the ARC in funding excellent research and supporting impact delivery. Table 4.1 shows that the case studies deliver multiple impacts that are highly attributable to the funding received from the ARC, and as such, these impacts could not have been achieved without the ARC. This is often because other funding sources were not available or not available at a sufficient scale or for the purpose needed (see section 4.1).

Table 4.1 Attribution of impacts to the ARC and NCGP

	Economic	Society	Culture	Environment	Research capability
Changing the Law to Protect Survivors of DFV					
Indigenous Persistence in Formal Learning					
Quantum Computation and Communication Technology					
Aquifer Reinjection					
RRR: Indigenous Remains Repatriation					
Onshore Lobster Aquaculture					



Note that the Irrigation Automation case study is not included as the level of attribution of benefits to the ARC could not be reported due to commercial sensitivities. See case study in Part II for further information.

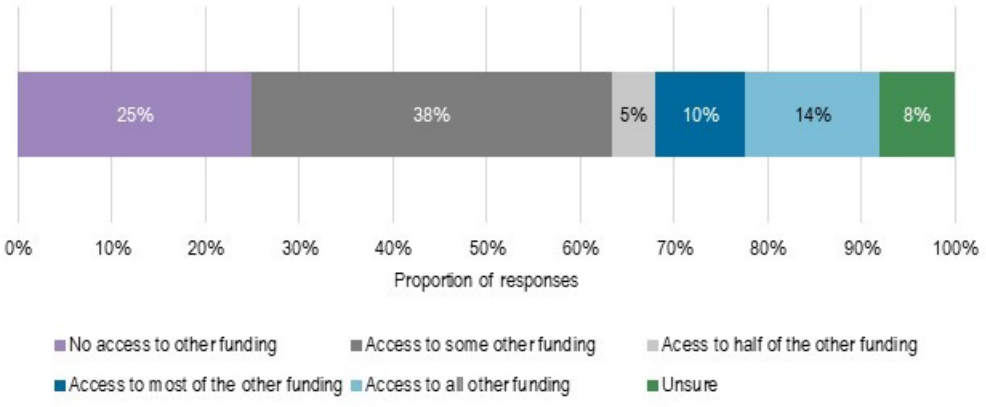
Source: ACIL Allen analysis

KEQ 6. How would the level and nature of the economic, environmental, social and other impacts delivered through Australian research be affected if the level of funding administered through the NCGP were to change?

If funding *decreased or was removed*, domestic stakeholders considered that the capacity of Australian research to support economic, environmental, social and other impacts would depend on the extent to which other funding sources filled the gap. Some research would likely not be funded at all, and thus the consequent impacts would not be delivered, and other research would be funded through different sources, thus allowing some impacts to emerge (see section 4.1.2).

This is supported by the survey results, which show that 25% of respondents would not have been able to access funding other than that from ARC (see Figure 4.6). Respondents reported that they would have had access to some (38%) to all (14%) of the required funding from other sources.

Figure 4.6 Survey results on the likelihood of respondents' access to other funding sources



N=829

Source: ACIL Allen survey of ARC funding recipients

One domestic stakeholder noted that the nature of the funding source would likely guide any research funded by these sources; for example, industry may fund applied, priority-driven and near-to-market research. As such, basic research (widely considered the funding responsibility of government) may be funded to a lesser extent. This also aligns with the core purpose of government in funding public goods (see section 1.4).

One domestic stakeholder highlighted the important role of ARC in enabling a connected and wholistic conversation about research in Australia. Without ARC, they considered that there would be duplication in funding and added complexity in the system. Further, capability development for later-stage researchers (funded largely though the NCGP) would be less certain without the ARC.

If the funding *increased*, the nature and scale of impacts would depend on funding allocation. Domestic stakeholders highlighted the value of additional funding in creating more equality in the way funding is distributed to universities (i.e. to smaller and regional universities), better connecting the research training system to boost workforce development, and funding longer-duration projects to provide greater certainty to researchers and improve the research efficiency and outcomes. However, one stakeholder noted that the relationship between funding and impacts is not linear and "impacts would not double with double the investment".

4.2 Measuring, monitoring and communicating the impacts

KEQ 8. What improvements, if any, could be made to the data and/or data collection methodologies the ARC uses to assess the outcomes and impacts of NCGP-funded research? What data points/metrics could the ARC collect to better inform future impact assessment work?

Key Finding 10 Measuring, monitoring and communicating the outcomes and impacts of NCGP-funded research

The ARC has in place systems for monitoring and measuring impact; however, there is an opportunity to improve these approaches and strengthen the capability and capacity of the ARC to undertake impactful data analysis and evaluation.

There is no single solution to impact measurement, as many countries around the world struggle to systematically understand all impacts generated by their research funding programs. However, high-level guiding principles were identified.

Impact should be measured more frequently than it has been and account for its lag time.

International comparators highlight opportunities for the ARC to better frame pathways to impact, develop fit-for-purpose indicators and metrics, and amend the data collection and analysis process (including using automation). This will enable researchers and the ARC to report on a broader and deeper level of impact occurring from NCGP-funded research.

4.2.1 Overview of how impact is currently measured, monitored and communicated

The Australian Research Council Strategy 2022-2025[72] outlines the ARC's ambition and strategic priorities to deliver world-class advice and engagement, research system excellence and empowered people. These strategic priorities are underpinned by initiatives and activities, 2 of which relate to communication and measurement:

— 1.2.2: Collaborate with the research sector to better communicate the national interest in all projects and assist with the translation of research.

— 2.2.1: Increase avenues for strategic engagement with the research community to strengthen criteria to measure impact and excellence.

The ARC has in place several systems for monitoring and measuring impact of NCGP-funded research:

— Grantees are required to submit final reports less than 12 months after finishing their project. There is currently minimal use of final report data analysis in external reporting. This reporting is collated by ARC and used for internal reporting and to inform evaluation.[73]

[72] Australian Research Council (2022a). Op. cit.

[73] Australian Research Council (2022f). *Evaluation*. Accessed March 2023: https://www.arc.gov.au/about-arc/strategies/evaluation.

— Evaluation of individual schemes and supports, noting that these have been ad hoc and not heavily focused on research impact.[74]

These measures have delivered insights to the ARC, government, university and research sector, and other important stakeholders about the impact of NCGP-funded research. However, there is an opportunity to explore emerging impact measurement and monitoring approaches in Australia and internationally. This will strengthen the capability and capacity of the ARC to undertake data analysis and evaluation to elicit further insights on the impact of the research it funds to inform its operations and the decisions made by key stakeholders.

Measuring research impact

Many domestic stakeholders did not have a detailed view of research impact measures and metrics, the data and information sources that could be used/collected, or the appropriate tools or techniques to collect data. They noted that many Australian universities were now considering how to best capture and measure impact and were at varying stages of impact measurement maturity.

The was no single solution to impact measurement, and instead, the consultations identified broad, high-level principles to guide impact measurement (see Box 4.2).

Box 4.2 Principles to guide impact measurement

Impact measurement should:

- balance the overarching impact story (e.g. portfolio wide-assessment) with evidence of project-level success (e.g. case studies)
- capture the breadth of research disciplines, impact types and end-users
- be accompanied by guiding principles, clear and consistent definitions, metrics and measurement approaches, with the potential for ARC to support education and upskilling across the sector to ensure consistent data collection
- consider the lag time between the research taking place and the impacts being delivered, and ideally track impacts longitudinally
- reduce the burden on universities and researchers to provide/collect data by:
  - building on, replacing or repurposing existing reporting processes by universities or the ARC
  - consider the requirements for data collection rigour and frequency
  - collect data once that can then be used multiple times for multiple purposes
  - be conducted independently, with a cross-disciplinary review of research outcomes and impacts to enable greater reflection on success
  - occur ideally every 5-10 years
  - extend beyond a compliance exercise by having a clear purpose, strategically aligning with government priorities and information needs, and meaningfully driving decision making (rather than being a simple compliance exercise), in order to encourage researcher and university engagement and deliver value for the financial and resource cost associated with measurement.

Source: ACIL Allen

Case studies were commonly identified as a way to capture the breadth of impacts delivered through NCGP-funded research. This was particularly the case for social, environmental and cultural impacts that may not be as readily quantified or contribute to a market or economic return. Case studies were valued for the flexibility to demonstrate research impact in a bespoke manner.

> *"Our universities want to move away from only using economic assessments." – Domestic stakeholder*

[74] Ibid.

This was also identified in the qualitative analysis of survey free text responses on the most significant impacts resulting from research projects (discussed in section 3.1.2). There were sensitivities around the ***difficulties of quantifying*** (87) these impacts and the ***long-term*** (26) nature of research impacts, particularly for some subject areas, such as climate change. Many researchers did not appreciate the emphasis on quantifying the monetary value of research impacts or consider this productive or connected with the research outcomes they were producing.

> *"It is really hard to quantify all of this, which is one of the frustrations that researchers in the Humanities - and I imagine more broadly - face. Our impacts are generally measured qualitatively." – Survey respondent*

> *"Long term impact on research and science cannot be quantified." – Survey respondent*

Domestic stakeholders that commented on impact measurement considered that this should both systematise and automate the capture and reporting of measures (e.g. citations and downloads) and seek to capture impacts that move beyond these measures. This could seek to measure progress toward achieving the research's intended outcomes and impacts.

> *"If you are going to get researchers to identify intended outcomes/impacts, then this needs to be more explicitly built into the process with a timeframe for coming back to check." – Domestic stakeholder*

One example identified was the Excellence in Innovation for Australia Trial (the Trial). The Trial was conducted in 2012 to measure the innovation dividend of research generated by Australian universities and as a potential companion to ERA..[75] It aimed to improve how universities articulate and communicate research impact to the broader community and highlight the need to collaborate better with industry to drive innovation.

The Trial used a case study approach, with 162 case studies assessed by industry-focused panels. The Trial was broadly successful and highlighted the breadth of compelling research stories that could be communicated to a range of audiences..[76] However, the extent of impact and quality of the case studies varied substantially, and the process was highly burdensome and difficult to scale.

Several domestic stakeholders wanted stronger links between excellence assessments and impact (e.g. to select case studies of excellent research for impact assessment) and to consider any future national impact assessment run by the ARC in line with processes to measure NCGP research impact specifically.

Timing of impact measurement

Domestic stakeholders considered that impact should be measured more frequently than has occurred for the NCGP. Ideally, a portfolio-wide assessment should occur every 5-10 years, and smaller scheme-specific assessments more frequently (in line with SFI, see chapter 7 of the technical supplement to this report).

> *"If we're trying to raise the profile of research and the rationale for spending funding on research, then the preference is for a shorter timeframe to ensure it remains on the top of people's mind and is still relevant." – Domestic stakeholder*

As noted throughout the report, there is a lag time between when the research concludes, and impacts are realised. This lag is challenging to define across NCGP-funded research, due to the wide variation in research discipline, maturity (i.e. basic or applied research and TRL) the likelihood

[75] Group of Eight and Australian Technology Network (2012). *Excellence in Innovation: Research impacting our nation's future – assessing the benefits*. Accessed January 2023: https://atn.edu.au/wp-content/uploads/2021/12/atn-go8-report-web-pdf.pdf.

[76] Ibid.

of success (i.e. achieving intended or unintended impacts), and the prevailing policy, economic, environmental and social conditions that shape research.

As such, domestic stakeholders considered that the timeframes to achieving impact from ARC-funded research were highly unpredictable and often lengthy. Impact could arise decades after the research was conducted, occur in a range of disciplines (not necessarily in the initial FoR, as shown by the 20% of Discovery and 16% of Linkage Program survey respondents delivering unintended impacts, see Figure B.4) and may not generate a market return that can be quantified within a timeframe that can be attributed (with some degree of certainty) to the research funding. Stakeholders suggested that research could also deliver impact through a series of projects that build on the initial knowledge before the impact could be observed. This creates further challenges for attribution of impact. This is clearly evidenced through the case studies, which often required a series of ARC grants, partnerships and years to deliver impact.

Qualitative analysis of survey free text responses also showed that it is challenging for the ARC to monitor and communicate the impacts of ARC-funded research as the timeframes for realising research impacts are often ***long term*** (16) rather than ***short term*** (13). Many respondents noted that ***impacts*** (197) are often difficult to quantify and can take ***years*** (16) to materialise.

> *"Academic research is primarily about long-term knowledge acquisition and foundational debates around social purpose and policy ends. Communication of short-term impacts is less important than building the narrative around the long-term contribution all research makes." – Survey respondent*

> *"Since not all fundamental research will have immediate impact just after the project completes. ARC should support researchers to translate the research outcome to impact rather than simply monitoring it. Communicating of the impact to the wider society may be useful, but not essential for the researcher." – Survey respondent*

KEQ 7. What, if any, lessons can be learnt to improve the NCGP's effectiveness in delivering outcomes and impacts from the research it funds?

4.2.2 How others measure impact – key considerations

The international comparators provide a series of lessons for measuring the impact of research. These are overviewed below and detailed in Appendix D.

UKRI, SFI and Horizon Europe have invested significant effort in developing capabilities to track outcomes and impacts from funded research. For SFI, this capability took 10 years to develop. MBIE is currently developing its monitoring and measurement capabilities. This capability is essential for enabling Horizon Europe and MBIE to address a legislated requirement to report on performance. Horizon Europe uses evaluations of research programs as key inputs into the decision-making process for future funding arrangements.

UKRI, SFI and Horizon Europe have developed program logics for each funding program/initiative and an overarching evaluation framework to guide evaluation activities across the funding portfolio. These metrics and program logics have been developed collaboratively with system stakeholders. For example, Horizon Europe partnered with member states, universities, and industry, while SFI developed its metrics and program logic with state and international organisations.

Horizon Europe has a well-defined process for collecting evaluation data, guided by Key Impact Pathways, an indicator methodology and metadata handbook, IT systems, and a baseline and benchmark report. It aims to reduce researcher burden by linking researcher grant reporting and survey data with external databases, such as Scopus citation index to measure citations and Opus business database to identify start-up and spin-off companies. This also allows them to compare funded and non-funded businesses and thus understand the impact delivered by the funding and the counterfactual scenario (i.e. what would have happened without funding). Horizon Europe's evaluations focus on the program overall (not by stream or discipline).

SFI requires its funding recipients to complete annual and final reporting. It accounts for the progress of individual awards against agreed milestones and the objectives of the funding call. Grants that are large, complex or awarded to first-time grantees are internationally peer-reviewed midway through the grant to identify whether the research is on track. This reduces the risk of a project failing, and enables SFI to support researchers to deliver impact.
SFI does not rely on big data for collecting and analysing impacts, but given its position in the EU, it requires interoperability with international standards and collection measures. This enables SFI to track its performance longitudinally against its strategy, KPIs, and international benchmarks. SFI does not generally attempt to quantify economic impacts.

UKRI uses the Researchfish platform to collect and longitudinally track impact data and measure attribution via an annual survey for at least 5 years after the grant being awarded (which supports assessment of impacts over time and accounts for the lag time to impact).[77] This is different to the ARC, which has not historically collected post-project report data, and only recently introduced this for the new Industry Fellowships scheme. Research Excellence Framework collects case studies for peer review approximately every 7 years, in a process that is comparable to Excellence in Research for Australia (ERA) and Engagement and Impact (EI). This captures broader research impact that is not readily quantified, noting that there are differences between system-wide impact assessment (i.e. REF, ERA, EI) and program based assessments (i.e. NCGP).
UKRI typically conducts evaluations at the fund level, with an overarching economic evaluation providing an assessment of the economic impact delivered by the research.[78] The evaluations focus on large and complex programs and help capture the breadth of impact delivered by these programs and inform opportunities to improve future program delivery.

MBIE does not have a system-wide view of research impact, as its monitoring focuses on funding acquittal. However, recipients must report on end-of-grant outcomes 2, 5 and 10 years after the grant's end. This longitudinal tracking provides an opportunity to capture and attribute research impacts to MBIE funding. Impacts can currently be attributed at the grant-level, although not at the overarching program level. MBIE is reviewing and developing measurement approaches to build a collective understanding of impact. This involves developing the NZ Research Information System to collect and track research inputs and outputs. This aims to develop a stronger culture around impact measurement and support the development and uptake of new data collection approaches. MBIE is exploring opportunities to review research funding mid-way, much like SFI, to promote opportunities for success.

These insights from international comparators highlight opportunities for the ARC to better frame the pathway to impact for the NCGP and individual schemes. There are opportunities to build on the ARC's current final reporting to collect data longer after the grant has concluded. This will enable the researchers to report on a broader and deeper level of impact. Capturing, storing and analysing data will require more automation in the future. Connecting with external databases will reduce researcher burden and enable the ARC to investigate the counterfactual. Given the ARC's position in the research and innovation ecosystem, there is an opportunity to design the indicators and metrics used to guide data collection at the sector level. This will make them, and the subsequent evaluations, more appropriate and impactful.

[77] Tableau Public (2022). *Researchfish Outputs 2021*. Accessed March 2023: https://public.tableau.com/app/profile/uk.research.and.innovation.ukri./viz/ResearchfishOutputs2021/Overview?publish=yes.

[78] UK Research and Innovation (2023). *Browse our evaluation reports.* Accessed March 2023: https://www.ukri.org/about-us/how-we-are-doing/evaluation-reports/browse/.

4.3 Communication of impacts

KEQ 9. What improvements, if any, could be made to the ways the ARC communicates the outcomes and impacts of NCGP-funded research?

Key Finding 11 Communication of impacts

Most survey respondents reported that it was somewhat or very important that the ARC monitor and communicate the impact of funded research (71%).

Stakeholders stated that the communication of research impact is a shared responsibility across the research ecosystem.

There is an opportunity to improve how the ARC communicates the impacts of its research to deliver more accountability and transparency around public funding and advocate for the value of research and the impacts delivered.

The ARC uses media releases, government briefings, social media (LinkedIn, Twitter and YouTube), and publications (e.g. Making a Difference[79]) to communicate with stakeholders. Much of the ARC's communication on impact also occurs through in-person meetings.

Most survey respondents reported that it was somewhat or very important that the ARC monitor and communicate the impact of funded research (71%, see Figure 4.7, left chart). Qualitative analysis of survey free text responses shows that this is important because of the ***public*** (720) and ***taxpayer*** (314) funded nature of ARC grants. Respondents considered that the ***benefits*** (172) of funding research need to be conveyed to the ***community*** (175) and ***general public*** (71), and these groups should be informed about how the ***investment*** (82) creates ***value*** (261) and ***impact*** (674). Crucial to effective communication is ***transparency*** (46) and ***accountability*** (187).

> *"Communication of the long-term benefits of research is important to help the broader community understand the value of ARC-funded research, which helps to ensure the programs remain in place." – Survey respondent*

> *"Scientific outreach and communication are a critically important role for academics, and this is especially true for those whose research is funded by federal programs like the ARC. Showcasing the diversity of impacts from ARC-funded research would also help motivate and inspire members of the Australian community to get involved themselves or take pride in their country's research community." – Survey respondent*

> *"To explain, promote and justify public expenditures and demonstrate value-for-money in its grants." – Survey respondent*

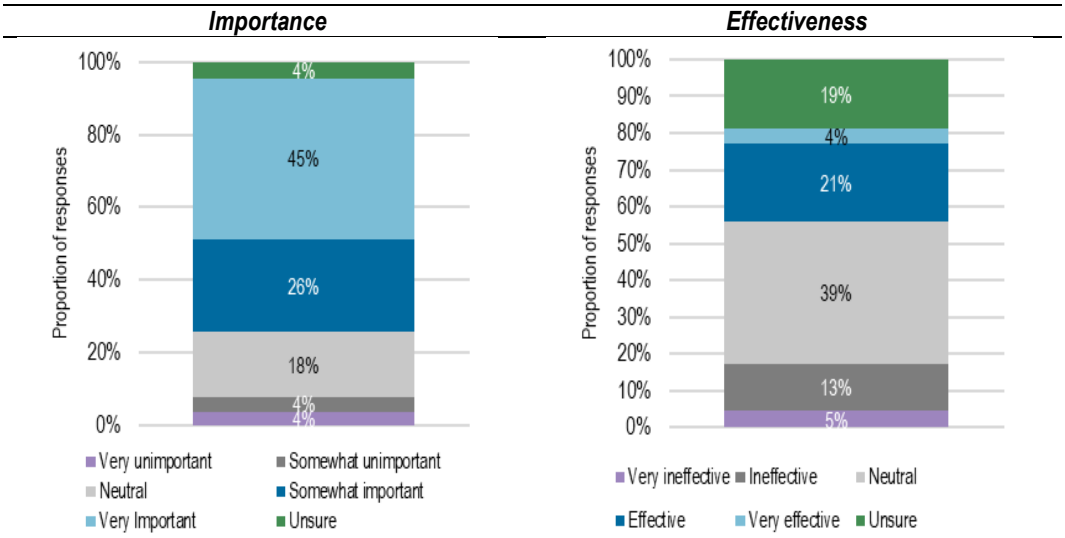
However, only 25% of respondents thought that the ARC was effective to very effective in communicating about impact (see Figure 4.7, right chart). 18% considered the ARC to be ineffective of very ineffective and a large proportion were neutral (39%) or unsure (19%).

This aligns with domestic stakeholders' mixed views on whether the ARC effectively communicated the outcomes and impacts of funded research. Some noted that ARC's communications with universities have improved in recent years and that they were timely and scheduled. However, 2 stakeholders did not have good visibility of the outcomes and impacts generated due to limited reporting or communication from ARC.

> *"Given the ARC is the primary funder of research, they should do more to talk about the outcomes and impacts of research to government so that it is better recognised as important. If they collect data about the research, what are they doing with it?" – Domestic stakeholder*

[79] Australian Research Council (2022). *Making a Difference*. Accessed April 2023: https://www.arc.gov.au/news-publications/publications/making-difference#:~:text=Making%20a%20difference%E2%80%94Outcomes%20of,to%20Australia%20and%20the%20world.

Figure 4.7 Survey results on the importance and effectiveness of ARC's monitoring and communicating of the impact of funded research



Importance n=3,518, effectiveness n=3,517

Source: ACIL Allen survey of ARC funding recipients

One domestic stakeholder considered that responsibility for communicating research impacts was shared across ARC (with a focus on Government), peak bodies, universities and researchers (with a focus on researchers and the general public). For impacts that emerge long after the grant concludes (e.g. 10 years), the responsibility should rest with the university and researcher.

Some domestic stakeholders considered that the ARC could better communicate with the general public to ensure accountability for government funding and improve awareness and understanding of the value of research. The ARC could also raise awareness of the ARC's existing researcher and project databases so that government, industry and other end-users know what research is being undertaken and who is impactful in their area of interest. For example, GovHack, was considered useful for raising awareness of the Government's open data sources and the value these can generate for end-users.[80]

Qualitative analysis of survey free text responses reveals strong support for ARC to better showcase research impacts through traditional ***media*** (283) and ***social media*** (80). Support for an ***annual report*** (21) showcasing the results and impacts of the suite of projects was common, as this was seen as useful for communicating and following up on researchers' ***final reports*** (44). Respondents considered that the ARC could better ***promote*** (66) the ***outcomes*** (199) of the research that it funds to the ***public*** (236) and ***industry*** (84).

> *"Broader public and government communication of research impacts and engaging projects through the media" – Survey respondent*
>
> *"Communicate the impacts of ARC-funded research in digestible accessible formats, e.g. widely read news media, via a biannual piece in ABC News/the Conversation or similar, via a podcast, on social media in the form of infographics with simple, pithy messaging to target publics of all ages, and especially engage younger publics (e.g. communicate impacts on Twitter, FB, TikTok and other widely used social media platforms)." – Survey respondent*
>
> *"An online, publicly available, publication outlining the annual outcomes of the research written for the public and politicians. Many people are totally unaware of what great work the ARC does." – Survey respondent*

[80] GovHack is an annual international open government data competition held in Australia and New Zealand. GovHack (2023). About. Accessed January 2023: https://govhack.org/about/.

Challenges, opportunities and future impact assessment

5

This chapter discusses the challenges of measuring, monitoring and communicating impact, the opportunities for improvement and considerations for a future state impact assessment framework.

KEQ 8. What improvements, if any, could be made to the data and/or data collection methodologies the ARC uses to assess the outcomes and impacts of NCGP-funded research? What data points/metrics could the ARC collect to better inform future impact assessment work?

5.1 The challenges of measuring, monitoring and communicating impact

Key Finding 12 Challenges of measuring, monitoring and communicating impact

There is no single solution to measuring, monitoring and communicating impact. International models provide guidance for opportunities in Australia.

However, the ARC's approach needs to be carefully considered and tailored to reflect the purpose of the impact assessment, reduce the burden on the sector and employ the best available tools and techniques to capture an understanding of the breadth of impact.

Our analysis shows there is no 'silver bullet' solution to impact analysis. Many domestic stakeholders consulted on this did not have strong visibility of the aggregate impacts generated from ARC-funded research, although they report the need for improved communication of impact in the future. Likewise, 71% of respondents to our survey reported that communication about impact was somewhat to very important (see Figure 4.7).

This desire for improved communication of impact but lack of visibility is primarily due to the large volume of projects funded over the past 2 decades (approximately 29,000), the diverse range of research activity supported by the NCGP, and the absence of a consolidated and regular report of impact. It means there are highly divergent views amongst key stakeholders in Australia's research system about the appropriate impact measures, metrics, data, information sources and analytical techniques required to measure impact more systematically in the future.

Moreover, many approaches, techniques and models of impact assessment have been deployed overseas (see section 4.2.2). Many of these models could be considered within the Australian context; however, caution is required. These models are often driven by different funding arrangements (and funding scale), program structures, policy requirements and disciplinary focuses, making translation complex.

Addressing these challenges requires an understanding of several aspects.

First, it requires clarity about the purpose of impact assessment. Impact assessment can be used to communicate, influence or advocate to a broad range of stakeholders about the benefits and outcomes of research. Funding agencies can use it to allocate or reallocate resources within

programs, between programs and across the broader research ecosystem. Impact assessment can also be used to manage the performance of researchers, their partners and institutions.

Second, impact assessment can burden the ARC, universities, researchers and their partners/end-users to collect and assemble the information required to appropriately demonstrate the outcomes and impacts of world-class research. As the case studies presented in this report show, research outcomes and impacts can be underpinned by a multi-year research program involving many participants, various institutions and multiple grants/funding sources. Demonstrating the pathway to impact for all NCGP research can significantly burden the ARC, the research sector and research partners.

Third, impact assessment requires understanding the tools and techniques suitable for the entire program, individual schemes and individual projects. It also requires an understanding of the techniques that are appropriate for different types of research (i.e. researcher-led or end-user-led) and different disciplines funded by the ARC. Once again, international practice identifies a range of potential techniques that could be used to support impact assessment in the future. Likewise, many Australian universities are considering how best to measure impact and are at varying stages of maturity. A range of lessons can also be derived from the Australian sector, and further consultation is needed to tease these lessons out.

5.2 Opportunities for improvement

KEQ 8. What improvements, if any, could be made to the data and/or data collection methodologies the ARC uses to assess the outcomes and impacts of NCGP-funded research? What data points/metrics could the ARC collect to better inform future impact assessment work?

Key Finding 13 Opportunities for improvement

As there is no one-size-fits-all solutions to impact assessment, ACIL Allen sees 4 opportunities that could enhance NCGP impact assessment in the future. These include developing a NCGP impact evaluation framework, strengthening NCGP impact data collection and reporting, exploring data-driven approaches to impact assessment and enhancing the communication and understanding of research impact.

These opportunities provide flexibility for ARC to design an impact assessment framework in consultation with the research community and within the context of ARC's broader reform discussions with the government and universities.

Given there are no one-size-fits-all solutions to impact assessment, ACIL Allen has identified a range of opportunities to enhance impact assessment of NCGP-funded research in the future. These opportunities are based on stakeholder feedback gained through this evaluation that there is a benefit in improving impact assessment in the future and an appetite to capture this benefit. They are preferable to recommendations as recommendations require a specific implementation activity, while the opportunities provide flexibility for ARC to design an impact assessment framework in consultation with the research community. It also allows the ARC to consider these opportunities within the broader context of the independent review into the ARC and its enabling legislation, refresh of the National Science and Research Priorities and National Science Statement, the policy review of NCGP programs, the ERA transition plan, and data analytics capability building within the ARC.

These opportunities relate to strengthening NCGP impact data collection and reporting, developing a NCGP impact evaluation framework, exploring data-driven approaches to impact assessment and enhancing the communication and understanding of research impact. They are summarised in Table 5.1 and described in more detail below.

Table 5.1 Summary of opportunities

Opportunity	Potential benefits	Evidence base for opportunity
1. Develop an NCGP impact evaluation framework – Develop agreed metrics with stakeholders, drawing on existing research and innovation metrics – Align with the national research evaluations (such as ERA and Engagement and Impact)	– Greater clarity and consistency on impact reporting requirements for the research sector	– Experience in other jurisdictions – System leaders – Case studies
2. Strengthen NCGP impact data collection and reporting – Capture case-studies of the impact of major projects – Capture impact data that can highlight trends for the ARC, researchers and the sector	– Improved evidence base that can better support the delivery of impact across the spectrum of basic to applied research – Improved data and narratives for communicating research impact – Greater ability for universities and government to demonstrate the value of research funding for both basic and applied research	– Experience in other jurisdictions – System leaders
3. Explore data-driven approaches to impact assessment – Connect to external data sources and metrics to supplement ARC impact data collection – Adapt approaches over time as metrics and data sources improve	– Improved capabilities to develop deep insights into the impact delivered by ARC-funded research – Reduced burden on the research sector of manual data assembly associated with impact assessment	– Experience in other jurisdictions – System leaders – Case studies
4. Enhance the communication and understanding of research impact – Regularly communicate the impact of research in an engaging, and targeted way for audiences using data and case studies	– Improved understanding of the value of research among all stakeholders, increasing social license for government investment – Improved early-stage extension, translation and adoption of excellent research, leading to increased collaboration and impact	– Experience in other jurisdictions – System leaders – Survey and program data

Source: ACIL Allen

5.2.1 Opportunity 1: Develop a NCGP impact evaluation framework

It is clear from this evaluation that research impact is closely aligned with research excellence. All case studies demonstrate that excellent research leads to high levels of economic, research capacity, social, environmental and cultural impact.

The option to do nothing in terms of developing a NCGP impact evaluation framework for the next 1-2 decades is real. In lieu of an integrated impact framework, the ARC could collect data and commission another study of this nature at a time of its choosing. While this is a low cost/effort option, it does not address key concerns raised by stakeholders consulted for this report.

It is clear that the ARC could benefit from developing a future state impact assessment framework that demonstrates the economic, social, environmental and cultural benefits that could be delivered by ARC-funded research (that includes agreed metrics and impact case studies). This is necessary for guiding impact measurement. The development of the framework would require considerable engagement with Australia's research sector before it can be developed, refined and deployed by the ARC. Such a framework would provide greater ability for universities and government to demonstrate the value of research funding for both basic and applied research. This framework should seek to reduce the uncertainty of the implications of a future impact assessment framework on the research sector. It should also treat impact across the different disciplines (some of which are more amenable to quantification than others) equally.

There may be opportunities to consider a range of existing research and innovation metrics (supported by the relevant learned academies as constructed under ERA) that help to capture impact from a broad range of research disciplines (like contribution to policy or legislation) for a future impact assessment framework.[81] Aligning the framework with national research evaluations (such as ERA and EI) could provide greater clarity and consistency on impact reporting requirements for the research sector.

Finally, understanding how assessment at the whole-of-NCGP-level differs from assessment at the scheme level will be important. As such, there are opportunities to develop a rolling plan of impact assessment for each scheme under the Discovery Program and Linkage Program over the next decade. Impact assessment at the scheme level requires different timings, data and analytical techniques, which must be considered to develop a plan. Important lessons from other jurisdictions can guide the development of a rolling plan. Those lessons can be captured and eventually integrated into any future state impact assessment framework that ARC implements.

5.2.2 Opportunity 2: Strengthen NCGP impact data collection and reporting

Once the foundations for impact assessment have been established through Opportunity 1, there is an opportunity to strengthen the capability and capacity of the ARC to collect impact data and undertake data analysis and evaluation to elicit further insights on the impact of the research it funds. The ARC has in place several systems for monitoring and measuring impact of NCGP-funded research. Primarily information is currently collected via final reports, which collect data on outputs, outcomes and impacts within 12 months of project completion. Additional impacts are likely to emerge after this time that are not currently captured.

By drawing on the different techniques for examining impact that are captured in this report, such as in-depth case studies and follow-up surveys, the ARC could significantly improve its ability to demonstrate the benefits of the research it funds. However, to improve its impact reporting, the ARC will need to consider the differences between the 2 main categories of NCGP-funded research: basic curiosity-driven research and applied, translatable or end-user-driven research. Within each category, the NCGP supports various research activities across all academic disciplines, which allows researchers to apply for different program funding when needed. As the case studies have shown, this flexibility is crucial in supporting the evolving needs of researchers and their communities of scholarship and practice (link to section 4.1).

As noted in section 3.5.1, many stakeholders believe discovery research should be investigator-driven, in line with the Haldane Principle.[82] This mirrors the key findings for the ARC's 2020 Evaluation of the Discovery Program, which noted:

> *While some stakeholders commented on the importance of the scheme's contribution to the fundamental knowledge base in laying the intellectual foundations for applied research and translational benefits, others perceived tensions between its support for basic research and its focus on both Australian Government priorities and the delivery of translational benefits.*
>
> *Part 5, Summary of key findings, Evaluation of the Discovery Projects scheme, Final report, ARC, November 2020*

[81] Department of Industry, Innovation and Science and Australian Academy of Technology and Engineering (2019). *Improving Innovation Indicators: Better data to track innovation in Australia.* Canberra: Australian Government.

Some stakeholders believe that measuring the impact of Discovery and Linkage Programs is fundamentally different and requires different tools and techniques. The ARC would need to build flexibility into its future impact assessment and reporting to ensure that the full potential to demonstrate and amplify impact is realised.

Another issue to consider is how there can be better pathways for the translation and adoption of NCGP-funded research, either through NCGP or some other government mechanism. At least 2 case study research leaders believed that the absence of post-NCGP funding for translation constrained their ability to amplify impact. This was especially important for LP and CE programs where the potential benefits are large but need additional support (i.e. potentially 1 year of additional funding) to work with end-users and beneficiaries of the research. There are examples within other jurisdictions (e.g. Horizon Europe provides additional funding at the end of grants to support researchers to disseminate their results, see section 5.1.2) where such funding is provided to exceptional research teams that require post-grant support. This issue could be explored further in wider reviews of the research system.

5.2.3 Opportunity 3: Explore data-driven approaches to impact assessment

Historically, impact assessment has placed considerable impost on the research sector and funding agencies. It is typically a bottom-up exercise that requires significant manual data collection and analysis.

There are also a large number of options related to the design and deployment of data-driven impact assessment exercises. Significant questions about *what* data are needed, *how* the data will be collected, *who* pays for data that is not publicly available, *how* data will be used and *when* data will be analysed and reported are all significant questions that require resolution in the future. Moreover, they raise a series of technology or platform-based investment questions that must be considered over time.

ARC is faced with many options to develop metrics of the NCGP's broader contribution and its non-economic impacts. With emerging data science techniques and technologies, ARC has opportunities to adopt a data-driven approach to impact that builds on the foundations provided by ERA, the Innovation Metrics Review and other metrics (such as those surrounding the United Nation's Sustainable Development Goals.[83]). This opportunity aligns with practice under Horizon Europe, which aims to reduce stakeholder burden of evaluation by linking data from grant reporting and regular surveys with external databases (e.g. the Scopus Citation Index and Opus Business Database, as occurs with Horizon Europe). This could improve the capability to develop deep insights into the impact delivered by ARC-funded research. Although some of these metrics do not capture research impacts, are imperfect and need to be complemented by impact case studies, they can provide an interim indication of impact potential and be built on, and improved over time.

The development of data-driven approaches to measuring NCGP research impact requires consultation with the sector before they are agreed and deployed.

5.2.4 Opportunity 4: Enhance communication and understanding of impact

The survey of researchers identified that 71% of respondents believe that regular impact reporting is 'somewhat' or 'very important' (see Figure 4.7). In the words of one respondent, it has long-term benefit in helping the "broader research community understand the value of ARC-funded research", noting that this also extends to governments and the general public. This can help to increase the social license for government investment in research. In addition, through improved communication

[83] Department of Economic and Social Affairs (n.d.). *The 17 Goals*. Accessed March 2023: https://sdgs.un.org/goals.

of NCGP-funded research impact in a range of settings, further extension, translation and adoption of excellent research could be achieved, leading to increased collaboration and impact.

To this end, there are many ways in which impact can be better communicated by ARC. However, the diverse nature of ARC-funded research and the volume of research funding over time makes communicating impact assessment in an accessible way difficult.

ACIL Allen believes there are opportunities to regularly communicate the impact of research in an engaging and targeted way for audiences using data and case studies. The ARC could model any impact assessment communication approach on the existing *State of Australian Research 2018-19: ERA National Report* dashboard already published by ARC. This interactive online platform provides an ability to search for ERA assessment outcomes by institution or FoR. There are opportunities to draw lessons from this dashboard, and from other jurisdictions and feedback from stakeholders about which aspects of it are most valued.

6 Concluding remarks

This report provides the first whole-of-program, independent assessment of NCGP-funded research undertaken in the past 2 decades. It demonstrates that ARC-funded research has delivered significant and diverse benefits to Australia and internationally that will continue into the future.

However, the evaluation is only a snapshot of the outcomes and impacts that have been delivered through investment in some 29,0000 projects over this time. The case studies of exceptional research show the potential for NCGP-funded research to deliver impacts that are profound and positively disproportional to the investment provided by the ARC. Moreover, the evidence presented in this report shows that NCGP-funded research impacts are significant, occur in all sectors of the economy, and are delivered to a broad range of end-users and beneficiaries. Much of this impact can be attributed to the NCGP.

ACIL Allen strongly believes that more of this impact could be attributed to ARC in the future. Further investment in the metrics and data collection tools required to capture and analyse impact data systematically should be part of ARC's future dialogue with the research sector and government.

TOR 1. Assess the outcomes of NCGP-funded research, including those relevant to the Government's broad strategic priorities
TOR 2. Assess the economic impact of NCGP-funded research
TOR 3. Assess the broader impacts of NCGP-funded research, including environmental, social and other impacts

6.1 Outcomes and broader impacts delivered by NCGP-funded research

6.1.1 Economic impacts

Economy-wide modelling of some 29,000 projects shows that the NCGP has delivered significant benefits to the Australian economy, including:

- **generating substantial economic activity**: boosting Australia's economic output (GDP) by $184.3 billion, equivalent to approximately 1.5% of Australia's current GDP
- **raising economic welfare across Australia**: increasing the real income of Australians by a cumulative total of $152.5 billion, equivalent to increasing the average income of *all* Australians by approximately $1,171 per person.[84]
- generating significant employment opportunities: creating around 6,570 FTE jobs per year
- **providing significant value for money**: generating $3.32 in additional economic output (GDP) for every dollar invested through the NCGP.

These estimated economic impacts understate the overall benefits of the NCGP as they do not account for the social and environmental impacts associated with research projects funded by the ARC. That said, this analysis shows that the NCGP is delivering broader economic impacts that directly support the intended outcomes of the Discovery and Linkage Programs. These include

[84] That is, the discounted present value using a 7% discount rate.

commercial outcomes such as invention disclosures, commercialising and licensing technology, patents, training and spin-out/spin-off companies.

The case studies have demonstrated that NCGP-funded research creates economic growth and opportunity through additional income generated by Indigenous students that graduate at a higher rate, the quantum opportunity in Australia, avoided costs associated with using desalination rather than groundwater recharge, the value of future lobster production, and the value of water savings. In particular, the case studies demonstrate how the NCGP's support for curiosity-led research can over time deliver economic impacts that are potentially substantial, as in the case of quantum computing.

6.1.2 Broader impacts

The NCGP's broader impacts assessed in this report have mainly been captured qualitatively, drawing on insights from stakeholders, funding and final report data, and the survey of researchers. Not surprisingly, researchers report more impact when these have had time to emerge. Further, researchers involved in Discovery Program report a greater contribution to generating knowledge and longer lead times to impact. Researchers involved in the Linkage Program report more applied research, including partnerships with and research impact for end-users. These impacts are delivered sooner on average.

The case studies provide examples of excellent research that, when funded and supported to occur over many years, delivers significant benefits to the economy, research capacity, society, culture, and the environment. These are illustrations of the types and nature of the impacts delivered over a long period of time.

Building research capacity

NCGP-funded research has built significant research capacity by enabling new research directions, research training (e.g. researchers and graduates) and new partnerships (in Australia and internationally). This is helping generate new knowledge, leverage Australia's expertise internationally and generate a research workforce for the future.

The 7 case studies alone are responsible for training 253 honours, 398 PhD students, 87 Masters and 52 postdoctoral fellows. They demonstrate the breadth of collaboration enabled by the funding to educate the community, translate research, broaden the research scope, and ensure research outputs focus on critical issues.

Further, research projects have leveraged substantial co-contributions from partners, totalling $9.3 billion cash and $12.4 billion in-kind. This demonstrates the extent of collaboration stimulated by NCGP-funded research.

Social impacts

NCGP-funded research has produced broad social impacts, including improved health and wellbeing, informed decision-making, improved safety and security, and reduced social problems. The case studies highlight significant social contributions, including support for stronger community engagement and entitlements, improved wellbeing and quality of life, improved accuracy, responsiveness and efficiency of the legal and justice system, reduced pain and suffering, and enhanced community wellbeing and reconciliation.

Environmental impacts

Research projects have and will continue to deliver environmental impacts. These include contributing to better natural resource management and reduced environmental damage. The breadth of impact is highlighted more fully in the case studies, which show the significant impact of

the research on the environment. These impact include supporting the environmental sustainability of Australia's emerging lobster aquaculture industry; modernising irrigation to save water and support water quality and ecological outcomes, mitigate drought impacts and protect key refuges for endangered species; developing more efficient clean energy technologies; reducing energy consumption and emissions; and enabling injection of water into aquifers to protect important wetlands and lakes, and, in turn, helping ensure the protection of flora and fauna that depend on those wetlands.

Cultural impacts

NCGP-funded research is contributing to cultural impacts by improving cultural understanding and preservation. While cultural impacts delivered by NCGP-funded research projects are difficult to systematically identify and quantify, the case studies again highlight the depth of impact delivered. These include supporting a culture change movement on DFV, and enabling deeper cultural connections, understanding and engagement across 3 community partners and other end-users globally.

Alignment with Government's strategic priorities

The case studies highlight the value of research in addressing Australia's needs, including those aligned with government priorities.

The government has a strategic role in identifying areas of focus and critical needs for applied and mission-based research, while the Haldane Principle should guide discovery research, such that researchers define 'blue-sky' challenges and priorities. Researcher-led curiosity and freedom has been the cornerstone of foundational discoveries in Australia, as evidenced by the *Quantum Computation and Communication Technology* case study (see chapter 7), a hugely successful program of research.

6.2 Supporting, monitoring and reporting on NCGP-research impact

TOR 4. Assess the effectiveness with which the ARC is supporting, monitoring and reporting on NCGP research impact

The ARC supports the delivery of outcomes and impacts by providing grants for basic and applied research, funding career development, and supporting the sector through outreach and engagement with universities. It also plays an essential funding role in the innovation ecosystem, which other funding sources would not support (noting that non-ARC funding sources are also essential in supporting pathways to impact and filling gaps in the activities/research funded by the ARC). Most stakeholders consulted consider that the ARC is effective in this role, and a large proportion of the impact described in this report is attributable to the NCGP's research funding.

TOR 5. identify lessons and recommendations on how the impact of ARC-funded research could be better supported, monitored and communicated in the future

The ARC has in place systems for monitoring, measuring and communicating impact. However, these can be improved to enable the ARC to undertake more impactful data analysis and evaluation, and for the ARC to deliver more accountability and transparency around public funding and advocate for the value of research and the impacts delivered.

There is no single solution to impact measurement. Australia's approach should be carefully considered and tailored to reflect the purpose of the impact assessment, reduce the burden on the sector, employ the best available tools and techniques to capture an understanding of the breadth of impact, and be developed in broad consultation with the sector. Impact assessment should also be undertaken more frequently than it has been.

ACIL Allen sees 4 opportunities for future growth that could enhance impact assessment in the future (see Table 5.1), including:

— developing a NCGP impact evaluation framework
— strengthening NCGP impact data collection and reporting
— exploring data-driven approaches to impact assessment
— enhancing the communication and understanding of impact.

These opportunities are inherently flexible as these changes would require the ARC to consult broadly with the research community. Several concurrent reviews and activities are also in progress, and the ARC will need to consider the emerging findings from these broader reforms.

ACIL ALLEN

Case studies

II

Quantum Computation and Communication Technology 7

This case study reports on the key findings of the Centre of Excellence for Quantum Computation and Communications Technology (CQC²T).

7.1 Key findings

$97.8m invested by ARC and **$218.3m** by participating organisations

$2.2 billion NPV of present and anticipated economic impacts BCR of 4.50.

951 jobs created, including training for **569** postgraduate/final year Honours students and **382** University roles

Since 2000 the Centre has published more than **2,203** refereed papers, over 100 granted patents with **50** patent applications underway

122 industry full time equivalent jobs created through spin-out companies

Alignment with Government science and research priorities including transport, cybersecurity; energy; resources; advanced manufacturing; environmental change, and health.

7.2 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to assess the impact and value of research undertaken by many organisations.[85] The results from applying that framework to the CQC²T case study are summarised in Figure 7.1.

[85] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F.

Figure 7.1 Impact Framework Diagram for CQC²T

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– $97.8 million cash support by ARC and $218.3 million cash and in-kind support from participating organisations – Funding and capital raising by the Centre's spin-off companies are not included in these input figures (examples of spin-off funding are included in Section 7.7).	– The CQC²T is a globally leading and highly coordinated effort involving 7 Australian universities and 25 international partner organisations with a focussed effort to achieve scaling in silicon and optical quantum computing hardware and the development of scalable error-corrected quantum communications networks. – CQC²T conducts research across 9 quantum computing and communications work programs (described further in section 9.6).	Key outputs include: – Delivery of world's first integrated circuit, and invented a globally unique technique to manufacture, at atomic scale – World record coherence times and fidelities in single electron and nuclear spin atom qubits in silicon – Demonstrated first single and 2 qubit gates in MOS dots – Invented methodologies to realise practical optical quantum computers – Demonstrated world-leading experiments in single photon, hybrid and continuous variable optical processors – Providing world's most popular & powerful online random number generator – Demonstrated quantum teleportation to avoid loss in communication channels – Demonstrated highest fidelity quantum memories — See further examples of key outputs in section 7.7.	– The Centre has published more than 2,203 papers since 2000 which includes more than 200 in the high impact factor (IF) Science and the Nature suite of journals – Global leadership in silicon and optical quantum computing, cyber-security, cryptography, and quantum information processing. – Examples of the private businesses who have invested in the Centre's research, and that of its spin out company, Silicon Quantum Computing, include IBM, Hewlett Packard, the Semiconductor Research Corporation, the Commonwealth Bank of Australia and Telstra.	– $2.2 billion NPV of present and anticipated economic impacts. – Benefit-cost ratio of 4.50.

Source: ACIL Allen 2023

7.3 Background

This case study relates to projects funded under the following ARC schemes:

— Discovery Program: Australian Laureate Fellowships.

— Linkage Program: ARC Centres of Excellence and Linkage Infrastructure, Equipment and Facilities.

7.3.1 The project

Quantum technologies work by controlling and manipulating the world at its very smallest length-scales using the principles of quantum mechanics. This includes understanding and controlling the physics of single atomic particles, including single electron spins, single nuclear spins, and single photons of light. Over the past 50 years, the applications of quantum physics have enabled the development of transistor and semiconductor technologies. These technologies have enabled the digital electronics revolution of the 20th century allowing us the internet, sending man to the moon and to communicate across the globe. It has also included laser technologies that underpin medical imaging technologies, bar code scanning and optical communication systems. A second wave of

quantum technological revolution is based on the ability to engineer and control quantum states for ultra-fast quantum computing, secure quantum communications technology and quantum sensing.[86] Quantum technologies can potentially bring significant benefits to numerous industries and areas of the economy (see examples provided in Box 7.1).

Box 7.1 Potential applications of quantum computing technology

Quantum computing has the potential to bring about significant benefits in a wide range of fields, including:

- **Materials science**: by optimising and discovering new materials, such as more efficient solar cells and better battery technology.
- **Drug discovery**: by expediting the discovery and development of new drugs by simulating complex molecular interactions.
- **Financial modelling:** by helping financial organisations to better model and understand complex financial systems and make financial predictions more accurate.
- **Supply chain optimisation:** by helping to optimise supply chain networks, reducing waste, and increasing efficiency in areas such as transportation and logistics.
- **Environment and sustainability:** by addressing some of the biggest challenges posed by climate change, such as improving our understanding of weather patterns and developing more efficient clean energy technologies.
- **Artificial Intelligence**: by significantly enhancing the performance and capabilities of artificial intelligence systems, enabling the development of more advanced and intelligent systems.
- **Cryptography**: by improving the security of sensitive data.

Source: EY (https://www.ey.com/en_se/innovation/could-quantum-computing-be-the-technology-that-drives-your-quantum-leap-forward) and Noetic (https://www.dst.defence.gov.au/sites/default/files/events/documents/Quantum%20Computing%20Insights%20Paper.pdf)

Australia is a global leader in the quantum technology sector, with world-class expertise and research capabilities developed over 2 decades of sustained investment in academic research. This long-term investment in foundational research enables the growth of exciting new start-ups and ventures. These emerging quantum businesses are developing and commercialising diverse offerings including quantum computing hardware, quantum simulators, quantum enhanced cybersecurity solutions, precision timing solutions, quantum sensing and other enabling technologies that support quantum technology development and more..[87]

The CQC²T is a hugely ambitious undertaking that continues to put Australia at the forefront of quantum physics globally. At its core, the CQC²T focuses on the experimental demonstration of the fundamental building blocks of a silicon-based solid-state quantum processor and an optical quantum processor, including the convergence of these 2 technologies using a quantum repeater for both secure communications and distributed quantum computation.

The CQC²T involves ~250 staff and students from 7 Australian universities, organised across 9 integrated work packages. All programs are supported by world-leading theorists who comprehensively describe solid-state and optical devices, including atomistic device design, computer architectures and circuits, quantum control, quantum metrology, quantum communications protocols and networks. The CQC²T has given these researchers a shared mission at an important intersection between fundamental discovery and technological development. Since 2000 the Centre has published more than 2,203 papers, produced over100 granted patents (with an additional 50 patents pending or at the Patent Cooperation Treaty (PCT)

[86] CSIRO 2020, Growing Australia's Quantum Technology Industry, accessed on 30 December 2022 at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/future-industries/quantum

[87] Cathy Foley in Foreword to CSIRO, 2020, Growing Australia's Quantum Technology Industry

phase) and employed approximately 950 people graduating 569 students in quantum science and engineering. In the past 12 years alone, the Centre has published 200 papers in the most prestigious peer reviewed publications, the Nature and Science suite of journals. As one of the major contributors to global university rankings, this exceptional record of publishing more than one article a month in these journals for over 12 years places CQC²T in the elite group of quantum information researchers internationally. Indeed, this exceptional track record of achievement would not be matched by any other quantum information research Centre globally.

Box 7.2 summarises just some of the CQC²T's key results to date, to provide a high-level overview of some of the Centre's breakthroughs in quantum computing and communications.

Box 7.2 Key results to date

The Centre has demonstrated the following key outcomes:

- Invented and pioneered manufacturing at the atomic-scale in silicon
- Developed the world's smallest single atom transistor
- Was the first to demonstrate both a single electron spin and a single nuclear spin qubit in silicon
- Demonstrated that atom qubits hold the world record for the highest quality qubits in silicon
- Developed the world's first integrated circuit at the atomic scale
- Developed and patented architectures to realise large scale, fault tolerant quantum computers
- First to demonstrate single qubit and 2 electron spin qubit gates in metal-oxide-semiconductor quantum dots
- Invented and pioneered an efficient scheme to realise quantum computation with linear optics
- Demonstrated small-scale quantum algorithms in optical quantum processors
- Pioneered novel continuous variable and hybrid protocols for large-scale optical quantum computing
- Demonstrated longest quantum memories at telecom wavelength for long distance quantum communication
- Demonstrated highest fidelity quantum memories
- Demonstrated chip entanglement, amplification and qualification for space-based quantum repeater link

Source: ACIL Allen and CQC²T

The university partners in CQC²T are: University of New South Wales (UNSW) (lead); University of Melbourne; Australian National University (ANU); Griffith University; University of Queensland (UQ); RMIT University; and University of Technology Sydney (UTS).

7.4 Inputs

ARC and others, including academic and non-academic partners, have provided $237 million in cash and in-kind contributions for this research (see Table 7.1).

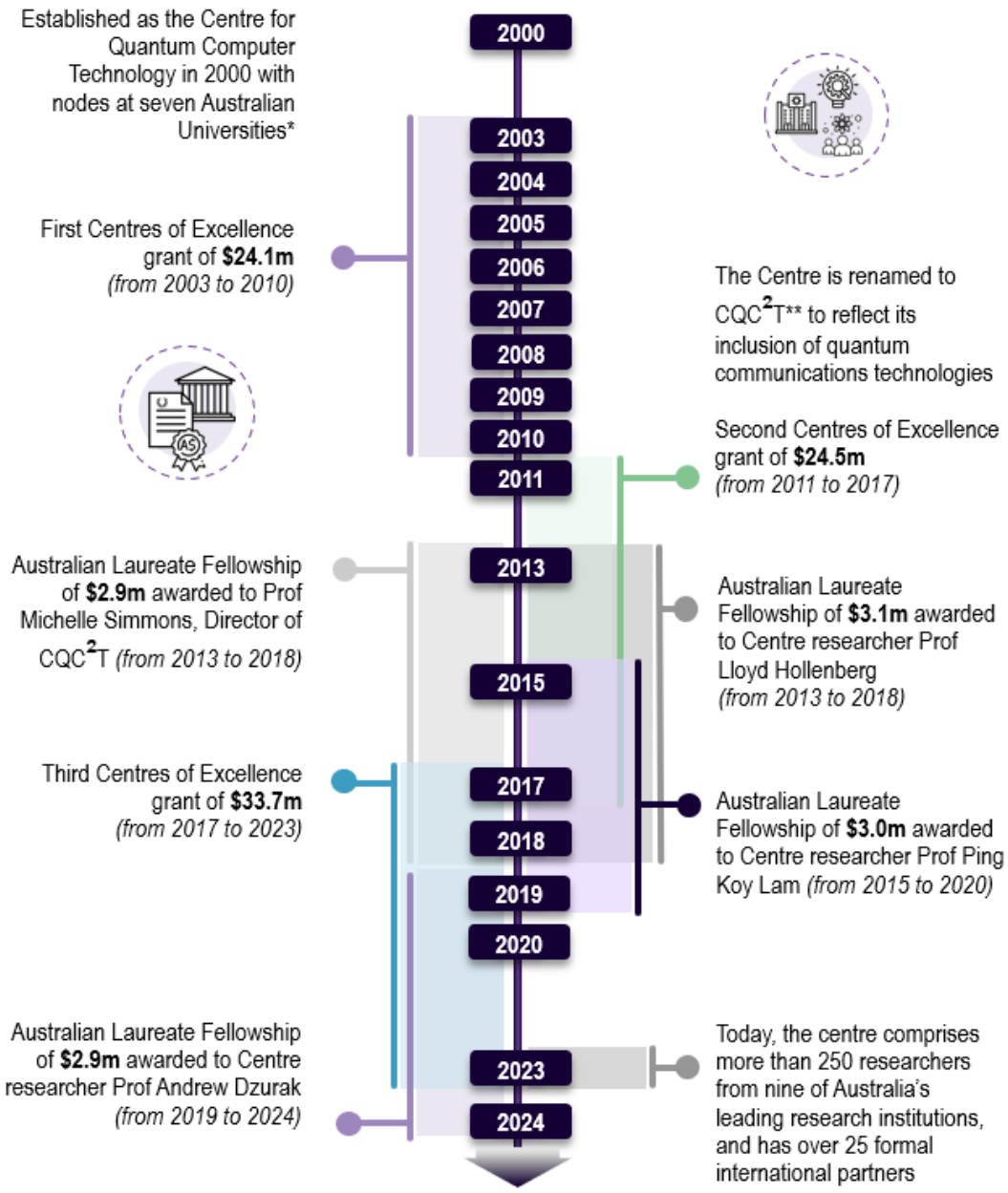
Table 7.1 Support for this research

Contributor / Type of support	2003-2010	2011-2016	2017-2025	Total Contributions
Cash				
CE0348250 – Centre of Excellence for Quantum Computer Technology				
Academic partner	$16,971,530			$16,971,530
Non-academic partner	$2,314,876			$2,314,876
ARC	$24,100,000			$24,100,000
CE1101027 – Centre of Excellence for Quantum Computation and Communication Technology				
Academic partner		$9,337,906	$1,585,875	$10,923,781
Non-academic partner		$750,000	$125,000	$875,000
ARC		$21,000,000	$6,290,504	$27,290,504
CE170100012 –Centre of Excellence for Quantum Computation and Communication Technology				
Academic partner			$9,249,016	$9,249,016
Non-academic partner			$1,339,750	$1,339,750
ARC			$33,700,000	$33,700,000
FL130100171 – Prof Michelle Simmons (Australian Laureate Fellowship)				
Academic partner		$460,863	$460,863	$921,725
ARC		$2,046,191	$817,251	$2,863,442
FL130100119 – Prof Lloyd Hollenberg (Australian Laureate Fellowship)				
Academic partner		$531,429	$398,571	$930,000
ARC		$2,222,500	$887,500	$3,110,000
FL150100019 – Ping Koy Lam (Australian Laureate Fellowship)				
Academic partner		$197,390	$493,475	$690,865
ARC		$928,360	$2,112,923	$3,041,282
FL190100167 – Prof Andrew Dzurak (Australian Laureate Fellowship)				
Academic partner			$1,817,165	$1,817,165
ARC			$2,895,366	$2,895,366
LE150100151 – Probe and engineer interactions in atomic-scale devices with a LT STM				
Academic partner		$342,200		$342,200
ARC		$760,000		$760,000
In-kind				
CE0348250 – Centre for Quantum Computer Technology				
Academic partner	$9,204,836			$9,204,836
Non-academic partner	$4,860,769			$4,860,769
CE1101027 – Centre of Excellence for Quantum Computation and Communication Technology				
Academic partner		$57,506,825		$57,506,825
Non-academic partner		$8,294,572		$8,294,572
CE170100012 – ARC Centre of Excellence for Quantum Computation and Communication Technology (Non-Lead) Hollenberg				
Academic partner			$84,019,609	$84,019,609
Non-academic partner			$7,971,925	$7,971,925

Contributor / Type of support	2003-2010	2011-2016	2017-2025	Total Contributions
LE150100151 – Probe and engineer interactions in atomic-scale devices with a LT STM				
Academic partner		$49,488		$49,488
Total	**$57,452,011**	**$104,427,723**	**$154,164,792**	**$316,044,526**

A timeline of CQC²T ARC grant funding is presented in Figure 7.2 below.

Figure 7.2 Timeline of CQC²T ARC grants



*The seven initial universities with Centre nodes were: University of New South Wales, University of Queensland, University of Melbourne, UNSW@ADFA, Griffith University, Macquarie University and University of Sydney
**The Centre for Quantum Computation and Communication Technologies

Source: ACIL Allen

7.5 Activities

The activities of the CQC²T are complex and spread across several quantum computing disciplines and include quantum communications. The Centre has 22 research programs run by program managers who are responsible for executing the detailed, milestone driven research program. These programs are organised into 9 work-packages[88] overseen by 9 research team leaders who coordinate the efforts of the different programs that contribute to the high-level work package milestones. Each program is linked to between 2 and 6 of the work packages. Sitting above this is the Centre Executive who coordinate, plan and provide effective control of the overall program.

Reporting[89] to the ARC has simplified these programs into 4 application areas, summarised below.

— **Intermediate quantum computing (IQC) —** Intermediate Quantum Computers provide a nearer-term realisation of quantum processors. A major goal of the Centre is to develop the technology to produce quantum processors at the intermediate scale (between 10 and 100 qubits[90]) based on silicon, optical or hybrid silicon/optical systems for simulation, sampling and adiabatic optimisation paradigms. Key breakthroughs in this space have included identifying the smallest quantum circuits capable of demonstrating quantum supremacy, providing benchmark performance for IQC devices, demonstrating the first integrated circuit with atomic precision that was able to simulate a polyacetylene molecule and demonstration that it is possible to develop quantum-enhanced machine learning for simulation thereby leveraging classical resources.

— **Universal Quantum Computing —** CQC²T is also developing long-term architectures for Universal Quantum Computing in both the silicon and optical platforms. This includes the design, fabrication, and measurement of a systematic series of devices for creating logical qubits to demonstrate complex operations and error-correcting codes. CQC²T is a world-leader in atom-based quantum computing in silicon, having invented and pioneered radical fabrication and measurement strategies to realise single-atom devices, including individual atom placement, single spin initialisation, manipulation, read-out and control. With results demonstrating the longest spin coherence times in a solid-state system, demonstrating world record single and two-qubit gate fidelities and patenting detailed architectures for scale-up, the research team is well positioned to realise fault-tolerant quantum computing processors. CQC²T's world-leading silicon program, anchored here in Australia, have also demonstrated the ability to optically address single dopant atom spins within a device architecture, providing a pathway for the long-term goal of linking solid state and optical architectures. CQC²T has also pioneered silicon metal-oxide-semiconductor (Si-MOS) quantum dot qubits, variants of commercial complementary metal-oxide-semiconductor (CMOS) transistor devices. Initially used to measure the electron and nuclear spins of atom qubits this program has since developed single and two-qubit gates with fidelities also sufficient for fault-tolerant quantum computing.

[88] The 9 work packages are: architecture & algorithms, scale-up engineering, logical qubits, quantum interconnects, protocol development, integrated optical platform, deterministic entanglement, memory technologies, and communication networks.

[89] Simmons, M.Y, 2020 and 2014, CQC²T Midterm Reviews, supplied by CQC² and 22 annual reports since 2000.

[90] A qubit (or quantum bit) is the quantum mechanical analogue of a classical bit. In classical computing the information is encoded in bits, where each bit can have the value zero or one. In quantum computing the information is encoded in qubits. A qubit is a two-level quantum system where the two basis qubit states are usually written |0⟩ and |1⟩. A qubit can be in state |0⟩, |1⟩ or (unlike a classical bit) in a linear combination of both states. Refer: https://www.quantum-inspire.com/kbase/what-is-a-qubit/

— CQC²T is also a world-leader in quantum optics, having pioneered both linear optics quantum computing and now cluster state and hybrid architectures. The ability to use photonic states for quantum computing (known as the KLM scheme[91]) was originally invented in the Centre with a first demonstration of an optical two-qubit gate in 2003. The Centre has subsequently demonstrated gold-standard, full characterisation of quantum processes; performed early error correction demos and applied quantum logic to tasks in measurement, fundamental science, and feedback control. Having demonstrated small-scale algorithms using photonic qubits the teams have since generated the largest cluster states for efficient measurement-based quantum computation that will integrate well with the secure communication systems. The Centre's work has driven a worldwide optical quantum computing research effort both in universities and industry.

— **Quantum Technology demonstrators** — CQC²T aims to realise dedicated systems that use quantum information to attain performance superior to classical computers. This includes developing quantum hard drives and portable quantum encryptors to achieve absolute security for cryptography use. Key breakthroughs in this space include the delivery of a telecom quantum memory, demonstrating telecom compatible quantum memory for storage times up to one second in $^{167}Er^{3+}:Y_2SiO_5$.[92] Using machine learning to establish state-of-the-art memory performance and the development of precision diamond-based quantum sensors for biomedical imaging applications

— **Quantum Internet**— CQC²T is a leader in quantum communications technology, particularly for the development of long-lived, highly efficient quantum memories and for high-speed random number generators. With the development of secure communications protocols and quantum key distribution (QKD) hardware, this program aims to improve cybersecurity for individuals, organisations, businesses, government and national infrastructure. The Centre is developing ultra-secure quantum communication networks and protocols for distributing entanglement and quantum information over extended distances using quantum cryptography and repeater networks. Key breakthroughs in this space include demonstrating the highest fidelity photon storage in an atomic vapour memory and developing an intra-1550nm communication band frequency converter.

7.6 Outputs

With over 2,200 papers CQC²T researchers and international partners have achieved numerous world-leading research outputs since 2000. This includes many reviews including 3 that have collectively garnered over 4,599 citations, "*Silicon Quantum Electronics*", Reviews of Modern Physics 85, 961 (2013); 776 citations; "*Gaussian Quantum Information*", Reviews of Modern Physics 84, 621 (2012); 2024 citations and "*Linear optical quantum computing with photonic qubits*", Reviews of Modern Physics 79, 139 (2007); 1799 citations.

Australia is a renowned world leader in silicon quantum computing. Here the teams have led the field demonstrating the highest quality qubits with the longest coherence times to date in the solid state using atom qubits in silicon, the most highly manufacturable material system with new programs now emerging in Si-MOS quantum dot quantum computing. In the optical program, Centre researchers are renowned for theoretically inventing the main techniques to make optical

[91] KLM stands for Knill, Laflamme, and Milburn, which are the surnames of the researchers who developed the Scheme.

[92] Spatial-spectral holography using spectral hole burning materials is a powerful technique for performing real-time, wide-bandwidth information storage and signal processing. For operation in the important 1.5 μm communication band, the material $Er^{3+}:Y_2SiO_5$ enables applications such as laser frequency stabilization, all-optical correlators, analog signal processing, and data storage. Refer: https://repository.usfca.edu/cgi/viewcontent.cgi?article=1062&context=phys

quantum computing practical and demonstrating key experimental milestones to confirm this. Significant highlight examples include:

— **Delivery of the world's first integrated circuit manufactured at the atomic scale**, which operates as an analogue quantum processor (Kiczynski et al., 2022).[93]. The Centre's quantum computing spin-out company, Silicon Quantum Computing Pty Ltd (SQC) used this quantum processor to accurately model the quantum states of a small, organic polyacetylene molecule – definitively proving the validity of the company's technology for modelling quantum systems. This has come less than a decade after the team's 2012 declaration that it had fabricated the world's first single-atom transistor (Fuechsle et al., 2012). Development of SQC's stable, low-noise atomic-scale circuit technology (Weber et al., 2012; Kranz et al. 2020) will not only allow the company and its customers to construct quantum simulations for a range of systems, including pharmaceuticals, materials for batteries, catalysts and new materials that have never existed before (SQC, 2022), but the high quality of the qubits are ideal for developing fault-tolerant processors (Hill et al, 2015).

— **Demonstrating the longest coherence times and highest single qubit fidelities:** Building off the success in demonstrating the first single electron spin qubit (Pla et al., 2012) and the first nuclear spin qubit (Pla et al, 2013) in silicon with record coherence times (Muhonen et al., 2014) (35 seconds) and quantum gate fidelities (Muhonen et al., 2015), the ion implantation program between the University of Melbourne and UNSW Sydney has recently shown that near error-free quantum computing is possible in atom qubits in silicon. Operations that are 99% error-free make it possible to detect errors and correct them when they occur. This result provides a critical step towards building universal quantum computers with low enough errors to handle meaningful computations (Madzik *et al,* 2022).

— **Precision manufacturing of atom qubits with world-leading qubit quality metrics:** The demonstration of our globally unique precision atom-scale manufacturing has allowed us to engineer each aspect of qubit quality for long-term scalability to achieve the fastest (Keith et al., 2019) and highest fidelity (Keith et al., 2022) qubit initialisation and read-out; the fastest 2-qubit gates (Gorman et al., 2019); the lowest charge noise qubit system (Kranz et al., 2020) and the demonstration of 3D integration in a monolithic chip (Koch et al., 2019). With both single and two-qubit gates reaching the fault-tolerant limit, these programs make long-term scaling of high-quality atom qubits in silicon a promising qubit platform for a large-scale, fault-tolerant silicon-based quantum computer.[94]

— **Quantum dot qubits:** In 2019, our quantum dot research teams demonstrated qubits in a second platform, quantum dot qubits in silicon as distinct from single atom qubits, that hold the fidelity benchmarks for both 1-qubit (Yang et al., 2019) and 2-qubit (Huang et al., 2019) logic gates for this platform. By using engineered control pulses and an isotopically enriched ^{28}Si device, the team at UNSW obtained a 1-qubit gate fidelity of 99.96% using Clifford-based randomised benchmarking, the highest reported to date in the quantum dot system. In 2020 the team also showed that SiMOS quantum dot qubits could maintain high fidelity at a temperature of 1.5 K, opening the possibility of qubit operation using simplified cryogenic systems (Yang et al., 2020).

— **Three modalities for Optical Quantum Computing:** The optical quantum computing team has pioneered a multi-pronged approach. In the first approach, quantum bits were encoded in the polarisation or spatial state of single photons where they developed new techniques for simplifying complex multi-qubit gates to implement real calculations using the iterative phase

[93] Note that to reduce the length of the case study, the full citation for the texts cited in this section are located in the publications and media releases section below.

[94] https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/CSIRO-futures/Future-Industries/Quantum

estimation algorithm (IPEA) using a small-scale quantum processor (Zhou et al., 2013). They then used these protocols to demonstrate the first 3 qubit Fredkin Gate, i.e. a controlled-controlled-NOT (R. B. Patel et al., 2016) and demonstrated Boson Sampling (Broome et al., 2013) – a problem believed to be intractable for classical computers. In the second approach, quantum information is carried by the states of optical modes, where in collaboration with PI Furusawa the optical quantum computing team showed that by multiplexing light modes in the time domain, they could deterministically generate and fully characterise a continuous-variable cluster state containing more than 10,000 entangled modes (Yokohama et al., 2013). This has since expanded to 10^4 to 10^6 entangled modes (Asavanant et al., 2019). Finally, in the third approach, a hybrid system combines qubit and modal techniques (Jeong et al., 2014) In collaboration with PI Furusawa, they demonstrated the teleportation of coherent superposition states, also known as Kitten states (Lee et al., 2011).

— **Noiseless linear amplification:** Noiseless linear amplifier (NLA) was first proposed in 2009 by Centre researchers at UQ as a way to probabilistically increase the signal-to-noise ratio of a quantum state.[95] A physical implementation of the NLA was experimentally demonstrated using quantum scissors and can be used to amplify qubits encoded in a photon's polarisation (Xiang et al., 2010). Since then, researchers have applied the NLA technology to demonstrate probabilistic cloning of information carrying coherent states (Haw et al., 2016) and to implement a high-fidelity squeezing gate (Zhao, 2020).

— **Integrated Optical Chip** By pioneering both linear optics quantum computing as well as cluster-state and hybrid architectures, the optical quantum computing researchers are now creating new integrated photonics platforms that can link to secure communications systems. They have demonstrated a first quantum optical chip that can generate, manipulate and measure quantum light using continuous variable protocols (Lenzini et al., 2018).

— **Providing the world's most popular and powerful online random number generator** (Symul et al., 2011). ANU Quantum Numbers (AQN) uses quantum technology to generate true random numbers at high speed and in real-time by measuring the quantum fluctuations of the vacuum. AQN is now available on AWS Marketplace. Random numbers are needed in IT, data science and modelling. Without random numbers, reliable forecasting and research simulation models are impossible. Artists also use them to help with removing human biases from their creative work. In computer gaming and smart contracts, true random numbers are also an indispensable resource.

— **Demonstrating quantum teleportation can be used to avoid loss in communication channels** on the quantum level. CQC²T researchers use both continuous variable and discrete variable quantum systems as the building blocks of quantum repeater networks. By extending quantum optical technology CQC²T researchers have enabled the transmission, storage, processing, and detection of quantum information for long distance quantum communication for quantum encryption and distributed quantum computing. Following the demonstration of the integrated optical chip in 2018 (Lenzini et al., 2018), where they were able to generate non-classical states of light, manipulate them in a reconfigurable way and then detect them, they were able to use teleportation to address the issues around inherent loss that occurs in communication channels (for example, internet or phone) and discover a mechanism to reduce that loss. This finding is an important step towards implementing the "quantum internet," which will bring unprecedented capabilities not accessible with today's web. This study was the first to demonstrate an error reduction method that improved the performance of a channel (Slussarenko et al., 2022). In collaboration with the Australian Space Agency, Defence Science and Technology Group, the German Aerospace Center,

[95] T.C. Ralph and A.P. Lund. 'Nondeterministic noiseless linear amplification of quantum systems', In AIP Conference Proceedings, vol. 1110, no. 1, pp. 155-160. American Institute of Physics, 2009.

CQC²T is now developing quantum components that are able to operate in space environment (Vogl et al., 2019).

Other key outputs, including publications and patents, are summarised below:

7.6.1 Publications and media releases

The Centre has published more than 2,203 papers, including more than 200 in the high impact factor (IF) Science and the Nature suite of journals, corresponding to more than one high-impact journal every month for the past 12 years.

The Centre publications from 2011 onwards have been cited 19,927 times, with 45 papers cited over 100 times.

Examples of recent and/or important articles are:

- Afach, S., et al. (2021). Search for topological defect dark matter with a global network of optical magnetometers. **Nature Physics** 17, 1396.
- Asavanant, W., et al. (2019). Generation of time-domain-multiplexed two-dimensional cluster state. **Science** 366, 373.
- Broome, M., et al. (2013). Photonic Boson Sampling in a Tunable **Circuit. Science**, Vol 339, Issue 6121, pp. 794-7
- Chrzanowski, H. M., et al. (2014). Measurement-based noiseless linear amplification for quantum communication. **Nature Photonics** 8, 333.
- Dehollain, J., et al. (2016). *Bell's inequality violation with spins in silicon*. **Nature Nanotechnology** 11, 242–246 (cover article).
- Fuechsle, M., et al. (2012). *A single atom transistor*. **Nature Nanotechnology** 7, 242.
- Haw, J.Y., et al. (2016). Surpassing the no-cloning limit with a heralded hybrid linear amplifier for coherent states. **Nature Communications** 7, 13222.
- He, Y., Gorman, S.K., et al. (2019). A fast (∼ns) two-qubit gate between phosphorus donor electrons in silicon. **Nature** 571, 371 (cover article).
- Hill, C., et al. (2015). *A surface code quantum computer in silicon*. **Science Advances** 1, e1500707.
- Hosseinidehaj, N., et al. (2021). Composable finite-size effects in free-space continuous-variable quantum-key distribution. Systems **Physical Review A** 103, 012605
- Huang, W., et al. (2019). Fidelity benchmarks for two-qubit gates in silicon. **Nature** 569, 532.
- Jeong, H., et al. (2014), *Generation of hybrid entanglement of light*. **Nature Photonics** 8, 564.
- Jiang, G.Y., et al. (2010). Heralded noiseless linear amplification and distillation of entanglement. **Nature Photonics** 4, 316.
- Keith, D., et al. (2019). Microsecond Spin Qubit Readout with a Strong-Response Single Electron Transistor. **Physical Review X** 9, 041003.
- Keith, D., et al. (2022). Ramped initialisation and measurement of semiconductor spin qubits. **Science Advances** 8.
- Kiczynski, M., et al. (2022). *Experimental realisation of the single particle Su-Schrieffer-Heeger model in phosphorus doped silicon quantum dots*. **Nature** 606, 694.
- Koch, M., et al. (2019). Spin read-out in atomic qubits in an all-epitaxial three-dimensional transistor. **Nature Nanotechnology** 14, 137 (cover article).
- Kocsis, S., et al. (2013). Heralded noiseless amplification of a photon polarization qubit. **Nature Physics** 9, 23.

- Kranz, L., et al. (2020). Exploiting a Single-Crystal Environment to Minimize the Charge Noise on Qubits in Silicon. **Advanced Materials** 32, 2003361 (cover article).
- Lanyon, B. P., et al. (2010). *Towards quantum chemistry on a quantum computer*. **Nature Chemistry** 2, 106.
- Lee, N., et al. (2011). Teleportation of Nonclassical Wave Packets of Light. **Science** 332, 330.
- Lenzini, F., et al. (2018). Integrated photonic platform for quantum information with continuous variables. **Science Advances** 4, No. 12.
- Mądzik, M.T., et al. (2022). Precision tomography of a three-qubit donor quantum processor in silicon, **Nature** 601, 348–353
- Marrero C.O., et al. (2021). *Entanglement Induced Barren Plateaus.* **PRX Quantum** 2, 40316.
- Muhonen, J., et al. (2014). *Storing quantum information for 30 seconds in a nanoelectronic device*. **Nature Nanotechnology** 9, 986–991 (cover article).
- Patel, R.B., et al. (2016). *A quantum fredkin gate*. **Science Advances**, 2(3).
- Pla, J.J., et al. (2012), *A single-atom electron spin qubit in silicon*. **Nature** 489, 541.
- Pla, J.J., et al. (2013). High-fidelity readout and control of a nuclear spin qubit in silicon. **Nature** 496, 334.
- Slussarenko, S., et al. (2022). Quantum channel correction outperforming direct transmission. **Nature Communications** 13, 1832.
- Symul, T., et al. (2011). Real time demonstration of high bitrate quantum random number generation with coherent laser light. **Appl. Phys. Letters** 98, 231103.
- Vahapoglu, JE., et al. (2021). Single-electron spin resonance in a nanoelectronic device using a global field. **Science Advances** 7
- Veldhorst, M., et al. (2014). A gate-addressable quantum dot qubit with fault-tolerant gate fidelity, **Nature Nanotechnology** 9, 981.
- Veldhorst, M., et al. (2015). *A two-qubit logic gate in silicon*, **Nature** 526, 410.
- Vogl, T., et al. (2019). Radiation tolerance of two-dimensional material-based devices for space applications. **Nature Communications** 10, 1202.
- Weber, B., et al. (2012). *Ohms Law survives to the atomic-scale*. **Science** 335, 6064.
- White, D., et al. (2020). *Atomically-thin quantum dots integrated with lithium niobate photonic chips*. **Optical Materials Express** 9 (2), 441-448 (2020 front cover of Laser and Photonics Review)
- Yang, C.H., et al. (2019). Silicon qubit fidelities approaching incoherent noise limits via pulse engineering. **Nature Electronics** 2, 151–158 (cover article).
- Yang, C.H., et al. (2020). Operation of a silicon quantum processor unit cell above one kelvin. **Nature** 580, 350
- Yokohama, S., et al. (2013). Ultra-large-scale continuous-variable cluster states multiplexed in the time domain. **Nature Photonics** volume 7, pages 982–986
- Zhao, J., et al. (2020) *A high-fidelity heralded quantum squeezing gate*. **Nature Photonics** 14, 306.
- Zhou, X.Q., et al. (2013). Calculating unknown eigenvalues with a quantum algorithm. **Nature Photonics** 7, 223.
- Zwanenberg, F.A., et al. (2013). *Silicon Quantum Electronics*. **Reviews of Modern Physics** 85, 961.

7.6.2 Major conference papers/presentations

Centre researchers are highly sought-after speakers and contributors to international conferences with over 1300 invited, plenary and keynote talks at international conferences since 2000. This includes meetings such as the Nobel symposium, American Physical Society March meeting, Institute of Electrical and Electronics Engineers (IEEE) meetings, International Electron Devices Meeting (IEDM), the world's preeminent forum for reporting technological breakthroughs in the areas of semiconductor and electronic device technology, Optical Society of America, International Conference on the Physics of Semiconductors, Silicon Quantum Electronics Workshops and many others. Australian quantum researchers are well-known and respected globally.

Models or tools

— **Benchmarking qubit read-out fidelity** – SQC and CQC²T have partnered to provide an on-line benchmarking tool for qubit read-out. This tool allows researchers to correctly determine qubit read-out fidelity and know how to optimise it so that different systems can be compared directly..[96]

— **Quantum Random number generator** – The ANU node has developed and demonstrated a real time, 2 Gbps random number generation scheme.[97] that has been verified using standard randomness tests. A stream of quantum random numbers is freely available on an open-access web-site (http://qrng.anu.edu.au), having attracted over 2.5 billion hits with more than 3 million independent visitors, who are able to verify the quality of our random numbers and use them for their own experiments. The ANU quantum random number generator is also developed into an on-demand ICT tool on Amazon Web Service Marketplace for computer scientists and developers who require dedicated high-speed access to entropy sources..[98]

7.6.3 Patents

CQC²T's vision was to lead the world in discovering and developing quantum information technologies and ensure long-term economic and strategic benefits for Australia. With this in mind, the Centre has implemented strong policies for IP protection and commercialisation from the outset. The success of this approach was demonstrated when in 2017, a public-private consortium (whose members included the Australian Government, Commonwealth Bank of Australia, Telstra, UNSW, and the NSW Government) invested $83 million into the company, Silicon Quantum Computing (SQC) tasked with developing the Centre's intellectual property in silicon-based quantum computing in a commercial context. This company has since thrived, attracting John Martinis (former head of Google's quantum computing initiative) to Australia in 2020 and achieving a series of world-leading developmental milestones that complement the fundamental discovery work that has continued in CQC²T. Intellectual property developed by the team at UNSW is continuing to be patented and licenced to SQC to provide a vehicle for the kind of development work that cannot be sustained within an ARC-funded university research program. In 2022 Silicon Quantum Computing spun out a second quantum computing hardware company based on Si-MOS quantum dot technology, Diraq to pursue this technology commercially.

More broadly, across all nodes, the Centre actively protects its intellectual property. Seven provisional patents are supported from Centre work at UM, RMIT, Griffith University, UTS and ANU. In addition to QuintessenceLabs, which was established in 2017, the ANU node of the Centre

[96] D. Keith et al. (2019). New Journal of Physics 21, 063011 has been provided as an online tool on Github:silicon-quantumcomputing/qubit_readout.

[97] Symul, T., et al. (2011). Real time demonstration of high bitrate quantum random number generation with coherent laser light. Appl. Phys. Letters 98, 231103.

[98] Refer: https://aws.amazon.com/marketplace/seller-profile?id=e78f02ee-ea04-4fc2-8b56-456f2dc2ffc8.

has also recently spun out a company, Aqacia, that uses state-of-the-art artificial intelligence to provide solutions to complex problems for key quantum technology industries.

There have been over 100 granted patents over 43 patent families in the centre-related portfolio with an additional 50 patents pending or at the PCT phase. The Centre's IP includes techniques for developing globally unique technologies to manufacture qubits at the atomic-scale, to operate high quality 2-qubit gates in silicon and highest fidelity qubits in the solid state.

Examples include:

- *Nanoscale and Atomic-scale Device Fabrication Method (2004).*[99]
- *Implanted counted dopant ions (2005).*[100]
- *Method for fabricating atomic-scale multi-terminal devices (2008).*[101]
- *2D surface code UQC architecture without interconnects (2015).*[102]
- *A method for selective incorporation of dopant atoms in a semiconductive surface (2015).*[103]
- *Systems and methods for initialising and measuring qubits (2021).*[104]

7.6.4 Awards and recognition

Many of the Chief investigators have achieved significant recognition. Over the past decade, these have included:

- **2021:** Director Prof Michelle Simmons was awarded the Bakerian Medal and Lecture, Royal Society of London and was Chair of the Division of Quantum Information for the American Physical Society; Prof Sven Rogge was the President of the Australian Institute of Physics.
- **2020:** Professor Ping Koy Lam, became a Fellow of the Australian Academy of Science and Prof Elanor Huntington, became a Fellow of the Australian Academy of Technology and Engineering (ATSE).
- **2019**: Director Prof Michelle Simmons was awarded an Officer of the Order of Australia; Prof Andrew Dzurak was awarded an ARC Laureate Fellowship; Prof Elanor Huntington was a Finalist of the CSIRO Eureka Prize, Leadership in Innovation and Science and the Telstra Business Women of the Year, Academia. Dr Alberto Peruzzo won a Google Faculty Research Award
- **2018:** Director Prof Michelle Simmons was made 2018 Australian of the Year and elected a Fellow of the Royal Society of London; Prof Lloyd Hollenberg was elected to the Australian Academy of Science; Prof Geoff Pryde was elected a Fellow of the Optical Society America; Associate Professor Mirko Lobino was awarded an ARC Future Fellow and Dr Rose Ahelfeldt, was named ACT Scientist of the Year.
- **2017**: Director Prof Michelle Simmons was awarded the L'Oréal-UNESCO Laureate in Physical Sciences and the George R. Stibitz Computing Pioneering Award by the American Computer Museum; Professor Andrea Morello was made a Fellow of the Royal Society of NSW and Pollock Memorial Lectureship Winner; Dr Arne Laucht, UNSW was made a Scientia Fellow; Professor Elanor Huntington was made an Honorary Fellow of Engineers Australia; Professor Tim Ralph was made a Fellow of the Australian Academy of Science; Professor

[99] Refer: https://patents.google.com/patent/WO2005019095A1/en.
[100] Refer: https://patents.google.com/patent/AU2005242730B2.

[101] Refer: https://patents.google.com/patent/WO2009097643A1/en.

[102] Refer: https://patents.google.com/patent/AU2015252051B2/en.

[103] Refer: https://patents.google.com/patent/US10229365B2/en?oq=10229365.

[104] Australian Patent: 2022228109, 22nd December (2021). Under examination in Canada, USA, Europe, Japan, China, Taiwan, South Korea, Singapore.

Howard Wiseman a Fellow of the Optical Society and Dr Alberto Peruzzo was awarded a Gold Medal for the 2017 Humies Awards at the Gecco Conference.

- **2016**: Prof Michelle Simmons was awarded the Feynman Prize in Nanotechnology from the Foresight Institute Awards, Prof Lloyd Hollenberg was awarded the Royal Society of Victoria Medal for Excellence in Scientific Research, Prof Andrea Morello was elected a Fellow of the American Physical Society and made the inaugural recipient of the Rolf Landauer and Charles H. Bennett Award, Prof Sven Rogge was elected a Fellow of the American Physical Society and Prof Howard Wiseman was elected a Fellow of the Optical Society (OSA).
- **2015:** Prof Michelle Simmons was awarded the Thomas Ranken Lyle Medal from the Australian Academy of Science, the CSIRO Eureka Prize for Leadership in Science and the Royal Society of New South Wales Walter Burfitt Prize.
- **2014:** Prof Michelle Simmons was elected member of the American Academy of Arts and Sciences. A/Prof Andrea Morello was awarded the David Syme Research Prize; Professor Elanor Huntington became the Dean of ANU College of Engineering and Computer Science and Professor Geoff Pryde awarded the Pawsey Medal from the Australian Academy of Science.
- **2013:** Director Prof Michelle Simmons and Deputy Director Prof Lloyd Hollenberg were awarded ARC Laureate Fellowships; A/Prof Andrea Morello was awarded the PM's Malcolm McIntosh Prize for Physical Sciences; Prof Lloyd Hollenberg was awarded the Victoria Prize for Science; the AIP Boas Medal and the Eureka Prize for Excellence in Interdisciplinary Research; Prof David Jamieson was awarded the AIP Outstanding Service to Physics Award; Professor Andrew White was awarded a Fellowship of the Australian Academy of Science and Dr Ben Buchler appointed to Associate Professor.
- **2012:** Prof Andrew Dzurak was awarded NSW Science and Engineering Award for Excellence in Engineering and Information and Communications Technology; Prof Michelle Simmons was elected as a Fellow to the UK Institute of Physics; Dr Andrea Morello was appointed to Associate Professor.
- **2011:** Prof Michelle Simmons was awarded NSW Scientist of the Year; Prof Andrew Dzurak and Dr Andrea Morello Eureka Prize for Scientific Research; Prof Sven Rogge and Associate Professors Geoff Pryde awarded ARC Future Fellowships; Professor Howard Wiseman was elected a Fellow of the APS.

7.6.5 Innovation / commercialisation

The ongoing success of CQC^{2}T has led to the development of 4 Australian quantum information companies:

- **QuintessenceLabs** for secure communication systems was launched in 2007 and produces encryption key and policy management products that conform to the Key Management Interoperability Protocol (KMIP), as well as a hardware quantum random number generator, development of a quantum key distribution (QKD) system, and other encryption solutions that include automatic key zeroization. The company is exporting these information security products to companies in Australia and the USA. Some of its commercial partners include PKWare, NetDocuments, VMware, Penten and Westpac.
- **Silicon Quantum Computing (SQC):** Australia's first quantum computing company, which focuses on atom-based quantum computing in silicon, was launched in 2017..[105] SQC is a unique corporate-Government-University start-up established with $83.7 million in funding from the Commonwealth Government, the Commonwealth Bank, Telstra, UNSW Sydney and the State Government of NSW. SQC is spearheading the manufacture of processors in silicon at the atomic-scale and is a global leader in the race to manufacture the world's first commercial

[105] https://newsroom.unsw.edu.au/news/science-tech/national-centre-excellence-quantum-opens-unsw

quantum computer. Since May 2017, SQC has assembled a world-class team of approximately 50 quantum scientists, engineers, and technicians along with specialist equipment and a globally unique atom-scale manufacturing foundry at UNSW to realise a quantum computer here in Australia. In addition to its core technology, SQC is developing a 'full stack' quantum processor to ensure it can deliver a useful and manufacturable quantum computer.

- **Diraq:** In 2022, Silicon Quantum Computing spun out Diraq, another silicon-based quantum computing company that focusses solely on silicon quantum dot qubits. Originally developed as read-out transistors for atom-based qubits, Diraq's quantum dot technology is compatible with existing Complementary metal–oxide–semiconductor (CMOS) processes where they aim to partner with international foundries.
- **Aqacia**: The ANU node of the Centre has also recently spun out a company, Aqacia, that uses the state-of-the-art artificial intelligence work to provide solutions to complex problems for key quantum technology industries. Aqacia uses neural network based technology to simultaneously optimise up to thousands of parameters in complex processes.[106]

7.7 Outcomes

Quantum information is a transformational technology that will create the next information revolution, delivering quantum hardware for ultra-fast computing, secure communications and precise quantum sensing. Many new start-up companies are emerging in quantum information technology presenting extraordinary opportunities in areas such as transformational computing power, cyber-security, and cryptography. CQC²T's vision is not only to lead the world in the discovery and development of these technologies, but also to ensure that there is a long-term economic and strategic benefit for Australia.[107] CQC²T researchers are working at the forefront of quantum information technology and innovation, which are expected to significantly impact the global economy. According to UNSW President and Vice-Chancellor Professor Ian Jacobs, "quantum computing not only has the potential to completely revolutionise the way many of us will work but could create jobs and even new industries we haven't even imagined yet".[108]

A number of businesses are beginning to explore the potential applications of quantum computers to their future operations. Examples of the private businesses that have invested in Silicon Quantum Computing (SQC) and its relationship with CQC²T include:

- **Commonwealth Bank of Australia:** the university – industry partnership between the Commonwealth Bank of Australia and the Simmons team at CQC²T started in 2013 with a collaborative research agreement. This has since grown into Commonwealth Bank of Australia becoming a shareholder in SQC. Ultimately the Commonwealth Bank of Australia is interested in ensuring value from quantum computing applications in the Finance sector and capturing the opportunity for Australia to become a quantum technology-enabled economy.
- **Telstra**: Telstra, Australia's largest telecommunications industry, recognises that innovation arising from research in quantum computing is likely to be disruptive for the telecommunications industry. Following the success of the CBA partnership, SQC also partnered with Telstra with the aim of using quantum computing to solve complex optimisation problems. Telstra remains enthusiastically committed to the development of the globally leading atom-scale silicon hardware technology developed in SQC/CQC²T.
- **Zyvex Corporation:** Zyvex Labs is a Texas-based nanotechnology company and has been a long-term partner of CQC²T since its inception at the start of 2011. Zyvex Labs is working with SQC and CQC²T to develop a fully automated Scanning Tunnelling Microscope based

[106] Simmons, M, 2020, CQC²T Midterm Review, supplied by CQC²T

[107] Ibid.

[108] https://newsroom.unsw.edu.au/news/science-tech/national-centre-excellence-quantum-opens-unsw

hydrogen depassivation lithography tool for faster, more reliable atomic-scale lithography. This co-development project ensures the long-term scalability of the technology being developed by the Australian team.

— **Silex Systems:** Silex Systems Limited is an Australian technology company focused on the commercialisation of innovative Separation of Isotopes by Laser Excitation (SILEX) technology for application to zero spin, isotopically pure silicon quantum computing. SQC and its partnership with CQC^{2}T have formed a joint development agreement with Silex on a CRC-P grant to deliver high purity isotopically pure ^{28}Si, a key feedstock material globally for silicon quantum computing.

The CQC^{2}T has been widely recognised around the world for its extraordinary contribution to the field of quantum computing and communications.

Professor Sankar Das Sarma, Distinguished University Professor and Director of the Condensed Matter Theory Center at the University of Maryland, and the US's most highly cited condensed matter theorist, was previously Chair of the CQC^{2}T International Scientific Advisory board. He provided a statement, noting that:

> *The [CQC^{2}T] is an example of excellence, a leader in quantum computing research on solid state systems, particularly silicon-based quantum computing efforts. It is quite unique as its approach is 'bottom up' using scanning tunnelling microscope and atomic force microscope techniques, rather than top down using lithography as in all other silicon-based quantum computing efforts worldwide.*
>
> *CQC^{2}T has excellent leadership and is well-placed to make breakthroughs […] Overall, CQC^{2}T has contributed a great deal to silicon quantum technologies over the years, and I am delighted that I played a crucial role in getting it started and helping it achieve excellence and maturity.*

Professor Klaus Ensslin, Director of Swiss Centre for Research in Quantum Science and Technology and Professor of Solid-State Physics at ETH – Zurich is the current Chair of the CQC^{2}T International Scientific Advisory board. He stated:

> *The CQC^{2}T Centre at UNSW consists of excellent scientists that cover a broad area within quantum science. The Center presently focuses on 3 directions, namely 1. Quantum computing with Si-spin qubits, 2. Optical quantum computing and 3. Quantum communication. This combination makes the Center unique worldwide. Other Centers mostly focus on one of these topics or have a narrower focus in general. In addition, CQC^{2}T has a critical number of researchers in all of these 3 subfields. Senior researchers collaborate across different universities and groups. These collaborations are essential and they demonstrate that CQC^{2}T is more than an assembly of individual excellent researchers. Australia truly has a marvellous research endeavour on Quantum Computation and Communication Technology that has been going on since 2000.*

Professor Michelle Simmons, Director of the CQC^{2}T, noted during consultations that she came to Australia specifically for the ARC grants program:

> *I specifically moved to Australia because of two of the main funding programs offered at that time by the ARC, the ARC QEII Research Fellowship and the ARC Special Research Centre scheme. These competitive programs allowed younger researchers to take on leadership roles at an early age and develop large, collaborative and ambitious research projects. The combination was unbeatable. I now see other nations try to replicate the ARC Centres of Excellence, but Australia stands out in this space and should be very proud and grateful of the opportunities this has provided and delivered for the nation.*

This not only demonstrates the significant impact that the CQC^{2}T research has had globally, but also that ARC has succeeded in attracting and supporting world-class research in Australia.

7.7.1 Alignment with government strategic priorities

Quantum computing aligns with several of the National Science and Research Priorities, including transport cybersecurity; energy; resources; advanced manufacturing; environmental change, and health. This is because quantum computing has the potential to dramatically improve existing processes in these fields. For example, quantum simulations and quantum computing could enable faster and more accurate civil engineering projects, allowing us to save time on infrastructure activities like roadworks, thus improving the transportation sector..[109]

Given the significant potential of quantum technology in Australia, the Government has invested heavily in this space. Several government and non-government bodies and initiatives have been established to advance Australia's quantum capability.

The National Quantum Strategy outlines Australia's vision for the quantum industry..[110] Australia's Chief Scientist Dr Cathy Foley is guiding the strategy with other experts from the Quantum Advisory Committee, which was established by the Department of Industry, Science and Resources in September 2022..[111]

An example of a quantum computing initiative at the state government level is the NSW Government's Quantum Computing Commercialisation Fund. The 2022 program provided grants of between $200,000 to $4 million for projects that progress quantum computing hardware and/or software towards commercialisation within NSW.

Other initiatives have also been established to collaborate with and provide advice to government. The Sydney Quantum Academy is driving collaboration between academia, industry, and government to explore the opportunities of Australia's quantum economy. Tech Council's Australian Quantum Alliance is an industry collaboration with members including Silicon Quantum Computing, Quintessence Labs, Quantum Brilliance, Diraq, Google and Microsoft, which provides advice to decision-makers and the public on the adoption of quantum technology..[112]

7.8 Impacts

7.8.1 Economic impacts

Quantum computing technology is likely to have significant global economic impacts. McKinsey[113] has examined 4 industry use cases and estimated global impacts of quantum computing to be $US300-700 billion by 2035. The 4 industries expected to realise these early benefits are pharmaceuticals, chemicals, automotive and finance..[114]

[109] Ibid.

[110] https://www.industry.gov.au/news/australias-vision-quantum

[111] https://www.industry.gov.au/news/national-quantum-advisory-committee-strengthen-australias-quantum-industry

[112] https://techcouncil.com.au/members/quantum/

[113] McKinsey & Co, 2021, Quantum computing: An emerging ecosystem and industry use cases, accessed on 30 December 2022 at https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/quantum%20computing%20use%20cases%20are%20getting%20real%20what%20you%20need%20to%20know/quantum-computing-an-emerging-ecosystem.pdf

[114] https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/CSIRO-futures/Future-Industries/Quantum

In Australia, CSIRO has estimated that in 2040 Quantum technology will contribute $4.6 billion with over 16,000 jobs to the Australian economy..[115] Of these figures:

— Quantum computing will contribute $2.8 billion and 10,300 jobs.
— Quantum communications will contribute $0.9 billion and 2300 jobs.
— Quantum sensing and measurement will contribute $0.9 billion and 3500 jobs.

This analysis is based on the expected use of Quantum technology in healthcare and medicine, natural resources, defence and financial services. The CSIRO roadmap notes that global quantum industry is maturing rapidly as nations invest in technology advancement.

Cost benefit analysis

The cost-benefit analysis (CBA) undertaken for this case study estimates the value of the ARC-funded research to the Australian economy and does not consider impacts on the global economy.

Counterfactual

The CQC²T remains a hugely ambitious undertaking, which continues to put Australia at the forefront of quantum physics globally. Given its position as an industry leader, it is well-established that without the success of the Centre, Quantum computing technology in Australia would not be as advanced as it is today.

Indeed, in their 2020 Annual report the Centre stated that:

> *"The realisation of a single atom transistor, where a single phosphorus atom has been used as the smallest functional element of the device, achieving a technological milestone ten years ahead of industry predictions"*

Therefore, we will assume that under the reference case (present day scenario) Australia's quantum capability is 10 years ahead compared to the counterfactual scenario (scenario with no ARC funding).

Attribution

Attribution describes the percentage of benefits that can be reasonably attributed to the ARC, due to their role in the funding of the research.

The attribution of this CBA is twofold. First, the overall attribution of Australia's quantum opportunity to CQC²T estimated as:

— 75% for quantum computing.
— 70% for quantum communications.
— 5% for quantum sensing and measurement.
— These estimates are based on the CQC²T being the leading focussed research effort in quantum computing and communications in the country..[116] The assumptions for quantum computing and communications have been tested below.

[115] CSIRO, 2022, https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/future-industries/quantum

[116] Figures are based on discussions with CQC²T. CQC²T has been running for 23 years being highly focussed on quantum computing throughout this time and incorporating quantum communications in 2011. In 2011 CQC²T also spun out a second Centre, EQUIS whose focus has been on quantum materials, quantum engines and quantum imaging systems. EQUIS has a greater focus on quantum sensing and measurement, hence why only 5% of these benefits are attributed to CQC²T in the CBA. This figure was not tested given the small proportion that has been attributed.

Then, the benefits attributed to the CQC²T are adjusted for attribution to the ARC. Based on the proportion of ARC funding compared to other Centre funding, an attribution of the Centre's benefits to ARC has been set to 31%. This assumption has also been tested below.

Methodology and key assumptions

The CBA estimates the identified costs and benefits relating to the potential quantum market in Australia. The CBA compares the total costs of the research funding (see Section 7.4) to the estimated opportunity in quantum computing; quantum sensing and measurement; and quantum communications that can be attributed to the ARC-funded research. The estimated benefits of Australia's quantum opportunity are based on modelling undertaken by CSIRO in 2022..[117]

The following assumptions underpin the CBA:

— A discount rate of 7% was used in the central case. A discount rate of 3% was used as a lower-bound sensitivity and a discount rate of 10% was used as an upper-bound sensitivity.

— Australia's quantum opportunity and variable growth rates in computing, sensing and measurement and communications are in-line with the figures proposed by the CSIRO in their 2022 report.

— The counterfactual scenario is that Australian quantum capability is 10 years ahead due to the ARC-funded research. Thus, benefits begin to fall from 2032 (when benefits would have likely occurred even in the absence of ARC funding).

— The analysis period is from 2003 (from the start of ARC funding) to 2037 (a 35-year analysis period, inclusive of starting year). This is consistent across the CBAs for the case studies in the ARC report.

Costs

The nominal costs included in the CBA are the cash and in-kind contribution of the ARC, academic, and non-academic partners (see Section 8.4). These nominal costs are adjusted for inflation using the Consumer Price Index by year, which produces the real costs (costs in 2022 dollars).

Benefits

The benefits are the estimated opportunity in quantum computing; quantum sensing and measurement; and quantum communications that can be attributed to the ARC-funded research.

The nominal benefits by year are calculated by taking the estimated benefits in each of the above quantum fields, adjusting for attribution to CQC²T, and adjusting that figure for the attribution to the ARC-funded research:

$$\begin{aligned} &Australian\ quantum\ opportunity\ (\$) \times attribution\ to\ CQC^2T\ (\%) \\ &\quad \times attribution\ to\ ARC\ funded\ research(\%) \\ &\quad = Nominal\ benefit\ (\$)^{118} \end{aligned}$$

[117] CSIRO, 2022, Growing Australia's Quantum Technology Industry: Updated economic modelling, available online at: https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/future-industries/quantum

[118] For example, in 2022, using CSIRO growth estimates, the size of the Quantum opportunity in Australia was estimated at $650,725,820. Of this figure, $394,982,225 is the opportunity in quantum computing, $157,826,347 is the opportunity in quantum sensing and measurement, and $97,917,248 is the opportunity for quantum communications. This is adjusted for the attribution of the CQC²T, which is estimated at 75% for quantum computing, 5% for quantum computing and measurement and 70% for quantum communication. The figure attributed to CQC²T in 2022 is $372,670,060. This is adjusted for attribution to the ARC (31%), which results in a total nominal benefit of $115,527,719 for 2022.

These nominal benefits are adjusted for inflation using the Consumer Price Index by year, which produces the real benefits (benefits in 2022 dollars).

Calculation of NPV and benefit-cost ratio

The estimated benefits and costs are provided in Table 7.2 for discount rates of 3, 7 and 10%

The benefit-cost ratio (BCR), obtained by dividing the present value of benefits by the present value of costs using a 7% real discount rate is above one at a value of 6.53. The present value of costs is $637.7 million, the benefits are estimated at $4,164.7 million, resulting in a NPV of $3,527.0 million.

Table 7.2 Summary of benefits and costs (2022$)

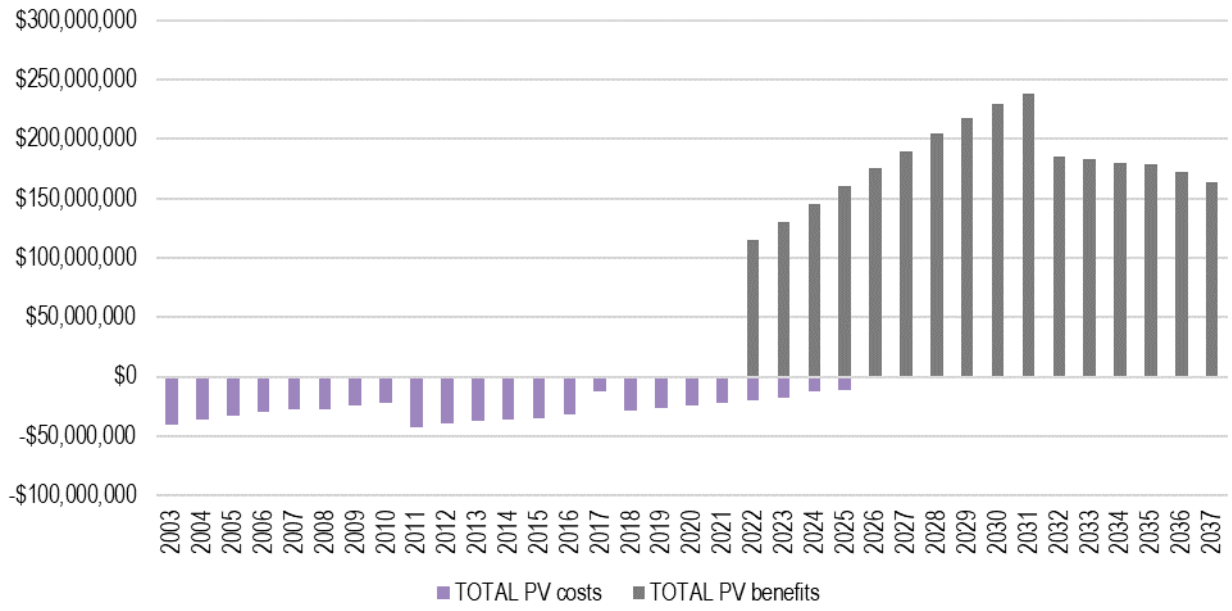
	Discount rate 3%	Discount rate 7%	Discount rate 10%
Present value costs			
ARC-funded research costs	$458,340,720	$637,737,772	$839,084,252
Present value benefits			
Benefit from quantum computing opportunity in Australia	$2,972,096,087	$2,184,194,052	$1,775,941,530
Benefit from quantum sensing and measurement in Australia	$61,223,822	$45,756,605	$37,683,012
Benefit from quantum communications in Australia	$886,442,581	$639,090,945	$512,353,984
Total PV benefits	$3,919,762,490	$2,869,041,601	$2,325,978,527
Results			
NPV	**$3,461,421,770**	**$2,231,303,830**	**$1,486,894,275**
BCR	**8.55**	**4.50**	**2.77**

Source: ACIL Allen

Note: All discount rates are real (i.e. discount rates are applied to real costs and benefits)

The present value of benefits and costs of the ARC-funded research by year are shown in Figure 7.3. The figure shows that the inputs of the Centre occur between 2003 and 2025. Benefits begin to flow from 2022 (as per CSIRO modelling of growth in Australia's quantum sector), and flow to the end of the analysis period in 2037. Benefits begin to fall in 2032, noting that this is when benefits are likely to start flowing under the counterfactual case.

Figure 7.3 Present value costs and benefits by year (7% DR)



Source: ACIL Allen

Sensitivity testing

Sensitivity testing at the 3% and 10% real discount rates[119] was conducted for this analysis (see Table 7.2 above). Sensitivity testing at these 3 rates shows that although the magnitude of the NPV changes at these 3 rates, the NPV remains positive even at a high discount rate of 10%.

Sensitivity testing was also conducted for the attribution of CQC^{2}T benefits to the ARC-funded research. The central case was an attribution of 31% based on the proportion of ARC's funding as opposed to other funding partners. The Cost Benefit Analysis results were tested with a lower bound attribution of 10% attribution (approximately 20% below the central case) and an upper bound attribution of 100% (approximately 20% above the central case). The results in Table 7.3 show that the Net Present Value would fall from $2.2 billion to $287.8 million, and the BCR would fall from 4.50 to 1.45 if the attribution fell to 10%. Whereas the NPV would rise to $3.9 billion, and the BCR would rise to 7.26 if the attribution increased to 50%. The estimated NPV of this research to the ARC remains above one even when the attribution to the ARC was significantly reduced. If the attribution was set to 100% (this effectively removes attribution to ARC and shows the quantum opportunity in Australia that can be attributed to the CQC^{2}T), the costs would be $637.7 million, the benefits would be $9.3 billion, resulting in an NPV of $8.6 billion and a BCR of 14.51.

Table 7.3 Sensitivity testing attribution of CQC^{2}T benefits to ARC-funded research (7% discount rate)

	10% attribution to ARC	31% attribution to ARC	50% attribution to ARC
Costs	$637,737,772	$637,737,772	$637,737,772
Benefits	$925,497,291	$2,869,041,601	$4,627,486,454
Net impact	**$287,759,519**	**$2,231,303,830**	**$3,989,748,682**
BCR	**1.45**	**4.50**	**7.26**

[119] The 3% and 10% discount rates are the Federal Government Office of Impact Analysis' recommended rates for sensitivity testing. Refer: https://oia.pmc.gov.au/sites/default/files/2021-09/cost-benefit-analysis.pdf.

Sensitivity testing was also conducted for the attribution of Australia's quantum opportunity in computing and communications to the CQC²T. The researcher requested that quantum computing and quantum communications be separated for this sensitivity analysis.[120] To do this, an assumption was made that 72% of all costs could be attributed to quantum computing, and 28% of all costs could be attributed to quantum communications, based on the financial information held by the researcher. Quantum sensing and measurement research costs could not be disaggregated from the quantum computing and quantum communications costs.

For quantum computing, the central case was an attribution of 75% to the CQC²T. The Cost Benefit Analysis results were tested with a lower bound attribution of 50% (significantly lower than the central case) and an upper bound attribution of 100% (if all benefits were attributed to the CQC²T). The results in Table 7.4 show that the Net Present Value would fall from $1.7 billion to $996.9 million and the BCR would fall from 4.76 to 3.17 if the attribution fell to 50%. Whereas the Net Present Value would rise to $2.5 billion and the BCR would rise to 6.34 if the attribution increased to 100%. This shows that the NPV remains significant even at the lower bound test of 50% attribution of quantum computing benefits to CQC²T.

Table 7.4 Sensitivity testing attribution of Australian Quantum computing opportunity to CQC²T, using only quantum computing costs and benefits (7% discount rate)

	50% attribution to CQC²T	75% attribution to CQC²T	100% attribution to CQC²T
Costs	$459,171,196	$459,171,196	$459,171,196
Benefits	$1,456,129,368	$2,184,194,052	$2,912,258,736
Net impact	**$996,958,172**	**$1,725,022,856**	**$2,453,087,540**
BCR	**3.17**	**4.76**	**6.34**

For quantum communications, the central case was an attribution of 70% to the CQC²T. The Cost Benefit Analysis results were tested with a lower bound attribution of 50% (significantly lower than the central case) and an upper bound attribution of 100% (if all benefits were attributed to the CQC²T). The results in Table 7.5 show that the Net Present Value would fall from $460.5 million to $277.9 million and the BCR would fall from 3.58 to 2.56 if the attribution fell to 50%. Whereas the Net Present Value would rise to $734.4 million and the BCR would rise to 5.11 if the attribution increased to 100%. This shows that the NPV remains significant even at the lower bound test of 50% attribution of quantum communications benefits to CQC²T.

Table 7.5 Sensitivity testing attribution of Australian Quantum communications opportunity to CQC²T, using only quantum communications costs and benefits (7% discount rate)

	50% attribution to CQC²T	70% attribution to CQC²T	100% attribution to CQC²T
Costs	$178,566,576	$178,566,576	$178,566,576
Benefits	$456,493,532	$639,090,945	$912,987,064
Net impact	**$277,926,956**	**$460,524,369**	**$734,420,488**
BCR	**2.56**	**3.58**	**5.11**

[120] Sensitivity analysis conducted for the other ARC case studies holds all other values constant except for the variable being tested. The researcher requested that for the sensitivity analysis of the attribution of Australia's quantum opportunity in computing and communications to the CQC²T, that the benefits and costs of quantum computing and communications be split out, to ensure that the reader can see the impact of the quantum computing research to the quantum communications research.

7.8.2 Social impacts

The successful commercialisation of quantum computing technologies can also enhance environmental and social outcomes such as energy savings from more efficient computation, better health outcomes through improved drug design using quantum simulation, more environmentally friendly chemicals development, and safer materials.[121]

Educational impacts

Over the course of the Centre 275 PhD, 65 Master students and 229 Honours have graduated or worked with the Centre. Of these undergraduate students, many obtain a first-Class Honours degree or win the University Medal. Eight Centre PhD students have won the prestigious Australian Institute of Physics Bragg Medal for the best PhD in physics since 1995.

In addition, each year, the Centre holds a tools-down full-day workshop dedicated to primary and high school students at UNSW, attracting approximately 200 students per year to tour the facilities and get to see the research in action. The Centre has a focus on increasing the number of girls and women in STEM, engaging with them from the primary level, through secondary and all the way through to our research leaders. The Centre also strongly believes in promoting the achievements of female researchers within CQC²T.

Employment impacts

In 2000 the Centre employed 82 people and in 2023 this has grown to 238 people. The total number of staff employed at the Centre since 2000 is 951. Of these 569 were students, and 382 were university staff.[122]

For 25 years the Centre has employed a yearly average of 180 full-time equivalent (FTE) staff. The current number of FTE staff in the Centre is 238. Since 2017 the Centre has also spun out 4 companies that employ 122 people.[123]

7.8.3 Other impacts

Research capability

The CQC²T has been a pioneer in quantum information technologies and the approaches to conducting large-scale deep technology quantum research in Australia. The Centre for Quantum Computing Technology was started in 2000 when researchers[124] joined from across the globe to establish a program in silicon quantum computing at UNSW that combined with the nascent optical quantum computing programs at UQ. The tremendous success of the research results and rapid development of the technology encouraged Centre researchers to advocate with the ARC for a new scheme that was more focussed and with higher funding. The Centres of Excellence scheme was started in 2003 and CQCT became a Centre of Excellence in 2003, making it one of the first Centre's of Excellence to be established. The Centre expanded in 2011 to include quantum communications, primarily at ANU, becoming CQC²T. With the Centre growing every year and producing globally leading research, it became so large that in 2011 it created a second Centre EQUIS of younger researchers focussing on engineering quantum systems whilst the core team at CQC²T maintained its focus on building optical and silicon-based processors.

[121] Ibid.

[122] University staff is made up of 44 tenured academic staff, and 338 research, technical staff and professional staff.

[123] 41 FTE at Quintessence Labs, 49 FTE at Silicon Quantum Computing, 27 FTE at Diraq, and 5 FTE at Aqacia.

[124] The researchers were Clark, Simmons, Dzurak, Hamilton, Hollenberg, Jamieson, Kane, Prawer

As the silicon technology started to cross the technical readiness levels (TRL) from TRL 3 to TRL 4.[125] Centre Director Simmons established a unique corporate-Government-University consortium to help the silicon quantum computing technologies cross the "Valley of Death", that is, to assist quantum technology transition from prototype to product. SQC was spun out in 2017, and from SQC Diraq was spun out in 2022. As the Centre grows, more than 6 Centres of Excellence have emerged in quantum physics across Australia (CQC²T, EQUIS, Exciton Science, Future Low-Energy Electronics Technologies (FLEET), Quantum Biotechnology and Gravitational Wave Discovery), demonstrating Australian strength in this field. In addition, the Centre for Quantum Software and Information at UTS recently launched the Australian Quantum Software Network.[126] Quantum science and technology is an area where Australia has unequivocal global leadership.

7.9 Potential future impacts

As discussed throughout this case study, Australia has strong research capabilities in quantum hardware development, quantum measurement, architecture development and the theory of quantum information science, all of which are critical to developing the hardware and software stack needed to enable functional quantum computing applications.[127] The country is already home to world-leading ventures undertaking the development of silicon-based quantum computing technology, quantum communication technologies and other quantum control-based technologies.[128] Australia has also attracted key international players, including Microsoft, IBM, Rigetti Computing and ColdQuanta, who have established a local presence to exploit Australia's quantum capabilities. The US Army Research Office has also been a notable funder of the Silicon Quantum Computing programs at UNSW, investing more the $36 million over the past 20 years. This shows that the potential future impact is significant and recognised by Australian governments, the private sector, and international players. This is expected to become an increasingly competitive space in the future.

Professor Klaus Ensslin, current Chair of the CQC²T International Scientific Advisory board stated that:

> *The Center director, Prof. Simmons, is not only an outstanding scientist, but has a hands-on management style, and is dedicated to the full breadth of the Center. Her forward-looking attitude when thinking about future research directions and possibilities for collaborations is impressive.*

This demonstrates that CQC²T leadership intends to continue to collaborate and produce world-leading research in this field.

According to a 2020 CSIRO report on Growing Australia's Quantum Technology Industry, future adoption is likely to occur in industries including:

— Drug and advanced materials development through chemistry simulation: The design of new molecules and materials typically involves testing many different molecules for desired properties. This process is time-consuming and costly, and it can be faster to use simulation instead. Quantum computers have already been used to model simple molecules (e.g. water). As their size and stability increase, they can simulate complex molecules that cannot be

[125] TRL 3 means that the critical function or proof of concept has been established, and TRL 4 means lab testing/validation of an alpha prototype has commenced. More information at: https://www.dst.defence.gov.au/sites/default/files/basic_pages/documents/TRL%20Explanations_1.pdf

[126] Refer: https://www.innovationaus.com/quantum-software-alliance-forms-to-keep-australia-ahead/

[127] https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/CSIRO-futures/Future-Industries/Quantum

[128] e.g., Q-CTRL, which is a company with ties to the ARC Centre of Excellence for Engineered Quantum Systems provides quantum control engineering solutions.

modelled using classical supercomputers. This application could accelerate drug design and be used to develop more efficient and sustainable industrial processes (e.g. fertiliser production) and materials.

— Accelerating machine learning and optimisation of complex systems: As quantum computers become more powerful, they can perform feature mapping, a critical component of machine learning on data structures with a complexity beyond the capabilities of modern classical computers. Quantum computing could also be beneficial for complex system optimisation problems, in contexts such as financial modelling, aerofoil design, traffic management, integrated circuit design, climate predictions, epidemiology and energy systems optimisation.

— National security: The development of quantum technologies for secure communications, defence applications, and codebreaking is expected to have implications for national security. Developing Australia's sovereign quantum technology capabilities will ensure that the country is prepared for the challenges and opportunities this presents.

8 Aquifer Reinjection

8.1 Key Findings – WA Aquifer Recharge

$1.3m in cash support from the ARC, and **$3.65m** cash and in-kind support from other organisations

The project demonstrated the feasibility of groundwater reinjection of wastewater and led to the construction of a plant that annually reinjects 28GL of treated wastewater

2 PhD students were trained as a result of the project

The NPV of the project is estimated to be **$64.5 million** The BCR was estimated to be **5.76**

ARC funding supported and built collaboration between Curtin and the WA Water Corporation (WAWC)

Curtin University's research aligns well with the Government's 2015 science and technology priorities.

8.2 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to assess the impact and value of research undertaken by many organisations.[129] The results from applying that framework to the Aquifer Recharge case study are summarised in Figure 8.1.

[129] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F.

Figure 8.1 Aquifer recharge project – Impact Framework Diagram

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– $1.3m cash support from the ARC and $3.65m cash and in-kind support from other organisations	– Developing novel analytical methods to test for the presence of around 400 potential micropollutants – Identified and validated 'marker' chemicals that can be used as indicators for ongoing monitoring of water treatment processes	– Confirmation that microfiltration and reverse osmosis treatment of wastewater adequately removed chemical contaminants – Process optimisation of the wastewater treatment plant – Successful conclusion of a groundwater replenishment trial by WAWC	– Research findings allowed the development of a framework and guidelines for water utilities considering wastewater reuse in Australia – Ongoing monitoring of wastewater treatment processes – Strong community acceptance of groundwater replenishment	– Commencement of wastewater treatment and reinjection into Perth's aquifers – More energy-efficient supply of Perth's water needs – The estimated NPV of the project is $64.5 million – The estimated BCR of the project is 5.76 – Protection of Perth's wetlands and lakes

Source: ACIL Allen

8.3 Background

This case study relates to projects funded under the following ARC schemes:

— Linkage Program: **Linkage Infrastructure, Equipment and Facilities (LIEF)** and **Linkage Project.** In this case, 2 Linkage Project grants supported collaboration between Curtin University and WAWC.

8.3.1 The project

Due to climate change, Perth's average annual rainfall has decreased by around 20% since the 1970s. However, it's not just the total volume of rain that has changed. Perth's rainy season now starts later, and there are more sunny winter days. In addition, the nature of Perth's rainfall means catchments do not receive consistent runoff. As a result, there is some 80% less streamflow (rainfall runoff) into Perth's dams.[130]

Water extracted from groundwater systems is particularly important for meeting the water needs of Perth. In 2000, groundwater from aquifers provided around two thirds of Perth's total water supply. Since then, Perth's water consumption has increased, and that share had declined to around one-third by 2022.

In Perth, there are 3 aquifers at different depths:

— *The superficial aquifer*. This is the shallowest aquifer that stretches across the coastal plain. Perth's superficial aquifer is close to the surface, often visible at the surface as a wetland or a lake.

— *The confined Leederville aquifer*. This aquifer lies below the superficial aquifer and is separated by confining layers that minimise water movement toward the surface and conversely from the superficial to the Leederville aquifer.

[130] WA Water Corporation (2023). *Climate & Perth*. Accessed March 2023: https://www.watercorporation.com.au/Our-water/Climate-change-and-WA/Climate-and-Perth.

— *The confined Yarragadee aquifer*. This is the oldest aquifer under Perth. It is a good source of supply even in dry years because of its vast storage and limited connection to the surface.

Groundwater (in excess of 1500 KL per year) in aquifers can only be extracted if the Department of Water and Environmental Regulation issues a license for that extraction to occur. This is to ensure that water extraction is done in an environmentally sustainable manner and public health protected.

In 2009, the WAWC prepared a 50-year plan to secure Perth's water supply in response to the early signs of a drying climate.[131] The plan projected a growing gap between water supply and demand to 2060 (see Figure 8.2). An important part of the plan is to progressively add new water sources independent of the changing climate to help secure supplies. These sources included seawater desalination and groundwater replenishment.

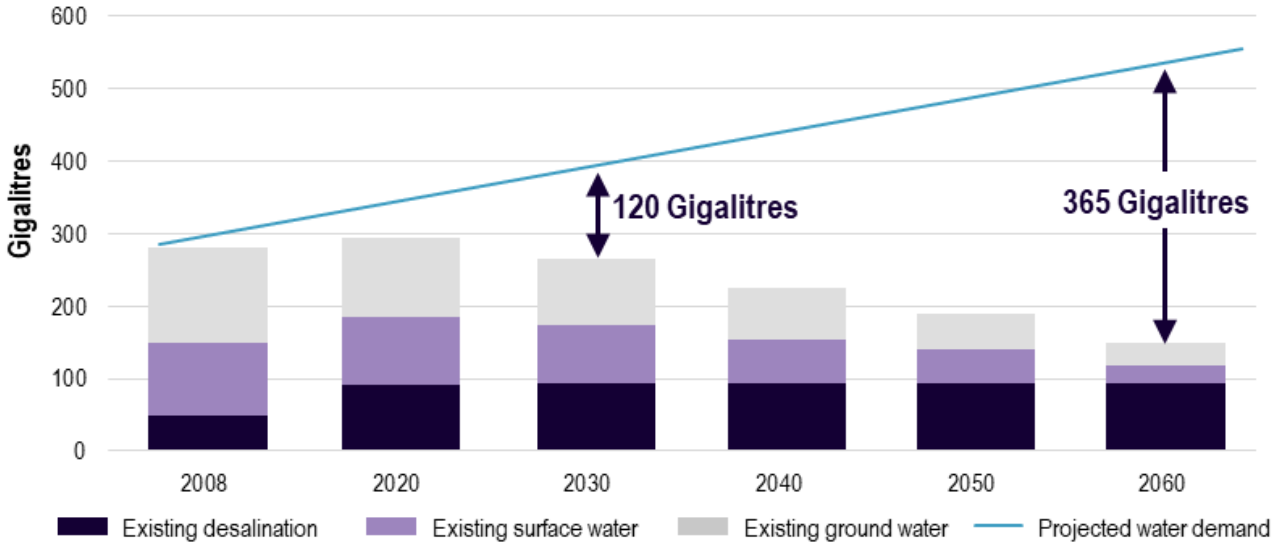
Groundwater replenishment is an approach where wastewater is treated to drinking water standards and injected into aquifers to recharge them. The injected recycled water is then stored in the aquifers, providing further natural treatment capacity. That water can then be extracted when required through existing production wells (assuming a licence to do so has been issued). By injecting recycled water, it is possible to reduce the reliance on rainfall to replenish the aquifers. WAWC's 50-year plan indicated that aquifer replenishment could allow extracted groundwater to contribute to as much as 20% of Perth's drinking water supply in 2060.

WAWC's objective was to be able to increase the amount of groundwater it was licensed to extract from Perth's aquifers by an amount equivalent to the volume of treated wastewater it injected into the aquifer. However, before the required approvals could be obtained to inject recycled water into aquifers supplying Perth's drinking water, it was necessary to demonstrate to the Department of Health, Department of Water and the Department of Environment and Conservation (now Department of Water and Environmental Regulation) and the broader community that it was safe to do so and that there would be no adverse impacts on water security, human health or the environment. 3 separate streams of research were required to demonstrate that this was the case, namely:

— An investigation of the hydrology of the aquifers. The CSIRO and the WAWC led this research.
— A study into the microbiology of treated wastewater. The WA Department of Health did this work.
— Research to establish the chemistry of treated wastewater and whether any contaminants were present following the recycling treatment. This project was led by Curtin University and is the focus of this case study.

[131] WA Water Corporation (2009). *Water forever – towards climate resilience*. Accessed March 2023: https://pw-cdn.watercorporation.com.au/-/media/WaterCorp/Documents/Our-Water/Groundwater/water-forever-50-year-plan.pdf?rev=32235003c4e04f2bb1fb916dd973c2d6&hash=B77B7F33E2B6545DC6A2BA1548940400.

Figure 8.2 Projected gap between water supply and demand to 2060 (Gigalitres per year)



Source: Water Forever – Towards Climate Resilience, WA Water Corporation, October 2009.

8.4 Inputs

This project received 3 ARC grants, 2 Linkage grants and a LIEF grant. The cash and in-kind contributions by the ARC and others for each of these grants are shown in Table 8.1. Where no specific information was available regarding the annual distribution of support, we assumed that it was distributed evenly across the grant period.

Total cash and in-kind support provided to the project over the period 2006 to 2018 was just over $5 million. Just over 63.4% of this was in cash. In-kind support was just over $1.84 million. In total, the ARC provided $1.38 million, which was over 43% of the total cash support provided for this project.

Table 8.1 Support for the project

Contributor / Type of support	2006-2008	2009-2012	2013-2018	Total Contributions
Cash				
LE0668452				
Academic partner	$170,000			$170,000
Non-academic partner	$55,000			$55,000
ARC	$290,000			$290,000
LP0989326				
Academic partner		$496,062		$496,062
Non-academic partner		$480,000		$480,000
ARC		$600,000		$600,000
LP130100602				
Academic partner			$570,000	$570,000
Non-academic partner			$40,000	$40,000
ARC			$490,000	$490,000
In-kind				
LE0668452				
Academic partner	$354,000			$354,000
Non-academic partner	$120,000			$120,000
LP0989326				
Non-academic partner		$541,725		$541,725
LP130100602				
Academic partner			$463,156	$463,156
Non-academic partner			$362,794	$362,794
Total	**$989,000**	**$2,117,787**	**$1,925,950**	**$5,032,737**

Source: ACIL Allen, various sources

8.5 Activities

Curtin University has a strong record of collaboration with the WAWC on research related to water quality. The collaboration began in the late 1980s and continues today (see Figure 8.3).

The WAWC supported the Curtin Water Quality Research Centre (CWQRC) from 2004 to 2016..[132] From 2005–2008, the CWQRC collaborated on a research project through a $1.54 million grant funded by the WA Government's Premiers Collaborative Research Program to determine the feasibility of micro-filtration and reverse osmosis processes to treat wastewater to acceptable health and environmental standards. The aim was to show the potential feasibility of using treated wastewater to replenish drinking water aquifers. From 2006–2009, the Centre also took part in a collaborative WA Government Premier's Water Foundation Project to determine requirements for

[132] In 2016 the WAWC decided that it wanted to broaden its ability to collaborate with researchers from other institutions and ended its formal support of the CWQRC. However, around 40% of its commissioned external research is still done by Curtin University.

managing aquifer recharge in WA urban areas. In 2006 the ARC provided $290,000 under a LIEF grant to purchase a liquid chromatograph – mass spectrometer for use in the Centre's water research. These activities laid the foundation for an ARC Linkage Project (LP0989326) from 2009–2012, which was awarded to the CWQRC and its key partners (WAWC, GHD and Water Research Australia[133]).

The research carried out by the CWQRC and its partners included developing novel treatment methods for water recycling, process optimisation of the wastewater treatment plant and studies of novel chemicals. The team developed analytical methods, which led to the ability to test for the presence of some 400 potential micropollutants in recycled wastewater. The research confirmed that the microfiltration/reverse osmosis (MF/RO) treatment process could adequately remove chemicals from the wastewater stream to a level that allowed health and safety concerns to be addressed.

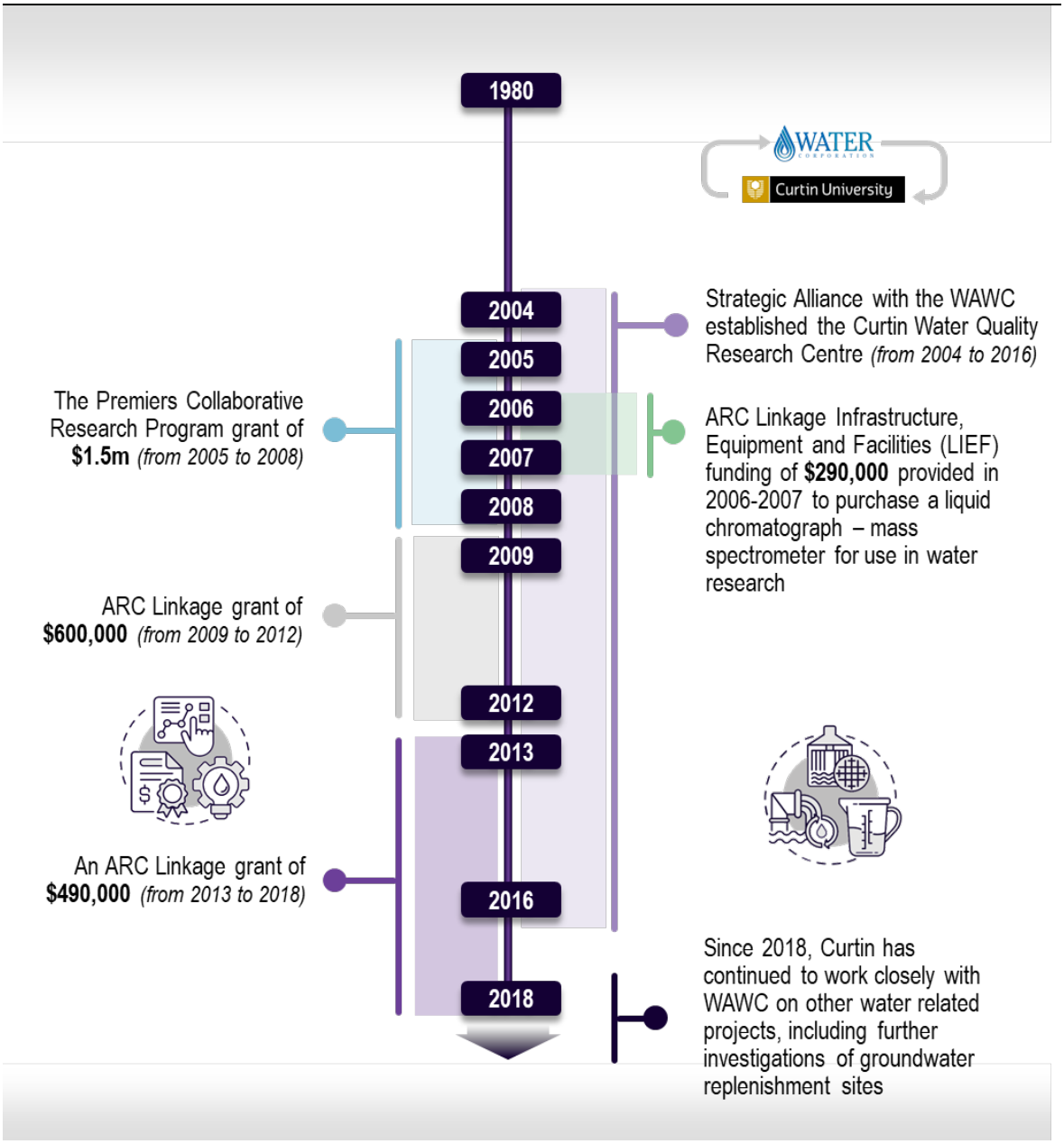
The research team also identified and validated chemicals that could be used as indicators for ongoing monitoring of water recycling plants to ensure that the treatment process was performing as required. The team also investigated how chemical micropollutants of concern responded to water treatment and determined what additional processes could be used to remove a small number of chemical contaminants in wastewater that could pass through the reverse osmosis membrane.

The second ARC Linkage grant (LP130100602) supported research that used updated analytical methods to examine smaller and simpler rural wastewater treatment plants that allow wastewater to be used for non-potable purposes. Work included testing for new emerging contaminants.

As a result of its work in this field, Curtin University is now recognised as one of the Australian leaders in research that combines chemical analysis and toxicity testing of treated wastewater.

[133] At the time the research was being done Water Research Australia was called Water Quality Research Australia.

Figure 8.3 Timelines of Curtin University's groundwater research



Source: ACIL Allen

Dr Stacey Hamilton, Team Leader - Membrane treatment, Water Quality Business Unit, WAWC, stated that:

> *Research has been a part of my life for the past 20 years, through my university degree and PhD at Curtin and now at the Water Corporation. I've been lucky enough to have been involved in the groundwater replenishment space for over 10 years and being able to see the implementation of research outcomes in the full-scale plant emphasises the importance of R&D to the Corporation and the water industry.*

Dr Cynthia Joll from Curtin University stated that she found research on real world issues to be fascinating. She went on to note that she and her colleague, Associate Professor Anna Heitz, had:

> *… been fortunate to be involved in collaborative research projects with Water Corporation over the 24 years I have been working at Curtin. Water Corporation leads Australia in terms of adaptation to climate change and water recycling, and it has been exciting to work with the Corporation on these new developments through projects such as the 2 ARC Linkage projects.*

8.6 Outputs

8.6.1 Publications

Since 2010, CWQRC's water recycling research has led to the publication of 2 book chapters, 28 refereed journal articles and 11 industry reports. Some examples of publications include:

- Bahnmueller, S., Loi, C., Linge, K. L., von Gunten, U. and Canonica, S. (2015) Degradation rates of benzotriazoles and benzothiazoles under UV-C irradiation and the advanced oxidation process UV/H2O2. Water Research, 74, 143-154.
- Busetti, F., Backe, W. J., Bendixen, N., U. Maier, Place, B., W. Giger, Field, J.A. (2011) Trace analysis by large-volume injection into liquid chromatography-mass spectrometry. Published in the 10th Anniversary Issue of Analytical and Bioanalytical Chemistry. DOI: 10.1007/s00216-011-5290-y.
- Busetti, F., Linge, K.L. and Heitz, A. (2009) Analysis of pharmaceuticals in indirect potable reuse systems using solid-phase extraction and liquid chromatography-tandem mass spectrometry. Journal of Chromatography A, 1216 (31), 5807-5818.
- Linge, K.L., Blythe, J.W., Busetti, F., Blair, P., Rodriguez, C., Heitz, A. (2013) Formation of halogenated disinfection by-products during microfiltration and reverse osmosis treatment: implications for water recycling. Separation and Purification Technology, 104, 221–228.
- Linge, K.L., Liew, D., Gruchlik, Y., Busetti, F., Ryan, U. and Joll, C.A. (2021) Chemical Removal in Waste Stabilisation Pond Systems of Varying Configuration, Environmental Science: Water Research & Technology, 7, 1587-1599. https://doi.org/10.1039/D1EW00129A
- Tang, J.Y.M., Busetti, F., Charrois, J. and Escher, B.I. (2014) Which chemicals drive biological effects in wastewater and recycled water? Water Research, 60, 289-299.
- Zahedi, A., Greay, T.L., Paparini, A., Linge, K.L., Joll, C.A. and Ryan, U.M. (2019) Identification of eukaryotic microorganisms with 18S rRNA next-generation sequencing in wastewater treatment plants, with a more targeted NGS approach required for Cryptosporidium detection. Water Research, 158, 301-312.

8.6.2 Models or tools

The research team identified chemicals that could be used to ensure the treatment process performs as required. WAWC used these indicator chemicals for monitoring the performance of the trial water recycling plants. The WAWC still uses Recycled Water Quality Indicators (RWQI) and the Recycled Water Quality Parameters (RWQP), which must be tested per their Memorandum of Understanding (MoU) agreement with WA Department of Health.

8.6.3 Awards

In 2013 the WAWC won the WA Branch of the Australian Water Association's (AWA's) Infrastructure Project Innovation Award for the Groundwater Replenishment Trial (CWQRC was part of the collaborative team that contributed to the trial).[134] The WAWC also won the Australian Water Association (WA branch) Infrastructure Project Innovation Award for the Groundwater Replenishment Scheme in 2018.[135] It subsequently won the National Infrastructure Project Award in the same year.

In 2015 the CWQRC team won a Curtin Research Impact and Engagement Award as part of the annual Curtin Research Awards Recognising Excellence. The citation for the award stated that:

> *With the support of Alliance partner, WA Water Corporation, and other partners, the CWQRC has undertaken 2 ARC Linkage Projects, an Australian Water Recycling Centre of Excellence project and 3 projects directly with WA Water Corporation, on water recycling in the past 5 years.*

It went on to note that the research team had:

> *… contributed to changing the way legislators, public utilities and the general public think about wastewater reuse. The adoption of water recycling as a water resource for Perth is a direct result of the underpinning collaborative research on chemical water quality conducted by the Curtin Water Quality Research Centre.*

The WAWC also won the Australian Water Association (WA branch) Infrastructure Project Innovation Award for the Groundwater Replenishment Scheme in 2018.[136] It subsequently won the National Infrastructure Project Award in the same year.

In 2019, a PhD student studying the removal of various drugs in wastewater treatment, Luis Restrepo Viera, was a finalist for the WA Branch AWA Student Water Prize.

In 2020 WAWC won the AWA (WA Branch) Infrastructure Project Innovation Award – Metro for Stage 2 of the groundwater recycling scheme. In 2022 the WAWC won bronze in the International Water Association (IWA) Project Innovation Award - Exceptional Project Execution and Delivery.[137]

8.6.4 Innovation / commercialisation

The research done by Curtin University was the first of its kind in Australia. It was integral to the decision by the WAWC to develop the Groundwater Replenishment Trial, which began aquifer recharge testing in November 2010. The test facility continued to operate until the end of 2012. While aquifer recharge for indirect potable reuse had been undertaken overseas, this was the first time the technology had been applied in Australia.

By the time the trial concluded, more than 7,300 community members had toured the water recycling facility. Events such as community open days provided further opportunities for community members to provide feedback. In August 2013, it was announced that each of the 62,300 water quality samples taken during the trial had met the required health and safety

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[134] Architecture & Design (2013). *2013 Project management achievement awards winners*. Accessed March 2022: https://www.architectureanddesign.com.au/news/2013-project-management-achievement-awards-winners#.

[135] https://14568786.fs1.hubspotusercontent-na1.net/hubfs/14568786/WA%20State%20Awards%20Honour%20Roll.pdf

[136] https://14568786.fs1.hubspotusercontent-na1.net/hubfs/14568786/WA%20State%20Awards%20Honour%20Roll.pdf

[137] International Water Association (2022). *18 winners at the 13th IWA project innovation awards*. Accessed March 2023: https://iwa-network.org/press/18-winners-at-the-13th-iwa-project-innovation-awards/.

guidelines, and the trial was declared a success. The public outreach during the trial helped ensure that 76% of the public supported the construction of a full-scale scheme.

Construction of a full-scale plant began in October 2014 and was completed in July 2016. More than 180 jobs were created during construction. The plant was Australia's first full-scale Groundwater Replenishment Scheme. The plant can recharge up to 14 billion litres of recycled water into groundwater supplies in the deep Leederville and Yarragadee aquifers each year through onsite bores.

In July 2016, former WA Minister for Water Mia Davies, announced the construction of an additional plant to double the capacity to a total of 28 billion litres of recycled water each year. Construction of the second plant began in late 2017 and it was commissioned in August 2022. When announcing the commissioning of the second plant, the Water Minister, Dave Kelly, stated that:

> *Water Corporation's Groundwater Replenishment Scheme is an innovative and sustainable way to recycle large volumes of water. By recharging our precious groundwater supplies through the scheme, we are able to abstract equivalent groundwater in later years, adding to Perth's drinking water supply, while reducing impacts to the environment and other water users..*[138]

The identification by the research team of 'marker' chemicals that could establish the effectiveness with which WAWC's trial water recycling plant could remove different categories of contaminants in the wastewater was an innovation. The WAWC still has Recycled Water Quality Indicators (RWQI) and the Recycled Water Quality Parameters (RWQP), which must be tested per their MoU agreement with WA Department of Health.

8.7 Outcomes

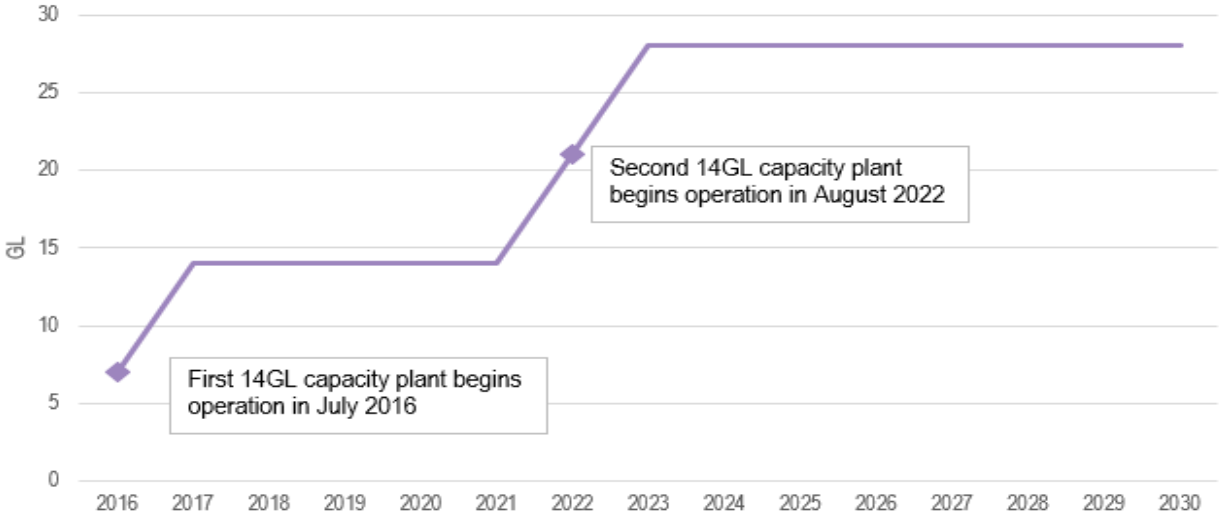
8.7.1 Adoption

The results achieved by this project were instrumental in the WAWC gaining approval to implement the Groundwater Replenishment Scheme. That Scheme is now treating 28 billion litres of wastewater each year and injecting it into the aquifers under Perth (see Figure 8.4). Treated wastewater is recharging the Leederville and Yarragadee aquifers via injection bores. The Leederville bores are between 200 and 500 metres deep, and the Yarragadee bores are between 700 and 1,400 metres deep.

The WAWC has received a licence to extract an equivalent amount of water from Perth's aquifers from downstream extraction bores for drinking water treatment.

[138] WA Water Corporation (2022). *$320m investment doubles Perth's rainfall-dependent water source*. Accessed March 2023: https://www.watercorporation.com.au/About-us/Media-releases/2022/August-2022/Stage-Two-Groundwater-Replenishment-Scheme.

Figure 8.4 Annual volume of recycled wastewater injected into Perth's aquifers



Source: ACIL Allen

According to the WAWC, the energy needed for the reverse osmosis treatment of wastewater before groundwater replenishment is around a quarter of the amount required to desalinate an equivalent amount of seawater.[139] A 2020 report by the Water Services Association of Australia (WSAA) found that the levelised cost of groundwater replenishment was $2.00 per kilolitre. In contrast, the cost of desalinated water was $2.74 per kilolitre (both figures are in 2019/20 dollars).[140] The difference in cost between these 2 sources of potable water is $0.74 per kilolitre.

The alternative to extracting groundwater to supply Perth's water needs would be to obtain the same amount of water from the desalination of seawater. This means that every billion litres of additional groundwater that the WAWC is licenced to extract effectively save the Corporation $740,000 (ultimately benefiting water customers).

8.7.2 Alignment with government strategic priorities

The research undertaken by Curtin University aligns with several National Science and Research Priorities, namely:[141]

- *Soil and water* – the research done by Curtin has clearly increased the resilience and sustainability of Perth's water supplies.
- *Energy* – by enabling the greater use of groundwater the research has helped the WAWC to reduce the amount of energy it needs to supply Perth's drinking water.
- *Environmental change* – greater energy efficiency of supplying Perth's water will help the WAWC achieve its target of net zero emissions across all operations by 2035. The recharging of Perth's aquifers is also helping to protect the flora and fauna that rely on access to the lakes and wetlands supplied by Perth's superficial aquifers. It has also enhanced Perth's water security in the face of the impacts of climate change on water supplies.

[139] https://www.watercorporation.com.au/About-us/Media-releases/2022/August-2022/Stage-Two-Groundwater-Replenishment-Scheme

[140] All Options on the Table - Urban Water Supply Options for Australia, Water Services Association of Australia, August 2020

[141] Australian Research Council (2023). *Science and research priorities*. Accessed March 2023: https://www.arc.gov.au/funding-research/apply-funding/grant-application/science-and-research-priorities.

The recently released terms of reference for the government's review of its science priorities identifies 3 priorities that could possibly form part of a refreshed set of priorities:

— Supporting stronger action on climate change, including investments in renewable energy, reducing emissions and transitioning to a net zero world.
— Elevating and investing in First Nations perspectives on science, technology and innovation.
— Harnessing the potential of emerging technologies and scientific research in pursuit of not only economic growth but improved Australian wellbeing.[142]

The government has also said that when finalising the revised priorities, it will consider how they:[143]

— Reflect the key challenges and opportunities facing Australia
— Align with government priorities, such as the National Reconstruction Fund
— Reflect Australia's competitive and comparative advantages
— Inform and align government decision making and investment into the future
— Provide greater certainty and focus for investment, including by industry
— Be reviewed and updated to ensure they remain contemporary and responsive to Australia's needs.

8.8 Impacts

8.8.1 Economic impacts

Counterfactual

Without the ARC-funded research, WAWC would most likely have developed additional desalination facilities/capacity in order to meet Perth's growing demand for drinking water.

As far back as the early 2000s the WAWC had begun to look at the potential for using treated wastewater to recharge Perth's aquifers. The WAWC was aware that this technology had been used in a small number of locations around the world, but not, at that stage, in Australia. However, there was at the time some opposition from both the local population and environmental groups to groundwater recharge and the decision was taken to instead build a desalination plant.

The ARC-funded research projects were a key element of the effort to deliver the science that could help build public support for the wastewater reinjection scheme. ACIL Allen's discussions with stakeholders suggest that if the research had not been able to demonstrate the safety of the process, then public opposition would likely have remained high, and the relevant government departments would not have been satisfied that the process would meet environmental and health requirements. Based on discussions with stakeholders, ACIL Allen believes that there is a strong chance that the WAWC may have focussed much more on desalination without the ARC-supported research projects. Although WAWC would still have pursued options for aquifer recharge in order to diversify drinking water sources, it is likely that the research would have taken a longer time and therefore benefits from aquifer recharge would have been delayed.

For the purposes of our analysis, we have adopted the assumption that without the research funded by the ARC the WAWC would have persisted in studying the groundwater injection option,

[142] Department of Industry, Science and Resources (n.d.). *Terms of reference*. Accessed March 2023: https://www.industry.gov.au/science-technology-and-innovation/revitalising-australias-vision-science-and-research/terms-reference.

[143] Ibid.

but the commencement of aquifer recharge would have been delayed by 10 years. This assumption has been tested below.

Attribution

The attribution describes the percentage of benefits that can be reasonably attributed to the ARC due to their role in the funding of the research.

Based on our discussions with stakeholders, ACIL Allen believes that it would be appropriate to attribute 40% of the benefits delivered by the aquifer recharge project to the ARC's funding of Curtin's water quality research. This is based on 2 discussions with WAWC personnel, one cited an attribution of 30-50%, and another cited 40% attribution. Therefore a sensitivity test at 30% and 50% attribution has also been conducted below.

Methodology and key assumptions

The cost-benefit analysis (CBA) estimates the identified costs and benefits relating to the ARC's funding of research that ultimately led to the construction and operation of WA groundwater recharge processes developed. The CBA compares the total costs of the LIEF grant and Linkage grants (see Section 8.4) to the estimated avoided costs by the program to recharge Perth aquifers with treated wastewater rather than installing additional desalination capacity.

The following assumptions underpin the CBA:

- A discount rate of 7% was used in the central case. Discount rates of 3% and 10% were used for lower- and upper-bound sensitivity testing.
- The difference in levelised cost of water using reinjection vs desalination is $0.74/KL.[144]
- The amount of water reinjected between 2016 and 2032 is shown in Figure 8.4. This was 280 gigalitres (GL) in total.
- The ARC-funded research has brought benefits forward by 10 years. In the absence of the ARC-funded research, we have assumed that WAWC would have continued to investigate the feasibility of groundwater recharge and that they would have begun to reinject treated wastewater after a delay of 10 years under the counterfactual case. Since benefits begin to flow in 2016 under the reference case, benefits will begin to decrease from 2026 in the CBA. By 2033, benefits counted in the CBA will be zero.
- The analysis period is from 2006 (the start of ARC funding) to 2040 (i.e. a 35-year analysis period).

Costs

The nominal costs included in the CBA are the cash and in-kind contribution of the LIEF grant and Linkage grants (see Section 8.4). These nominal costs are adjusted for inflation using the Consumer Price Index by year, producing real costs.

Benefits

The benefits are the costs avoided by WAWC that would have been associated with utilising desalination rather than groundwater recharge.

The nominal benefits by year are calculated by taking the amount of water processed using aquifer recharge in GL, multiplied by the costs avoided per GL for using aquifer recharge as opposed to desalination, adjusted for the attribution to the ARC-funded research:

[144] Water Services Association of Australia (2020). Op. Cit.

$$Aquifer\ rechage\ (GL) \times costs\ avoided\ (\$/GL) \times attribution\ to\ ARC\ funded\ research(\%) = Nominal\ benefit\ (\$)$$[145]

These nominal benefits are adjusted for inflation using the Consumer Price Index by year, which produces the real benefits.

Calculation of NPV and BCR

The estimated benefits and costs are provided in Table 8.2 for discount rates of 3, 7 and 10%.

The benefit-cost ratio (BCR), obtained by dividing the present value of benefits by the present value of costs is 5.76 (using a 7% real discount rate). The present value of costs is $13.6 million, the benefits are estimated at $78.1 million, resulting in an estimated NPV of $64.5 million.

Table 8.2 Summary of benefits and costs (2022$)

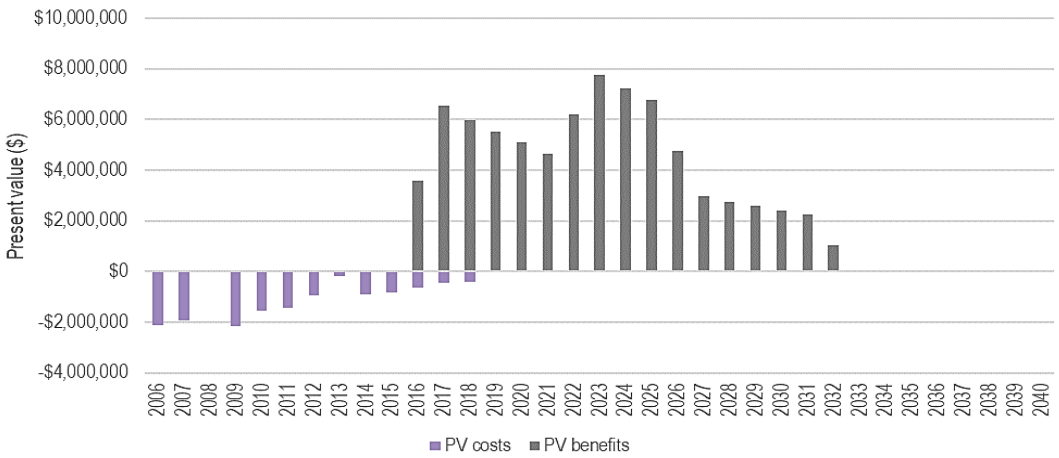
	Discount rate 3%	Discount rate 7%	Discount rate 10%
Present value costs			
ARC-funded research costs	$8,795,028	$13,558,319	$18,769,781
Present value benefits			
Savings for WA Water Corporation	$81,070,370	$78,058,893	$77,144,024
Results			
NPV	**$72,275,342**	**$64,500,574**	**$58,374,243**
BCR	**9.22**	**5.76**	**4.11**

Source: ACIL Allen

Note: All discount rates are real (i.e. discount rates are applied to real costs and benefits)

The present value of benefits and costs of the ARC-funded research by year are shown in Figure 8.5.

Figure 8.5 Present value costs and benefits by year (7% DR)



Source: ACIL Allen

[145] For example, in 2016, 7 GL of water was saved. At a cost savings of $740,000/GL ($0.74/KL) compared to desalination (which would have likely been the alternative method for drinking water in the absence of aquifer recharge), this leads to $5,180,000 of savings. Adjusting for attribution to ARC of 40%, this results in a $2,072,000 nominal benefit in 2016 that can be attributed to ARC.

Sensitivity testing

The results were sensitivity tested at the 3% and 10% real discount rate.[146] (see Table 8.2Table 8.3). The results of the sensitivity testing show that the NPV remains significant and the BCR is well above one, even at a discount rate of 10%.

Sensitivity testing was also conducted by varying the difference in the levelised cost of water using reinjection versus desalination. The central case was $0.74/KL, based on discussions and material provided by WAWC.[147] The CBA results were tested with a lower bound difference in levelised cost of $0.37/KL (50% below the central case) and an upper bound difference in levelised cost of $1.11/KL (50% above the central case). The results of that analysis are shown in Table 8.3. They show that the NPV would fall from $65.5 million to $25.5 million and the BCR would fall from 5.76 to 2.88 if the difference in levelised cost fell by 50%. Whereas the NPV would rise increase to $103.5 and the BCR would rise to 8.64 if the difference in levelised cost increased by 50%. This demonstrates that the estimated benefits of this project remain considerable even under significantly more conservative assumptions.

Table 8.3 Sensitivity testing levelised cost of water using reinjection and desalination (7% DR, 2022$)

	Difference in cost $0.37/KL	Difference in cost $0.74/KL	Difference in cost $1.11/KL
Costs	$13,558,319	$13,558,319	$13,558,319
Benefits	$39,029,446	$78,058,893	$117,088,339
Net impact	**$25,471,128**	**$64,500,574**	**$103,530,020**
BCR	**2.88**	**5.76**	**8.64**

Source: ACIL Allen

Sensitivity testing was also conducted for the attribution of benefits to ARC. The central case was an attribution of 40%. The CBA results were tested with a lower bound attribution of 30% and an upper bound attribution of 50%. The results in Table 8.4 show that the NPV would fall from $64.5 million to $44.9 million and the BCR would fall from 5.76 to 4.32 if the attribution is reduced to 30%. Whereas the Net Present Value would rise to $84 million and the BCR would rise to 7.20 if the attribution was increased to 50%. The CBA is positive at all 3 discount rates. This demonstrates that the estimated benefits of this project remain considerable even when tested by the range of attribution figures suggested by stakeholders.

Table 8.4 Sensitivity testing attribution to ARC (7% DR, 2022$)

	30% attribution	40% attribution	50% attribution
Costs	$13,558,319	$13,558,319	$13,558,319
Benefits	$58,544,169	$78,058,893	$97,573,616
Net impact	**$44,985,851**	**$64,500,574**	**$84,015,297**
BCR	**4.32**	**5.76**	**7.20**

Source: ACIL Allen

Finally, sensitivity testing was conducted for number of years that the ARC research brought the benefits forward by. The central case was that benefits were brought forward by 10 years. The Cost Benefit Analysis results were tested with a lower bound of 5 years and an upper bound of 15 years. The results in Table 8.5 show that the Net Present Value would fall from $64.5 million to $33 million

[146] The 3% and 10% discount rates are the Federal Government Office of Impact Analysis' recommended rates for sensitivity testing. Refer: https://oia.pmc.gov.au/sites/default/files/2021-09/cost-benefit-analysis.pdf

[147] Water Services Association of Australia (2020). Op. Cit.

and the BCR would fall from 5.76 to 3.44 if the benefits were only brought forward by 5 years. Whereas the NPV would rise to $84.5 million, and the BCR would rise to 7.23 if the benefits were brought forward 15 years. The CBA is positive at all 3 discount rates. This demonstrates that the estimated benefits of this project are still positive even if the research only brought forward the benefits by 5 years.

Table 8.5 Sensitivity testing number of years that ARC funding brought forward benefits (7% DR, 2022$)

	5 years	10 years	15 years
Costs	$13,558,319	$13,558,319	$13,558,319
Benefits	$46,601,353	$78,058,893	$98,056,782
Net impact	**$33,043,034**	**$64,500,574**	**$84,498,464**
BCR	**3.44**	**5.76**	**7.23**

Source: ACIL Allen

8.8.2 Social impacts

Educational impacts

2 PhD students have specifically worked on the water recycling research discussed in this case study. Both of these students are currently writing their theses while working full-time. One works for an analytical chemistry company and the other for an engineering consulting company delivering water services to the mining industry.

Other PhD graduates from the CWQRC are employed by the WAWC (2 former students), consulting engineering firms (2 former students), commercial analytical laboratories (3 former students), postdoctoral fellowships/academia (5 former students). It is clear that the CWQRC has, over time, provided a steady supply of graduates that have contributed their expertise to the operations of different businesses and carried out further research.[148]

Dr Cynthia Joll stated that:

> *My research has also informed my undergraduate and Masters teaching, providing training to domestic and international students on water chemistry.*

Employment impacts

As noted above, several hundred workers were employed over several years to construct each of the 2 stages of the aquifer recharge scheme. There is also ongoing employment of staff to operate and maintain the wastewater treatment and reinjection plant. However, ACIL Allen believes that similar numbers of jobs would have been created to build and operate the additional desalination plant that would have had to be built if the aquifer recharge scheme had not gone ahead.

8.8.3 Other impacts

Environmental

As discussed above, the research carried out by Curtin has enabled the WAWC to source an estimated total amount of around 100GL of groundwater from Perth's aquifers. This has enabled

[148] In addition, many Honours and Bachelor Chemistry graduates have been employed at WAWC over the years.

the WAWC to significantly reduce its energy consumption and is helping it to meet its emissions reduction targets.

The injection of water into Perth's aquifers is helping to protect important wetlands and lakes associated with its superficial aquifers. This is, in turn, helping to ensure the protection of flora and fauna dependent on those wetlands. It also provides social benefits as a result of the public enjoying these wetlands and lakes.

Collaboration

The ARC funding for this project helped strengthen the existing relationship between Curtin University and the WAWC. Those organisations have continued to collaborate on water quality research up to now, and both parties expect that their collaboration will continue into the future.

The CWQRC also collaborated with leading international organisations in water research, including the Swiss Federal Institute of Aquatic Science and Technology, Oregon State University, the University of Queensland, and the Advanced Water Technology Centre at the Colorado School of Mines. The strong collaborations with the Swiss Federal Institute of Aquatic Science and Technology over the years helped establish the centre's initial involvement in groundwater replenishment research.

Policy

The findings from Curtin University's research were instrumental in helping to inform the design of Australian guidelines for water recycling.

8.9 Potential future impacts

Curtin University and the WAWC continue to collaborate on water quality research, including multiple projects on optimisation of drinking water treatment processes. They are also continuing to collaborate on aquifer recharge as Water Corporation considers the possibility of additional groundwater replenishment from other wastewater treatment plants.

Stakeholders have noted that treated wastewater could potentially be a water source for hydrogen production. If this was to be pursued, then Curtin's work to understand wastewater chemical removal by reverse osmosis could underpin such a future use of treated wastewater.

9 Irrigation Automation

9.1 Key Findings

$2.8m invested by ARC and **$6.8m** by participating organisations

$9.7 billion NPV of unattributed present and anticipated economic impacts. BCR of 2.94.

The project has contributed to the development of **Rubicon Water's automated irrigation system, Total Channel Control**

10 full time equivalent jobs created at the University of Melbourne

20 students impacted by the research

Alignment with Government priorities

Soil and Water Science and Research Priority, and **Water for**

9.2 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to assess the impact and value of research undertaken by many organisations.[149] The results from applying that framework to the Irrigation Automation case study are summarised in Figure 9.1.

[149] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F.

Figure 9.1 Irrigation automation – Impact Framework Diagram

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– $2.8m cash from ARC – $6.8m in cash and in-kind support from other organisations	– Continuous partnership between the University of Melbourne and Rubicon Water since 1998 – Rubicon designed Total Channel Control, a fully automated system for controlling irrigation, based on the first project in 1998 – University and industry partner have been involved in several Linkage projects from 2003, each of which had different research objectives to advance Rubicon Water's irrigation automation processes	– In September 2021 Rubicon Water debuted on the Australian Stock Exchange, aiming to raise $42.6 million at a market capitalisation of $171.9 million. – Comprehensive suite of 218 patents – Numerous awards, including Australian Academy of Technological Sciences and Engineering Clunies Ross Award (2008) – Publications and invitations to international conferences	– Rubicon's irrigation system addresses many of the issues with manual systems, e.g., through eliminating spills, improving the reliability and timeliness of water supply, and enabling precise application to crops. – Examples of adoption of Rubicon Water's technology includes the Goulburn-Murray Irrigation District Connections Project, and the Karnataka irrigation modernisation project in India.	– $9.7 billion NPV of unattributed economic impacts as a result of the Connections Project – Impacts have not been attributed due to commercial sensitivities; however, Rubicon Water has stated that the ARC funding has supported the development of the Total Channel Control algorithm, which is part of the system responsible for delivering benefits under the Connections Project – BCR of 2.94.

Source: ACIL Allen

9.3 Background

This case study relates to projects funded under the following ARC schemes:

— Linkage Program: **Linkage Projects**.

9.3.1 The project

Irrigation accounts for more than 70% of the global demand for fresh water. This water comes primarily from purpose-built reservoirs, which are supplied by rivers. However, less than 70% of distributed irrigation water generally reaches farms. In some countries, such as China, water efficiency can be as low as 30%. Water is lost in transit through leakage, seepage, evaporation, system spills, unauthorised use, inability to control and measurement errors. To avoid poor service to irrigators located in these manually managed open-channel irrigation systems, the operators tend to supply excess water, often resulting in substantial end-of-system spills.

Pressure on water supplies is increasing, due to climate change, a growing global population and urbanisation. People are also eating more meat, which can take up to 10 times more water to produce per kilogram, than grains, fruit and vegetables. To safeguard water resources and ensure food security, irrigation infrastructure needs to be modernised. Improving the efficiency of existing open-channel systems is more cost-effective than installing new water irrigation infrastructure such as pressurised pipelines. Developing efficient, automated open-channel irrigation systems was the focus of the University of Melbourne and industry partner Rubicon Water's research projects.

Rubicon Water is a Melbourne-based manufacturer that improves the efficiency of large-scale, gravity-fed irrigation systems. Rubicon Water's flagship solution, Total Channel Control (TCC), leverages intelligent control devices, software and communications to accurately measure and control the flow of water from the source (such as a river or reservoir) to the farm in real-time. TCC combines information from the sensors integrated into the control devices to inform operators of system status in real-time across the entire modernised irrigation network. These sensors measure water levels and flow at distinct points in open channels. Based on these data, the system can automatically adjust the gates and valves to deliver the amount of water each farm requests. System operators can leverage the sensory data communicated by each site to identify parts of the network that are losing water through leaks, seepage or other factors. Combined with Rubicon products for on-farm surface irrigation automation, TCC allows farmers to monitor and manage their irrigation remotely, enabling water to be applied on-farm efficiently and precisely when crops need it.

Figure 9.2 Rubicon Water's FlumeGates are a key component of the TCC solution

Source: University of Melbourne, 2021, available at: https://www.unimelb.edu.au/newsroom/news/2021/september/rubicon-water-debuts-on-the-asx

Rubicon Water and the University of Melbourne have a long-standing partnership that has been in place for over 20 years. During this time, they have completed 4 Linkage Projects (LP0349134, LP0989497, LP130100605, and LP160100666) and are currently involved in an active Linkage Project (LP200200917) related to irrigation automation research. The University of Melbourne researchers have brought their expertise in systems engineering, mathematical modelling and control theory to the Linkage Projects.

9.4 Inputs

ARC, the University of Melbourne and Rubicon Water provided $9.6 million in cash and in-kind contributions for this project (see Table 9.1).

Table 9.1 Support for the project

Contributor / Type of support	2003-2008	2009-2012	2013-2016	2017-2020	2021-2024	Total Contributions
Cash						
LP0349134 – Control and safety monitoring systems for large-scale irrigation networks						
Academic partner	$307,867	$102,622				$410,489
Non-academic partner	$111,563	$37,188				$148,750
ARC	$550,000					$550,000
LP0989497 – Managing Australia's water resources: Automated demand scheduling and supply control systems for large scale irrigation networks						
Academic partner		$268,878	$201,658			$470,536
Non-academic partner		$185,714	$139,286			$325,000
ARC		$600,000				$600,000
LP130100605 – Improving the operation of large-scale irrigation networks through automation						
Non-academic partner			$136,543	$102,407		$238,950
ARC			$615,000			$615,000
LP160100666 – Automatic control systems for low-energy pipelines in irrigation networks						
Non-academic partner			$41,617	$166,467	$41,617	$249,700
ARC			$65,000	$405,000		$470,000
LP200200917 – Control systems for irrigation networks in storage critical operations						
Non-academic partner					$183,050	$183,050
Academic partner					$100,239	$100,239
ARC					$593,636	$593,636
In-kind						
LP0349134 – Control and safety monitoring systems for large-scale irrigation networks						
Non-academic partner	$748,125	$249,375				$997,500
LP0989497 – Managing Australia's water resources: Automated demand scheduling and supply control systems for Large-scale irrigation networks						
Non-academic partner		$447,571	$335,679			$783,250
LP130100605 – Improving the operation of large-scale irrigation networks through automation						
Non-academic partner			$351,429	$263,571		$615,000
Academic partner			$268,927	$201,695		$470,622
LP160100666 – Automatic control systems for low-energy pipelines in irrigation networks						
Non-academic partner			$104,500	$418,000	$104,500	$627,000
Academic partner			$47,875	$191,499	$47,875	$287,248
LP200200917 – Control systems for irrigation networks in storage critical operations						
Non-academic partners					$538,500	$538,500
Academic partners					$311,874	$311,874
Total	**$1,717,554**	**$1,891,348**	**$2,307,512**	**$1,748,639**	**$1,921,290**	**$9,586,344**

Source: ACIL Allen, research project applications

Totals may differ due to rounding.

9.5 Activities

The partnership between the University of Melbourne and Rubicon Water has existed since 1998 and continues today (see Figure 9.3).

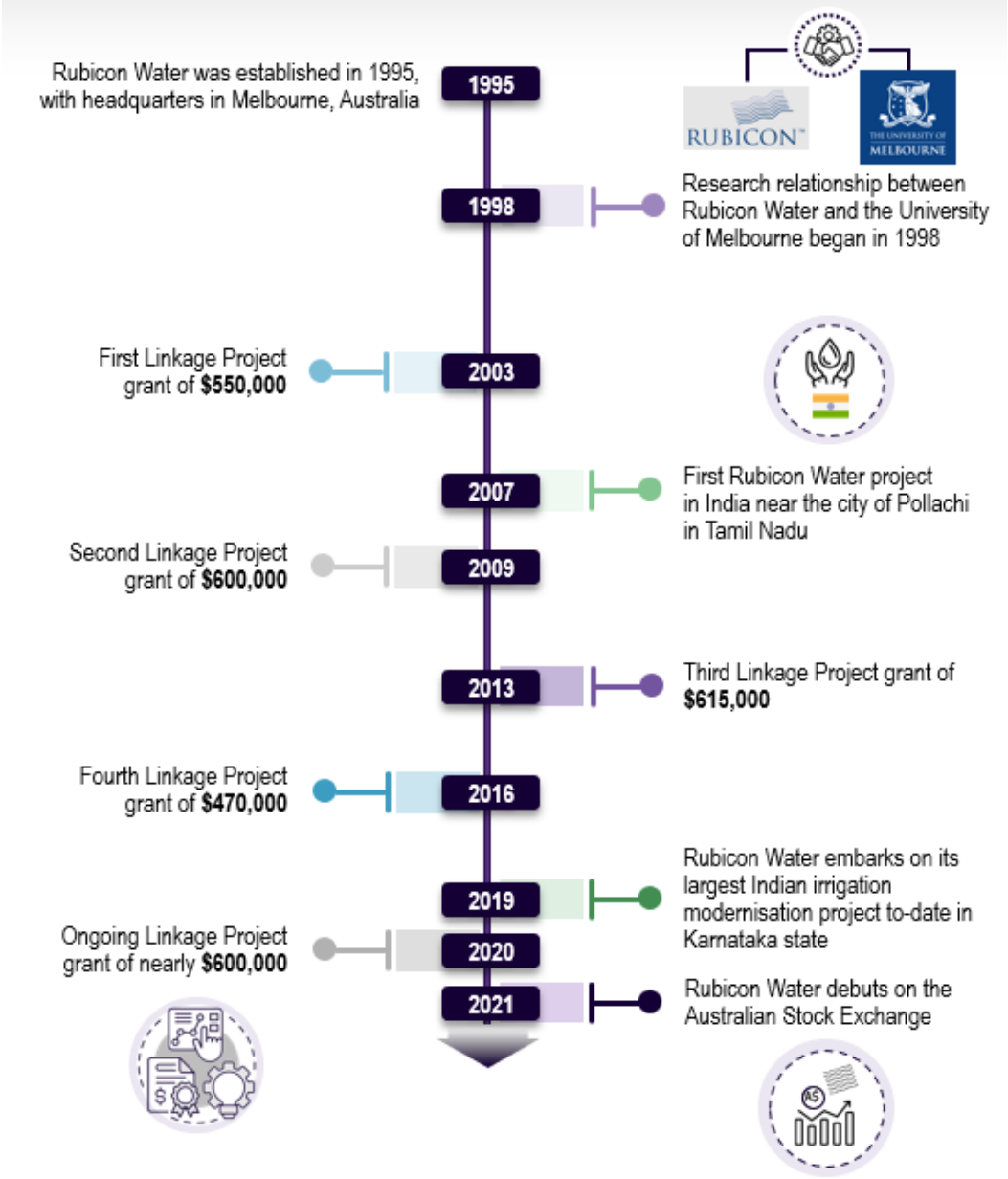
The first project began in 1998 when Rubicon Water approached Professor Iven Mareels to help solve a problem on one of its projects. Professor Mareels is a Redmond Barry Distinguished Professor at the Melbourne School of Engineering. The research team, led by Professor Mareels, began by modelling how water flows through channels. They then investigated how to measure and manage water flow accurately. Based on this work, Rubicon Water designed TCC, a fully automated system for controlling irrigation.

The research team helped trial TCC at the Central Goulburn number 2 channel, which includes a working farm. TCC was also trialled in pilot projects in Coleambally in New South Wales and Victoria in 2002.

From 2003, Rubicon Water and the University of Melbourne embarked on several Linkage Projects, each with different research objectives to advance Rubicon Water's irrigation automation processes. These projects' research focus and output are discussed in more detail in section 9.6 below.

TCC was introduced to the market in 2002 with the initial pilot project. All major irrigation authorities in Australia now use TCC. The solution is now leveraged across international markets, including India, Italy, Central Asia and the USA, with site management solutions in other countries such as Chile, Spain, France, New Zealand and Rwanda. The University of Melbourne now jointly owns the intellectual property of many patents with Rubicon, including the patents associated with the TCC solution, with collaborative research and development still ongoing.

Figure 9.3 Timelines of Rubicon Water and University of Melbourne research partnership



Source: ACIL Allen

9.6 Outputs

The research team has been successful in producing the following outputs as part of the 4 completed Linkage Project grants:

— The research from the 2003 Linkage Project led to the development of a control parameter that advanced the core functionality of Rubicon Water's TCC solution. The specific discoveries of the 2003 Linkage Project include new methods for designing controllers for irrigation channels and algorithms for performance monitoring of controllers and demand-driven network control. Deployment of the technologies containing these parameters has resulted in large water savings and an increased level of service to farmers. Aside from the direct agricultural benefits, there are also positive environmental outcomes, with the substantial recovery of water being allocated to controlled and timely environmental flows.

The research received international attention, as evidenced by several invited plenary addresses and journal papers.

— The research from the 2009 and 2013 Linkage Projects resulted in developing the algorithms underpinning Rubicon Water's Demand-Integrated Network Control Solution..[150] The Demand-Integrated Network Control Solution allows farmers to enter and manage water delivery requests through a web-based interface. When a request is entered, the software checks the farmer's usage and any other necessary rules and regulations, then calculates whether the channel network can deliver the water. If the order is successful, the request is confirmed with a notification to the farmer or if not, adjacent time slots are offered for immediate selection. At the same time, demand peaks and troughs are smoothed, and orders are linked to better utilise the channel's capacity and to deliver to more farmers simultaneously..[151] These 2009 and 2013 projects led to the development of a hierarchy of automatic controls for large-scale gravity-fed water distribution systems, which forms the basis of the Demand-Integrated Network Control Solution. The hierarchy consists of 3 layers; a low-level network of feedback controllers to regulate water levels at supply points along the open-water channels; an intermediate layer that plans the references and manages the low-level feedback controllers based on scheduled demand; and a high-level scheduling system. The continuing development of this technology contributes to Rubicon Water's standing as an international leader and, therefore, an export earner for Australia. Furthermore, large-scale deployment and continued development of Rubicon Water's technologies in Australia have led to substantial reductions in conveyance losses, with corresponding savings for the environment, while improving the quality of service provided to irrigators.

— The research from the 2016 Linkage Project resulted in further improvements to Rubicon's TCC package through advancements in the optimisation-based methods for reference management and demand scheduling in irrigation networks. This Linkage Project has contributed to the control solution in Rubicon's single largest international modernisation project in India. Known as the Narayanpur Left Bank Canal (NLBC) Phase II Modernisation project, it included the installation of more than 4,200 automated Rubicon flow control gates, along with sophisticated software and communications infrastructure that will automate approximately 1,500 km of canals to improve the delivery efficiency and equitability of water to farmers located along more than 3,000 km of canals. The project is expected to improve water efficiency within the NLBC network by up to 20% while delivering an equitable service to farmers and supplying water at consistent flow rates to support the production of higher yields and diversification into higher-value crops. Early survey data has already revealed an improvement in crop yield by up to 50%.

— Rubicon Water is anticipating the award for the subsequent modernisation project for the Narayanpur Right Bank Canal (NRBC), which will have a total project value of approximately $40 million.

[150]Rubicon Water's commercial model is to offer site management solutions to provide remote control and monitoring of a particular location or group of sites – with the scalability to introduce TCC technology as a whole-of-network control solution. The Demand-Integrated Network Control solution is made up of modular TCC components including integrated irrigation control gates and meters (FlumeGates, SlipMeters, PikoMeters), dedicated irrigation management software to handle district functions and sophisticated telemetry that enables the inter-communication between gates throughout the network and communicated back to a central control room.

[151] Rubicon Water (2021). *Demand-integrated network control solution*. Accessed March 2023: https://rubiconwater.com/en/demand-integrated-network-control-solution/.

Publications

A list of the most recent publications resulting from the project are below.

— Bedjaoui, N, and E. Weyer (2011). Algorithms for leak detection, estimation, isolation and localization in open water channels, Control Engineering Practice, Vol. 19, no. 6, pp. 564-573.

— Cantoni, M., E. Weyer, Y. Li, S.K. Ooi, I. Mareels and M. Ryan (2007). Control of Large-Scale Irrigation Networks, IEEE Proceedings special issue on The Emerging Technology of Networked Control Systems, Vol. 95, no. 1, pp.75-91

— Choy, S., and E. Weyer (2008). Reconfiguration schemes to mitigate faults in automated irrigation channels, Control Engineering Practice, Vol. 16, no. 10, pp. 1184-1194.

— Euren, K. and E. Weyer (2007). System identification of irrigation channels with undershot and overshot gates, Control Engineering Practice, Vol. 15, no. 7, pp. 813-824.

— Weyer E. (2008). Control of irrigation channels. IEEE Trans on Control Systems Technology, Vol. 16 no. 4, pp. 664-675

— Lang A, Cantoni M, Farokhi F, Shames I (2020). Rigid-profile input scheduling under constrained dynamics with a water network application. IEEE Transactions on Control Systems Technology. 2020 Dec 29;29(6):2457-72.

— Mavkov B, Strecker T, Zecchin AC, Cantoni M, (2022) "Modeling and Control of Pipeline Networks Supplied by Automated Irrigation Channels," Journal of Irrigation and Drainage Engineering. 2022 Jun 1;148(6):04022015.

— Nasir, H.A., M. Cantoni, Y. Li, and E. Weyer (2019). Stochastic model predictive control based reference planning for automated open-water channels, IEEE Transactions on Control Systems Technology vol. 29 no.2, pp. 607-619.

— Soltanian L, Cantoni M (2015). Decentralized string-stability analysis for heterogeneous cascades subject to load-matching requirements. Multidimensional Systems and Signal Processing. 2015 Oct;26(4):985-99.

— Strecker, T. Aamo, OM and Cantoni, M (2022), "Boundary Feedback Control of 2×2 Quasilinear Hyperbolic Systems: Predictive Synthesis and Robustness Analysis," IEEE Transactions on Automatic Control, vol. 67, no. 3, pp. 1397-1413, March 2022

Conference Papers

A list of the most recent conference papers resulting from the project are below.

— Structured Moving Horizon Estimation for Linear System Chains (2019)

— Moving Horizon Estimation for Linear Cascade Systems (2018)

— Scalable iterations for solving constrained LQ control problems with cascade dynamics (in Proceedings of 23rd International Symposium on Mathematical Theory of Networks and Systems, Hong Kong) (2018)

— Control system design for concrete irrigation channels (2017)

Patents

Rubicon and the University of Melbourne have built a comprehensive portfolio of 218 patents that focus on agricultural water management from dams right through to the application of water to crops. Rubicon's IPO is another strong example of the University's commitment to research commercialisation and building relationships that support this goal.

Some of the key patents in Australia are:

— AU2008201858 (Control gates), filed 21 August 2001.

- AU2010201936 (Control gates), filed 21 August 2001.
- AU2010201935 (Fluid regulation), filed 1 March 2002.
- AU2011200645 (Control gates – slidable frame), filed 21 August 2001.
- US9952601B2 (Supervisory control of automated irrigation channels), filed 4 May 2013.[152]
- AU2018317494 (Method and system for water distribution and soil moisture determination), filed 14 August 2018.[153]

Awards

- Australian Academy of Technological Sciences and Engineering Clunies Ross Award (2008).
- The Institute of Engineers Australia Engineering Excellence Award for Infrastructure (2009).
- Iven Mareels, Michael Cantoni and Erik Weyer were awarded the 2014 IEEE Control Society Technology Award. For the development and implementation of controls for irrigation channels and water management (2014).
- The National Export Award for Environmental Solutions by the Australian Government (Rubicon, 2015).
- The Australian Export Award for Sustainability (Rubicon, 2022).
- International Commission of Irrigation and Drainage's (ICID) WatSave award under the Transformational Technology Category for leveraging canal automation technology to improve Karnataka's precious water resource (Rubicon, October 2022).
- Finalist for the IABCA Impact Award (ceremony scheduled to be in New Delhi in Q1 2023).

Innovation / commercialisation (if any)

In addition to the commercialisation of TCC described in the sections above, in September 2021, Rubicon Water made its debut on the Australian Stock Exchange, with the aim of raising $42.6 million at a market capitalisation of $171.9 million.

Rubicon Water has offices in Australia, USA, New Zealand, Spain, Chile, China and India and agents in many other countries.

9.7 Outcomes

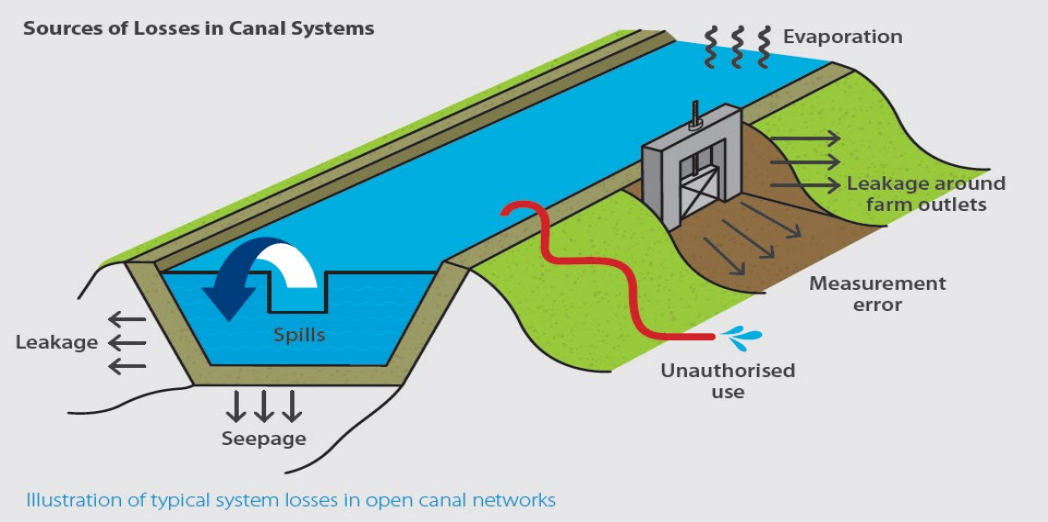
Studies of Australia's Murray-Darling Basin canal distribution systems found that most distribution losses came from the source known as 'spills' – water that flows out of the system unused. Estimates vary from 20% to 46% of all losses.[154] Figure 9.4 shows the typical sources of water losses in irrigation canal systems. Leakage, seepage, evaporation and unauthorised use (theft) were all minor compared to spills. Autonomous control systems target spill losses by precisely matching supply with demand.

[152] Refer: https://patents.google.com/patent/US9952601B2/en

[153] University of Melbourne (n.d.). *Addressing the global challenge to conserve irrigation water*. Accessed March 2023: https://research.unimelb.edu.au/research-at-melbourne/climate-hub/climate-collaboration/irrigation-conservation.

[154] Marsden Jacob Associates (2003). *Improving water-use efficiency in irrigation conveyance systems*. Accessed March 2023: http://www.insidecotton.com/jspui/bitstream/1/1756/2/pr030516.pdf.

Figure 9.4 Source of losses in canal systems



Source: Rubicon Water 2022

Spills are an operational problem that results from an inability to precisely control water in manually-operated canal systems. Under manually-operated systems, farmers need to either receive water according to a pre-planned roster system or, if an ordering system is in place, request water several days in advance to give planners time to schedule and manage the logistics of operating canal regulating gates to move water through the canal network. In unmodernised systems, measurement of basic water attributes (flow rate, volume, canal water levels) at canal regulating gates and farm outlets is generally inaccurate, sporadic, incomplete and unsuitable for operational management purposes. To compensate for the uncertainty this lack of information causes, operators intentionally release more water into the system than is required at farm outlets to smooth out the service problems caused by inadequate measurement and control. These problems include fluctuating canal water levels, canals running dry, low and inconsistent flow rates through farm outlets and late or failed water deliveries.[155]

Rubicon's modernised irrigation automation system addresses many of these issues through accurate measurement and accounting, eliminating spills, improving the reliability and timeliness of water supply, and enabling precise application to crops. Examples of positive outcomes from the adoption of Rubicon Water's irrigation systems in Australia and abroad are provided in the section below. According to the University of Melbourne, farmers have also reported improvements in their general wellbeing and reduced working hours thanks to the ability to irrigate crops remotely.[156]

Adoption

Rubicon Water's TCC technology has led to significant positive outcomes through its adoption in Australia and international irrigation projects.

One example in Australia is the Mareeba-Dimbulah Efficiency Improvement Project, undertaken by Sunwater in Queensland. The Australian Government jointly funded the project through the National Water Grid Fund and the Queensland Government. The project was completed in January

[155] Rubicon Water, 2022, *Narayanpur Left Bank Canal Automation: Achieving World's Best Practice Irrigation Modernisation*, supplied by Rubicon Water

[156] Tippet, G, n.d., *Food That Doesn't Waste Water*, https://pursuit.unimelb.edu.au/features/food-that-does-not-waste-water

2022, and the modernised irrigation technology has already led to the recovery of 8000 megalitres of water in the first 12 months of operation

Another example in Australia is the Goulburn-Murray Irrigation District Connections Project, one of Australia's most significant irrigation modernisation projects. The project's objective was to recover 429 gigalitres of water per year from the modernised system and improve the ability to control water flow through the large-scale network (more detail on this project below).

9.7.2 Goulburn-Murray Irrigation District Connections Project

On 25 February 2022, Victorian Minister for Water Lisa Neville announced the successful recovery of over 429 gigalitres of water as part of the Connections Project, the largest irrigation modernisation project in Australian history..[157] Funded by the Victorian and Australian Governments, the world-leading delivery system is expected to support the sustainable future of productive agriculture in the Goulburn-Murray Irrigation District (GMID) for future generations.

The Project was completed by the Connections Project Control Group and Goulburn Murray Water and utilised Rubicon Water's network control technology to accurately distribute water within the complex system, resulting in the water recoveries mentioned above..[158] The automated technology targets system losses through accurate measurement and control of water while providing a near on-demand water ordering service to irrigators. The project supports Victoria's obligations under the Murray Darling Basin Plan to increase water savings without the removal of water entitlements from farmers.

In October 2021, irrigators received 77 gigalitres as part of the irrigation water share distribution, and 279 gigalitres were recovered for the environment – avoiding the need for buybacks under the Murray Darling Basin Plan. Melbourne water retailers will also receive their full 75 gigalitres as part of the original agreement.

The remaining 2 gigalitres will be distributed equally to the original partners in the project – irrigators, the environment – represented by the Victorian Environmental Water Holder (VEWH) – and Melbourne retailers.

Both the VEWH and the Melbourne retailers have agreed their additional water will be set aside for Traditional Owners in northern Victoria – a total of 1.36 gigalitres.

This is the first time that Traditional Owners in northern Victoria will receive a water entitlement as part of the Government's commitment to Aboriginal values and aspirations for water. How that water is distributed will be determined by the Traditional Owner groups.

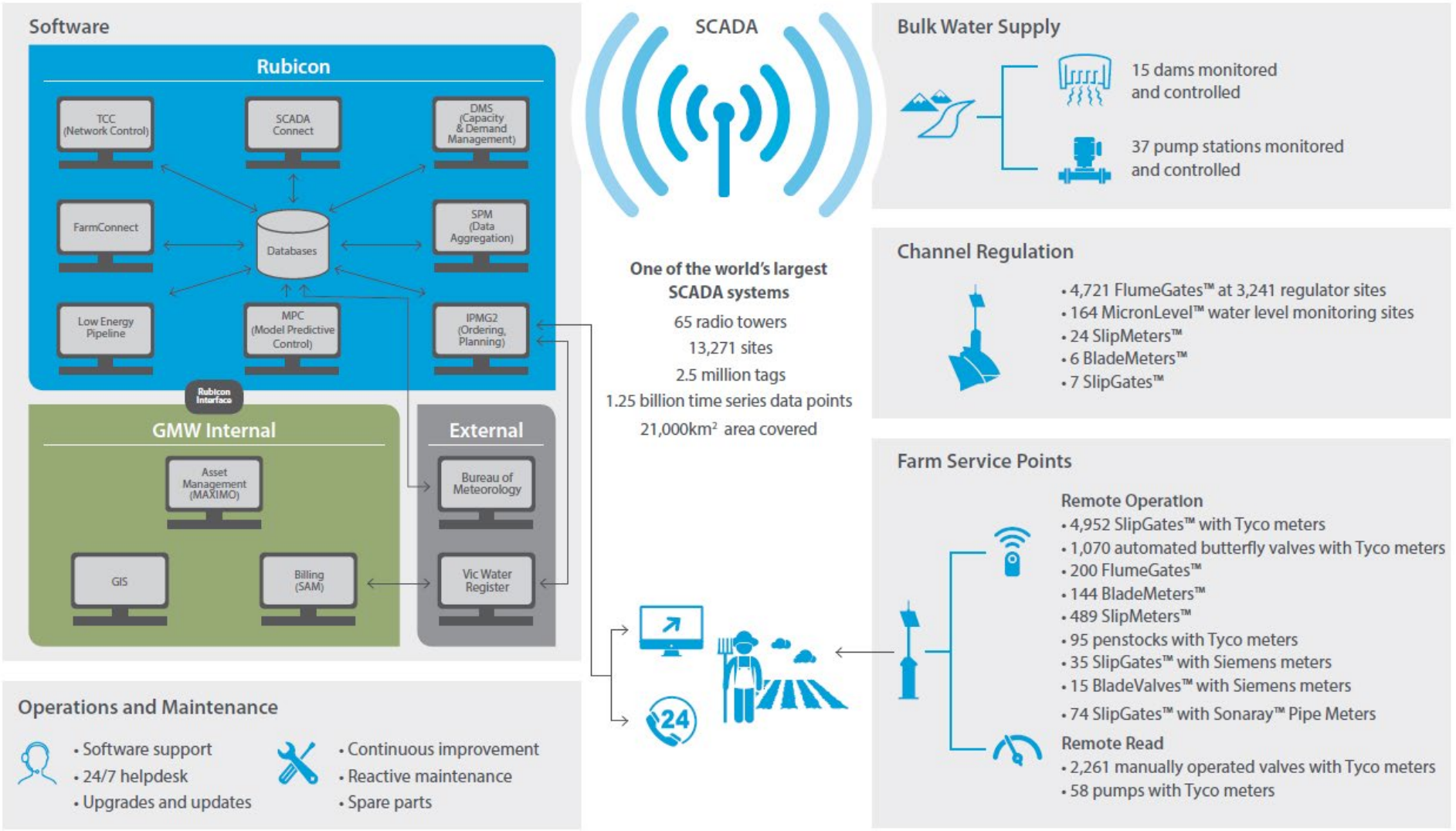
The resulting modernised irrigation supply system is one of the world's largest supervisory control and data acquisition systems..[159] The system covers 21,000 km^2, monitors and controls 15 dams and 37 pump stations, and regulates the irrigation channel with over 4,700 FlumeGates. The full complexity of this system is demonstrated in Figure 9.5 below.

[157] The Hon Lisa Neville MP (2022). *Successful connections project delivers extra water*. Accessed March 2023: https://www.premier.vic.gov.au/successful-connections-project-delivers-extra-water.

[158] Consultation with Rubicon Water

[159] Supervisory control and data acquisition (SCADA) is a system of software and hardware elements that allows industrial organizations to: Control industrial processes locally or at remote locations. Monitor, gather, and process real-time data.

Figure 9.5 Goulburn-Murray Water's Modernised Irrigation Supply System



Source: Rubicon Water 2022

9.7.3 Global projects

Rubicon Water's software and hardware technology automates the operation and management of irrigation districts across 6 continents. Today, Rubicon technology is automating the delivery of water servicing an area of more than 2.5 million hectares worldwide, supporting annual economic output of more than $17 billion.[160]

For example, in California, the Oakdale Irrigation District uses a century-old gravity distribution system to divert 370 gigalitres of water annually to around 3,500 farmers and domestic users across a 29,000-hectare area in the San Joaquin Valley. After installing TCC, the district eliminated unintentional water loss, saving up to 16 megalitres of water per day across just one of the upgraded channels. Across the system, initial water savings are estimated to be up to 40 gigalitres per year – enough for a city of 500,000 people.[161]

Another example is Rubicon Water's Angeli-Cerese automated canal system project in Italy. This project signifies the first fully automated Total Channel Control (TCC) project that Rubicon deployed in Europe. In February 2023, Rubicon Water announced that the automation of the network had decreased storage pumping costs for the Italian client by 25% within the first 12 months of the project being rolled out.[162]

In early 2019 Rubicon commenced the installation of its largest Indian irrigation modernisation project to date in Karnataka state. The project, known as the Narayanpur Left Bank Canal (NLBC) Phase II Modernisation Project, was a joint venture with local partner Medha Servo Drives for Krishna Bhagya Jala Nigam Ltd. (KBJNL). The project aimed to improve canal distribution efficiency by up to 20%. Such improvements provide farmers with an equitable and consistent service to promote improved crop vitality and boost the region's economic output.[163] The project specified the scope to install more than 4,200 automated gates to accurately distribute water to farmers across approximately 400,000 hectares of irrigated land. The NLBC Phase II Project is now at the stage of practical completion and early benefits are flowing through for farmers, operators and the economy.

Alignment with government strategic priorities

The Australian Government has identified 9 National Science and Research Priorities and associated Practical Research Challenges. The priorities, developed in consultation with leaders from industry, research and government, are designed to focus Australian Government support for science and research on Australia's most important challenges. The irrigation automation research collaboration between the University of Melbourne and Rubicon Water are aligned with the Soil and Water priorities.

The research is also aligned with the Australian Government's commitment to delivering water security. The Australian Government is investing in long-term water security through a range of evidence-based science, planning and construction projects. Investments in critical water infrastructure projects were a key feature of the 2022 Budget, with the Government delivering more

[160] Rubicon Water, 2022, *Narayanpur Left Bank Canal Automation: Achieving World's Best Practice Irrigation Modernisation*, supplied by Rubicon Water.

[161] Rubicon Water, n.d., *Oakdale implements Network Control for stable water levels and to eliminate outfalls*. Accessed March 2023: https://rubiconwater.com/en/project/oakdale-irrigation-district/.

[162] Rubicon Water (2023). *Rubicon Water's Post*. Accessed March 2023: https://www.linkedin.com/posts/rubicon-water_irrigation-automation-agtech-activity-7022077154318319616-2Zk0/.

[163] Ibid.

than $2 billion for the Water for Australia Plan. Delivering on Murray-Darling Basin Plan commitments to return water to the environment is part of the Water for Australia Plan.[164] [165]

9.8 Impacts

9.8.1 Economic impacts

The University of Melbourne and Rubicon Water's research partnership has led to Rubicon Water implementing irrigation automation services that have generated significant benefits through better-managed irrigation networks. This economic analysis focuses on the water savings achieved through the Goulburn-Murray Irrigation District Connections Project (see section 9.7.2).[166] Unlike the other CBAs conducted for the ARC report, this analysis does not consider attribution.[167] Benefits to international water distributors from international projects will not be estimated in this CBA, as the analysis focuses on benefits to the Australian economy only.

Counterfactual

The counterfactual scenario for this analysis describes what would have happened if the Goulburn-Murray Irrigation District Connections Project did not go ahead. Without the Project, the Goulburn-Murray Irrigation District would have continued to operate on a manual irrigation network, which is less cost-efficient and leads to significant water loss, including through spillage.

Methodology and key assumptions

The CBA estimates the costs and identified benefits of the Connections Project, which was made possible through Rubicon Water's irrigation automation solution. The CBA compares the total capital expenditure costs of the Goulburn-Murray Irrigation District Connections Project, to the benefits realised by the Goulburn–Murray Rural Water Corporation through water savings and operational expenditure savings.

[164] The Goulburn-Murray Irrigation District project, discussed above, was part of the Delivering on Murray-Darling Basin Plan.

[165] The Hon Tanya Plibersek MP (2022). *Australian Government delivers on its Water for Australia plan*. Accessed March 2023: https://minister.dcceew.gov.au/plibersek/media-releases/australian-government-delivers-its-water-australia-plan.

[166] The CBA analysis was based on the Connections project due to the availability of publicly available audited and documented costs and benefits. Although not quantified, Rubicon Water noted that there are also additional benefits associated with the deployment of the technology in canal networks in Australia and throughout the globe. These include water savings from other projects, as well as other impacts such as on the environment (described in section 9.8.2) and impacts on wellbeing and time savings (e.g. due to the ability to schedule water deliveries and irrigate crops remotely).

[167] Attribution describes the percentage of benefits that can be reasonably attributed to the ARC due to its role in funding the research. The level of attribution of benefits to the ARC could not be reported due to commercial sensitivities. It focuses on the benefits generated through the Connections Project, which the ARC has indirectly supported through its funding of the University of Melbourne and Rubicon Water research partnership. Rubicon Water has stated that the ARC funding has supported the development of the Total Channel Control algorithm, which is part of the system responsible for delivering benefits under the Connections Project. The attribution amount is not specified at the request of Rubicon Water.

The following assumptions underpin the CBA:

- The central case uses a 7% discount rate. A discount rate of 3% was used as a lower-bound sensitivity, and a discount rate of 10% was used as an upper-bound sensitivity.
- Ongoing water savings of 433,046 megalitres per year for Goulburn–Murray Rural Water Corporation (2020/21 audit report).[168]
- The price of water per kilolitres in Victoria is $2.99. The cost of water prices in Melbourne, Victoria, in 2020-21 was between $2.63 to $3.35 per kilolitre. An average of the 2 prices was selected for this analysis.
  - The price of water per megalitres in Victoria is $2,990.
- The analysis period is from 2003 (from the start of ARC funding) to 2037 (35-year analysis period, inclusive of starting year). This is consistent across the ARC case study CBAs.

Costs

The nominal costs included in the CBA are:

- The in-kind and cash Linkage Project costs are presented in section 9.4.
- The capital expenditure for the Goulburn-Murray Irrigation District Connections Project was contributed by the Victorian Government, Commonwealth Government, and Melbourne retail water corporations.
- These nominal costs are adjusted for inflation using the Consumer Price Index by year, which produces the real costs (2022 dollars). The costs relating to Rubicon's operation and the Goulburn-Murray Irrigation District Connections Project were adjusted for attribution to ARC.

Benefits

The benefits are:

- Value of water savings achieved through the Goulburn-Murray Irrigation District Connections Project.
- Reduced operational expenditure for the Goulburn-Murray Irrigation District due to moving to an automated irrigation system, contributed by Victoria Government

The nominal benefits by year in terms of the value of water savings are calculated by taking the amount of water saved per year (megalitres) multiplied by the value of water (megalitres):

$$Quantity\ of\ water\ saved(ML) \times Cost\ of\ water\ (\$/ML) = Nominal\ benefit\ (\$)$$[169]

The nominal benefits by year in terms of the operational expenditure savings are calculated by taking the operational savings per year ($)

$$\begin{aligned} &Operational\ expenditure\ reference\ case\ (\$) \\ &\quad - operational\ expenditure\ counterfactual\ (\$) \\ &\quad = Operational\ expenditure\ savings\ (\$) = Nominal\ benefit\ (\$) \end{aligned}$$[170]

[168] Department of Energy, Environment and Climate Action (2023). Independent audit of water recovery – GMW connections project. Accessed March 2023: https://www.water.vic.gov.au/water-for-agriculture/investment-in-irrigation-efficiency/Connections-Water-Recovery.

[169] For example, in 2021, the quantity of water saved due to the upgraded infrastructure of the Connections Project was 433,046 megalitres. Multiplied by the value of water in Victoria of $2,990 per megalitre ($2.99 per kilolitre), this results in a total nominal benefit in 2021 of $1,294,808,437.

[170] For example, in 2021, the operational expenditure under the reference case was $29,825,000, and the operational expenditure under the counterfactual case (if the upgrades did not happen and costs remained the same as before the upgrades) was $34,500,000. The savings in operational expenditure is therefore $4,675,000, which is the nominal benefit counted in 2021.

These nominal benefits are adjusted for inflation using the CPI by year, which produces the real benefits (2022 dollars).

Calculation of NPV and CBR

The estimated benefits and costs are provided in Table 9.2 for discount rates of 3, 7 and 10%.

The benefit-cost ratio (BCR), obtained by dividing the present value of benefits by the present value of costs using a 7% real discount rate, is positive at a value of 2.94. The present value of costs is $4.9 billion. The benefits are estimated at $14.6 billion, resulting in an NPV of $9.7 billion

Table 9.2 Summary of benefits and costs (2022$)

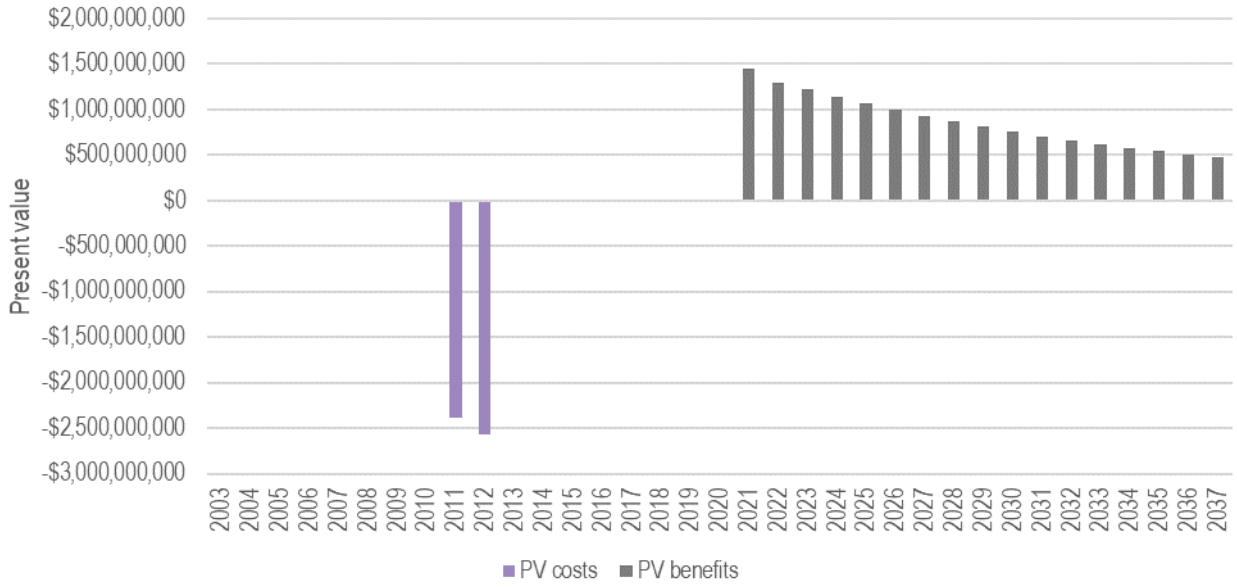
	Discount rate 3%	Discount rate 7%	Discount rate 10%
Present value costs			
ARC research grant costs	$10,645,694	$15,607,885	$21,229,783
Goulburn-Murray Water Connections Project costs	$3,327,597,429	$4,959,870,059	$6,627,848,494
Total PV costs	*$3,338,243,123*	*$4,975,477,944*	*$6,649,078,277*
Present value benefits			
Benefit to Water Distributor (water savings)	$18,147,220,251	$14,537,062,659	$12,633,107,866
Benefit to Water Distributor (operational expenditure savings)	$116,708,364	$98,400,372	$89,733,961
Total PV benefits	*$18,263,928,615*	*$14,635,463,031*	*$12,722,841,827*
Results			
NPV	**$14,925,685,492**	**$9,659,985,087**	**$6,073,763,550**
BCR	**5.47**	**2.94**	**1.91**

Source: ACIL Allen

Note: All discount rates are real (i.e., discount rates are applied to real costs and benefits)

The present value of benefits and costs of the Goulburn-Murray Irrigation District Connections project by year are shown in Figure 9.6. The figure shows that the capital expenditure for the project occurred in 2011 and 2012. The majority of benefits begin to flow from 2021 onwards (following the finalisation of audit reports on the water savings). Benefits decrease overtime to the end of the analysis period due to the effect of discounting.

Figure 9.6 Present value costs and benefits by year (7% real DR)



Source: ACIL Allen

Sensitivity testing

Sensitivity testing at the 3% and 10% real discount rates[171] was conducted for this analysis (see Table 9.2 above). Sensitivity testing at these 3 rates shows that although the magnitude of the NPV changes at these 3 rates, the NPV remains positive even at a high discount rate of 10%.

Sensitivity testing was also conducted by varying the difference in the price of water in Victoria. Based on publicly available data, the central case was $2.99 per kilolitre.[172] The CBA results were tested with a lower price of water of $1.50 (approximately 50% below the central case) and an upper bound difference in levelised cost of $4.50 per kilolitre (approximately 50% above the central case). The results of that analysis are shown in Table 9.3. They show that the NPV would fall from $9.7 billion to $2.4 billion, and the BCR would fall from 2.94 to 1.49 if the price of water fell by 50%. Whereas the NPV would rise to $17 billion and the BCR would rise to 4.42 if the price of water increased by 50%. This demonstrates that the estimated benefits of this project remain considerable even under significantly more conservative assumptions.

Table 9.3 Sensitivity testing price of water in Victoria (7% real DR, 2022$)

	Price of water $1.5/kl	Price of water $2.99/kl	Price of water $4.5/kl
Costs	$4,975,477,944	$4,975,477,944	$4,975,477,944
Benefits	$7,391,241,171	$14,635,463,031	$21,976,922,769
Net impact	**$2,415,763,227**	**$9,659,985,087**	**$17,001,444,825**
BCR	**1.49**	**2.94**	**4.42**

Source: ACIL Allen

[171] The 3% and 10% discount rates are the Federal Government Office of Impact Analysis' recommended rates for sensitivity testing. Refer: https://oia.pmc.gov.au/sites/default/files/2021-09/cost-benefit-analysis.pdf

[172] Team Poly (2018). Water prices in Australia. Accessed March 2023: https://teampoly.com.au/2018/06/15/water-prices-in-australia/.

9.8.2 Social impacts

This section describes the social impacts of the Linkage Projects undertaken by the University of Melbourne and Rubicon Water.

Educational impacts

The educational impacts of the ARC-funded research to date are:

- 6 PhD students have received their training on the LP projects (Su Ki Ooi, Yuping Li, Laven Soltanian, Amir Reza Neshastehriz, Adair Lang and Armaghan Zafar)
- 2 Master by Research students have received their training (Ping Zhang, Sumith Choy)
- 12 Visiting Master students from overseas have done their research project on the LP project.

Employment impacts

The University of Melbourne has employed 10 Research Fellows as a result of the University of Melbourne and Rubicon Water research collaboration (Yuping Li, Alireza Farhadi, Michael Kearney, Nadia Bedjaoui, Farhad Farokhi, Marzia Cescon, Hasan Nasir, Bojan Mavkov, Meichen Guo, Timm Strecker).

Environmental Outcomes of Irrigation Modernisation

The recovery of large volumes of water for the environment in overallocated systems has occurred only in recent years. For example, in October 2021, 279 gigalitres of water were recovered for the environment through the Connections Project.[173] To put this volume into perspective, the municipality of Melbourne uses 18.5 gigalitres of mains water in a year.[174]

Over the 10-year period from 2021 to 2031, the Connections Project is expected to return over 3,000 gigalitres to the environment (see Figure 9.7). The reserved water will be used for maintaining the long-term health of Victoria's rivers and groundwater ecosystems, and the plants and animals that depend on them.[175]

It will take some time for the full environmental benefits of this recovery to be realised as ecological restoration is a long-term process. However, according to a study by the Productivity Commission, there is already some evidence of improved water quality and ecological outcomes at the local level. For example, the provision of environmental water has mitigated some of the most severe impacts of the drought by enabling environmental managers to protect key refuges and prevent some species' extinctions.[176]

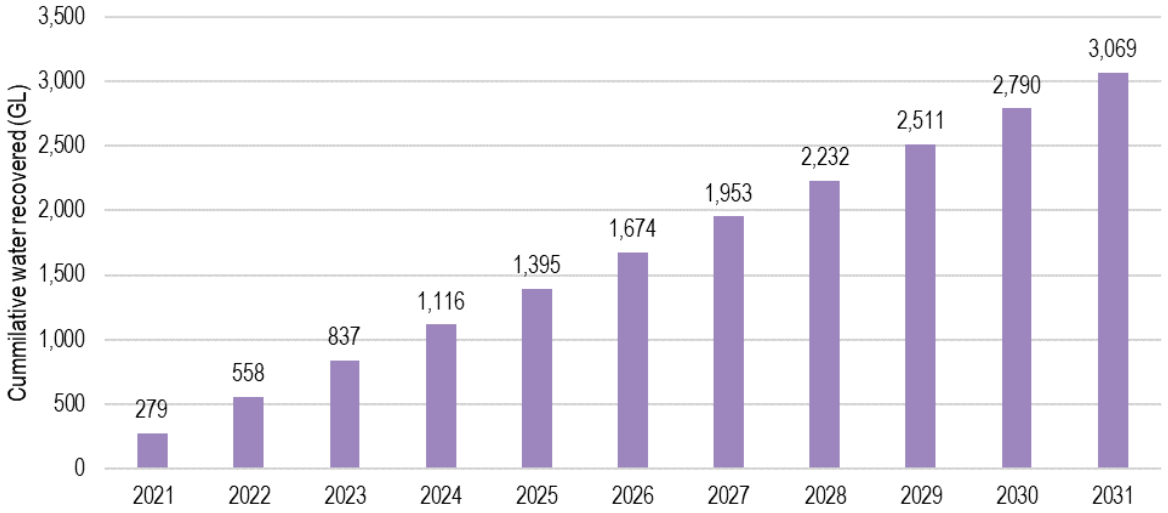
[173] The Hon Lisa Neville MP (2022). *Successful Connections Project Delivers Extra Water.* Accessed March 2023: https://www.premier.vic.gov.au/successful-connections-project-delivers-extra-water.

[174] City of Melbourne (n.d.). *Water use facts*. Accessed March 2023: https://urbanwater.melbourne.vic.gov.au/melbournes-water-story/water-use-facts/.

[175] Melbourne Water (2021). *Water for the environment*. Accessed March 2023: https://www.melbournewater.com.au/water-and-environment/water-management/allocating-melbournes-water-resources/water-environment.

[176] Productivity Commission (2017). *National Water Reform: PC Inquiry Report*. Accessed March 2023: https://www.pc.gov.au/__data/assets/pdf_file/0009/228177/water-reform-overview.pdf

Figure 9.7 Cumulative water recovered for the environment through the Connections Project (2021-31, gigalitres)



Source: ACIL Allen

Other impacts

The research activities undertaken by the University of Melbourne and Rubicon Water were highlighted in a Futurum article in November 2022. The article showcases the importance of the research as well as the role that control engineering can play in improving society..[177] Futurum is a free online resource and magazine aimed at introducing 14-to-19-year-olds worldwide to the work in STEM (science, tech, engineering, maths, medicine) and SHAPE (social sciences, humanities and the arts for people and the economy). The research has been translated into a free education resource that can be used in the classroom, at home and in STEM and SHAPE clubs. These outreach activities are expected to positively impact education and future interest in these sectors.

9.9 Potential future impacts

The University of Melbourne and Rubicon Water are completing another Linkage Project, which commenced in 2020.This research aims to further develop automatic control technologies for irrigation channels, with a particular focus on supply mode operations for channels with critical limits on storage and inflow. This will help Rubicon Water improve its offering in Australia and further expand into overseas markets.

Rubicon Water expects that its technology will continue to benefit society not only through water savings but also through improvements to the processes of water district operators and farmers. Its integrated end-to-end system is expected to continuously improve distribution efficiency for water district operators. On-farm application technologies and irrigation scheduling techniques for farmers will boost on-farm productivity from increased yields and allow farms to diversify into higher-value crops.

[177] Futurum (2022). *How are control engineers improving the sustainability of irrigated agriculture*? Accessed March 2023: https://futurumcareers.com/how-are-control-engineers-improving-the-sustainability-of-irrigated-agriculture.

Rubicon Water is continuing to explore and find opportunities overseas. For example, on 17 October 2022, Rubicon Water signed a Memorandum of Understanding (MoU) with the Ministry of Water Resources of the Republic of Uzbekistan.[178] Compounding issues around the sustainability of water supply in the Aral Sea and increasing water scarcity threats throughout Uzbekistan are driving the need for remediated action to improve the management of the country's water resources. The Ministry of Water Resources has acknowledged the similar issues faced in Australia's Murray-Darling Basin during the Millennium Drought and is exploring the modernisation strategies that Australia leveraged to address water scarcity.

The MoU is just one example of how Rubicon Water hopes its technology can help alleviate the increasing water management issues experienced worldwide. Rubicon Water has noted that irrigation automation technology could have significant impacts in other regions that are experiencing water stress, such as the Colorado River (Southwest US and Northern Mexico), Po River (Italy) and the Nile (Egypt).

[178] Rubicon water (2022). *Rubicon Water signs MOU with the Ministry of Water Resources of the Republic of Uzbekistan*. Accessed March 2023: https://rubiconwater.com/en/rubicon-water-signs-mou-with-the-ministry-of-water-resources-of-the-republic-of-uzbekistan/.

Onshore Lobster Aquaculture 10

10.1 Key Findings – Lobster Aquaculture

$10m in cash support from the ARC, and **$33m** cash and in-kind support from other organisations

The NPV of the project is estimated to be **$201** million. The BCR was estimated to be **3.08**

The project developed and demonstrated the technology for hatching, raising and grow out of tropical rock lobsters.

ARC funding supported collaboration between University of Tasmania (UTAS) University of Sunshine Coast, University of Auckland and industry partners Ornatas and PFG to commercialise the technology

26 PhD students have been trained as a result of the ARC funding

UTAS' research aligns well with the Government's 2015 science and technology, also with industry and regional development priorities

10.2 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to assess the impact and value of research undertaken by many organisations.[179] The results from applying that framework to the Lobster Aquaculture research project are summarised in Figure 10.1.

[179] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F.

Figure 10.1 Aquifer recharge project – Impact Framework Diagram

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– $10 million in cash support from the ARC – $33 million in cash and in-kind support from Ornatas and other partners	– Research on lobster larval and juvenile development, nutrition, physiology, population and molecular biology, husbandry, culture systems – Engineering and automation, social science and market research for commercialisation	– Developed commercial hatchery technology. – 4 provisional patents for larval and juvenile feeds and culture systems – Publications and conference presentations	– A new firm was established (Ornatas) that took up a licence to the technology – Large ongoing private sector investment to commercialise technology – Pilot lobster hatchery in North Queensland – Commercial scale hatchery commissioned	– The estimated NPV is $201.1 million – The estimated BCR is 3.08 – Pilot lobster hatchery has been operating for 2 years – Employment opportunities (up to 1,000 people by 2032) – Lobster export earnings (up to $100 million a year by 2032) – More sustainable lobster industry

Source: ACIL Allen

10.3 Background

This case study relates to projects funded under the following ARC schemes:

- Linkage Program: Industrial Transformation Research Hubs.
  - The first ARC grant supported research and development into hatchery technology and larval feeds for spiny lobsters.
  - The second ARC grant supports the development of shore-based nursery production solutions for lobsters and in particular the development of manufactured feeds. This incorporates the commercialisation of the results of the previous R&D and strengthens the partnership between UTAS and Ornatas.

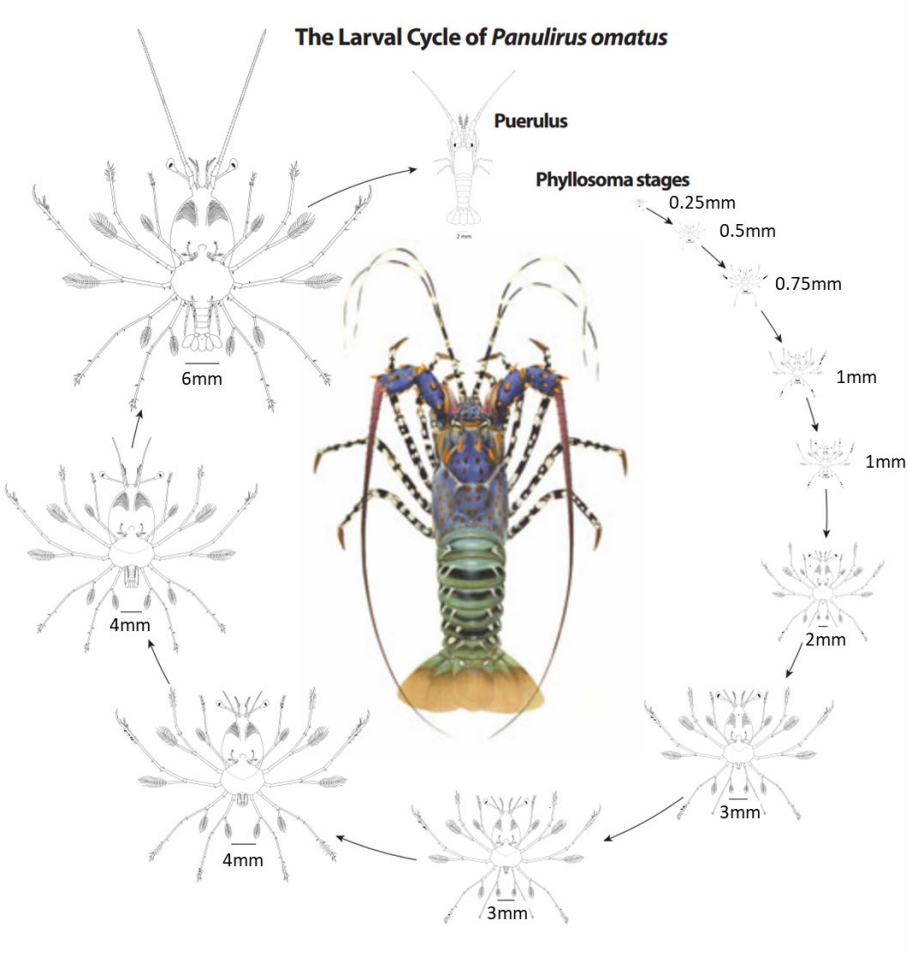
10.3.1 The project

Developing the commercial farming of lobsters has been a long-term goal of the aquaculture sector. Reasons for this include the high value of the product (around $100-140 /kg) and the limited availability of wild stocks that can be harvested each year. The global harvest of spiny lobsters has remained static at around 80,000 tonnes per year since the 1980s. In addition, many populations of native lobsters are under pressure from overfishing and climate change.

In the past, there have been international efforts to farm lobsters by catching wild seedstock and raising them to maturity in sea cages. However, the supply of lobster seedstock is variable, and the species of lobster available to harvest as puerulus are limited. Vietnam is currently the largest user of wild-caught seedstock. Each year it uses approximately 10 million larval seedstock to produce around 3,000 tonnes of lobsters for the market.

In Australia, capturing wild seedstock to grow lobsters is not viable due to low and unreliable supply, the presence of established fisheries with strict regulations and environmental degradation concerns. Hence in Australia, there has been a strong focus on developing hatchery technology to enable a lobster aquaculture industry to be established.

Figure 10.2 Generalised larval cycle of the tropical rock lobster (Panulirus ornatus)



Source: Lifecycle of Panulirus ornatus, phyllosoma stages, puerulus and adult (Australian Institute of Marine Science, 2009).

This research aimed to develop methods to close the complex and protracted life cycle of spiny lobsters in captivity. This was achieved by developing world leading hatchery technology and larval feed manufacture techniques to produce hatchery-reared seedstock. The current research is taking the next step and developing the tools and equipment to enable onshore culture of spiny lobsters to market size. International efforts to achieve this goal have been ongoing for more than 100 years without success. It is only through the collaborative efforts of the University of Tasmania (UTAS) led research backed by local industry and supported by the ARC that this world's first goal has been able to be achieved. The commercial production of hatchery-reared seedstock is a gamechanger for establishing a new lobster aquaculture sector, with seedstock being able to be delivered to grow out facilities at specified times from known origin and in appropriate quantities. The onshore grow out of lobsters to market size will be able to supply Australian and international fresh seafood markets. Efforts to achieve this outcome are well progressed, with strong industry commitment and investment currently being realised in Northern Australia.

10.4 Inputs

This project received 2 ARC Industrial Transformation Research Hub grants (IH120100032 and IH190100014). The cash and in-kind contributions by the ARC and others for each of these grants are shown in Table 10.1. Where no specific information was available regarding the annual distribution of cash or in-kind support, we assumed it was distributed evenly across the grant period.

Total cash and in-kind support expected to be provided to the project over the period from 2012 to 2024 are over $43 million. Just over 52.4% of this was in cash. Total in-kind support was just over $20.5 million. The ARC provided grants worth $10 million, which was over 44% of the total cash support for this project.

The major private sector supporter of the project was the Australian firm Ornatas Pty. Ltd. Ornatas are leaders in the world lobster aquaculture industry. The firm was expressly established in 2018 to commercialise research developed by UTAS. This partnership was born out of the desire to use the ability and talent of the research community at UTAS and the commercialisation capabilities of Ornatas to grow a significant new aquaculture business and, ultimately, a new industry-.

The CEO of Ornatas, Scott Parkinson, noted that:

> *The UTAS technology is truly the Holy Grail of aquaculture and does what so many have tried and failed at before – commercial production of Tropical Rock Lobster from egg that will underpin production of premium lobsters to a marketable size on land using sustainable practices.*

Table 10.1 Support for the project

Contributor / Type of support	2012-2018	2019-2024	Total Contributions
Cash			
IH120100032			
Non-academic partners	$3,281,428	$468,775	$3,750,203
Academic partners	$976,483	$139,498	$1,115,980
ARC	$5,000,000	$0	$5,000,000
IH190100014			
Non-academic partners	$0	$5,000,000	$5,000,000
Academic partners	$0	$2,675,339	$2,675,339
ARC	$0	$5,000,000	$5,000,000
In-kind			
IH120100032			
Non-academic partners	$2,032,217	$290,317	$2,322,534
Academic partners	$4,149,910	$592,844	$4,742,754
IH190100014			
Non-academic partners	$0	$6,383,971	$6,383,971
Academic partners	$0	$7,052,852	$7,052,852
Total	**$15,440,037**	**$27,603,596**	**$43,043,633**

Source: ACIL Allen, various sources

10.5 Activities

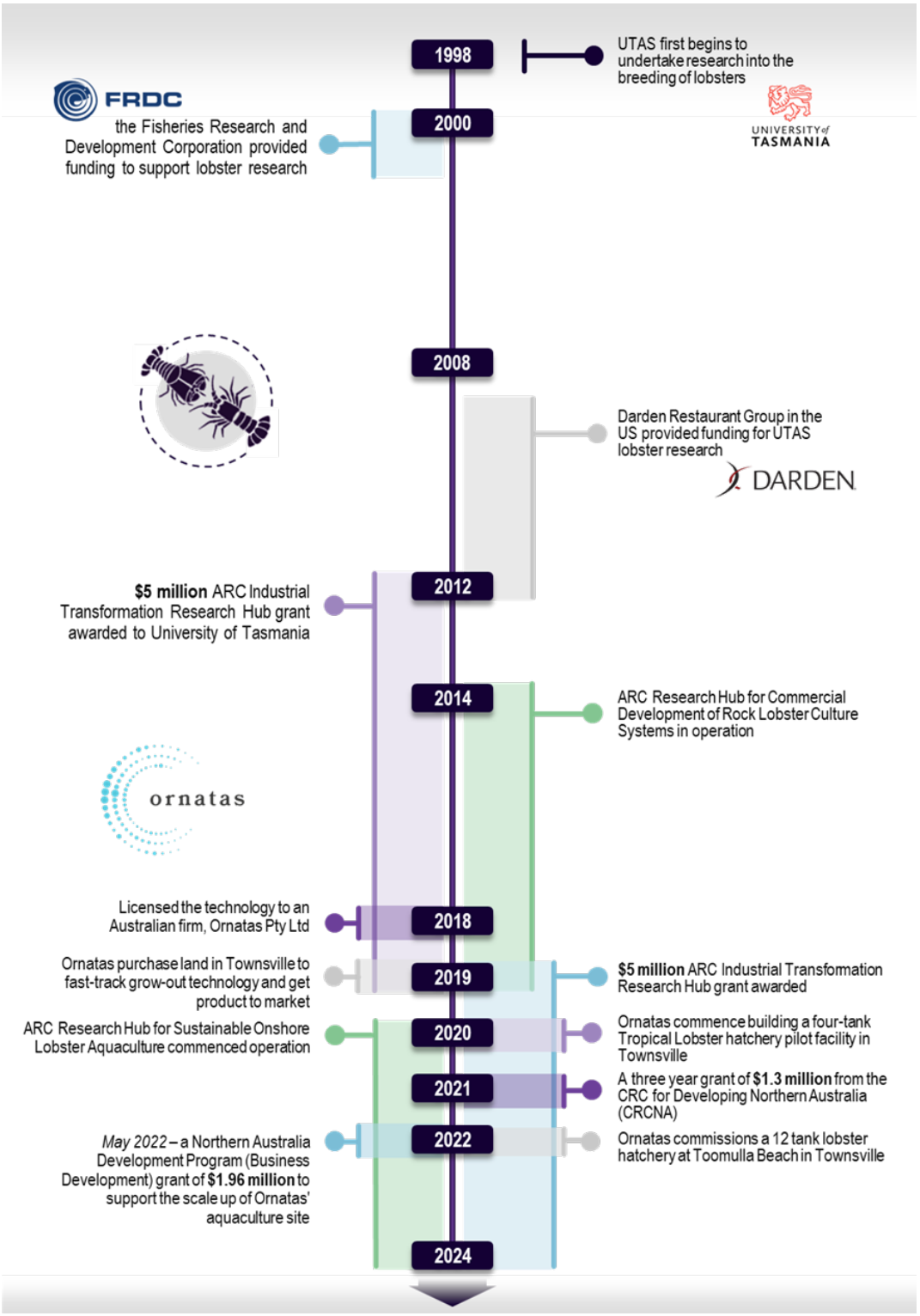
The first ARC grant enabled the establishment of the *ARC Research Hub for the Commercial Development of Lobster Culture Systems.* The research focus for this Hub included:

- Developing and refining tropical rock lobster (TRL) broodstock holding protocols in a way that allows consistent year-round high-quality egg and larval production
- Designing, testing, refining and manufacturing larval mass culture vessels for lobsters. (These vessels are now being manufactured commercially and used by Ornatas in their facilities.) Specialised culture and holding vessels were also designed for the TRL's puerulus phase.
- Investigating the treatment of hatchery water to ensure it meets the specific requirements of lobster larvae. In particular how to manage the increased risk of disease due to the significant increase in density required to culture larvae in a hatchery compared to in the wild
- Investigating different strategies for addressing cannibalism during the period when the lobster larvae undergo metamorphosis during the moult from the final larval stage to the non-feeding puerulus phase. Lobsters moult to grow, which makes them vulnerable. Up to 10% of the metamorphosising larvae can be lost due to cannibalism by other less advanced larvae at this stage of their life cycle. There are a number of potential strategies to address this including manipulating the supply of feeds and the access that less developed larvae have to those metamorphosing.
- Developing rearing protocols and equipment to enhance juvenile lobster survival and growth. This research demonstrated the feasibility of holding and growing lobsters in onshore tank-based systems.
  - Further research in this area is being pursued with industry partner Ornatas as part of the *ARC Research Hub for Sustainable Onshore Lobster Aquaculture*.
- Developing a manufactured larval feed that reduces cannibalism, encourages growth, positively impacts animal health, is affordable, and environmentally sustainable. Such a feed is required to minimise the opportunity for opportunistic disease outbreaks and optimising larval nutrition. It will also be essential for the establishment of commercial lobster grow out industry within Australia.
  - A dedicated program of research to develop grow out feeds for TRL juveniles is being pursued by the new *ARC Research Hub for Sustainable Onshore Lobster Aquaculture*

The second ARC grant enabled the establishment of the *ARC Research Hub for Sustainable Onshore Lobster Aquaculture.* The focus of this Hub was commercialising the technology that UTAS developed. As seen from the discussion above, the key challenges being addressed by the second Hub are developing ways to grow lobsters at high density onshore, and developing a suitable feed to grow the lobsters to market size (with a weight of around 1.2 kilograms each).

The feed conversion rate is a measure of how many kilograms of feed are required to grow a kilogram of lobster. Currently, other lobster grow out industries are utilising fresh feeds where the feed conversion rates are 15, and the Hub is currently producing experimental feeds where the feed conversion rates are 1.5. The aim is to produce feed for less than $10 per kilogram. Further reductions are expected through collaboration with commercial feed producers.

Figure 10.3 Timelines of UTAS's lobster aquaculture research and



Source: ACIL Allen

10.6 Outputs

10.6.1 Publications

Since 2012, the research carried out under the 2 Hubs has led to the publication of a large number of refereed journal articles, conference publications and reports. Some examples are provided below:

- Andrea Wirtz, Chris G. Carter, M. Basseer Codabaccus, Quinn P. Fitzgibbon, Ashley T. Townsend, Gregory G. Smith, Protein sources influence both apparent digestibility and gastrointestinal evacuation rate in juvenile slipper lobster (Thenus australiensis), Comparative Biochemistry and Physiology, Part A 265 (2022) 111121, https://doi.org/10.1016/j.cbpa.2021.111121
- Cameron J. Hyde, Quinn P. Fitzgibbon, Abigail Elizur, Gregory G. Smith and Tomer Ventura. *CrustyBase: an interactive online database for crustacean transcriptomes,* BMC Genomics (2020) 21:637, https://doi.org/10.1186/s12864-020-07063-2
- Katarzyna Kropielnicka-Kruk, Quinn P. Fitzgibbon, Basseer M. Codabaccus *, Andrew J. Trotter, Dean R. Giosio, Chris G. Carter and Gregory G. Smith, *The Effect of Feed Frequency on Growth, Survival and Behaviour of Juvenile Spiny Lobster (Panulirus ornatus)*, Animals 2022, 12, 2241. https://doi.org/10.3390/ani12172241
- Mei C. Ooi, Evan F. Goulden, Gregory G. Smith and Andrew R. Bridle, Predatory bacteria in the haemolymph of the cultured spiny lobster Panulirus ornatus, Microbiology 2021;167:001113, DOI 10.1099/mic.0.001113
- Smith, G., Knibb, W., Nguyen, N.H. & Fitzgibbon, Q.P., *Mass rearing of spiny lobster larvae in recirculation systems - do some broodstock produce larvae better adapted to culture*?, Programme for RAStech 2019, 13-14 May, Washington DC (2019) [Conference Extract]
- Tara R. Kelly, Quinn P. Fitzgibbon, Dean R. Giosio, Andrew J. Trotter & Gregory G. Smith, *Development of a two-current choice flume behavioural bioassay for juvenile Panulirus ornatus response to moulting cues*, Nature Scientific Reports | (2022) 12:21474 | https://doi.org/10.1038/s41598-022-25969-7
- Thomas M. Banks, Tianfang Wang, Quinn P. Fitzgibbon, Gregory G. Smith and Tomer Ventura, A Tale of 2 Lobsters—Transcriptomic Analysis Reveals a Potential Gap in the RNA Interference Pathway in the Tropical Rock Lobster Panulirus ornatus, Int. J. Mol. Sci. 2022, 23, 11752. https://doi.org/10.3390/ijms231911752
- Wang, S., Carter, C.G., Fitzgibbon, Q.P. & Smith, G.G., *Respiratory metabolism of juvenile spiny lobster (Sagmariasus verreauxi) under different feeding conditions*, Abstracts of the 18th International Symposium on Fish Nutrition and Feeding, 03-07 June 2018, Las Palmas de Gran Canaria, Spain (2019) [Conference Extract]

10.6.2 Patents

The following patents have either been granted or are pending:

- Feed compositions and uses for Tropical Rock Lobster aquaculture.
- Larval culture tanks design and system operation.
- Lobster grow out tank design
- Lobster grow out feeds.

10.6.3 Awards

The research funded by the ARC received 2 awards in 2018. One was the University of Tasmania Vice Chancellor's Award for Outstanding Research Program, and the other was the Minister for Science and Technology's Tasmanian STEM Innovation of the Year.

10.6.4 Innovation / commercialisation

The technology developed by UTAS was licenced to Ornatas in 2018. This firm was specifically established to commercialise and use the technology to develop and operate a commercial lobster aquaculture facility.

10.7 Outcomes

10.7.1 Adoption

The Australian firm Ornatas was established in June 2018. It has licenced the technology developed by the *ARC Research Hub for the Commercial Development of Lobster Culture Systems*. The firm has already had considerable success in using the results of the research by the Hubs to scale up their production of the puerulus stage of the lobster aquaculture production chain. In December 2020, the first tropical lobster larvae were hatched at the firm's hatchery at Toomulla in Queensland (see Figure 10.3). Production increased rapidly from 200-300 hundred initially up to around 11 thousand in 2021. In 2022, Ornatas produced some 32 thousand lobsters at the puerulus stage of their life cycle and around 18 thousand at the juvenile stage. The firm is expecting to increase puerulus production to around 80 thousand in 2023. They expect that a similar proportion (i.e. over 40%) to reach the juvenile stage.

In February 2022, Ornatas commissioned a 12-tank lobster hatchery at Toomulla Beach (see Figure 10.4). Production of commercial quantities of lobsters is expected to commence by 2025. They have already established partnerships with marketing and distribution companies. Ornatas believes their annual lobster production could increase to 1,000 tonnes by 2032 with a value of $100 million. They expect lobster aquaculture to become a $150 million industry by around 2036.

Figure 10.4 Ornatas' lobster hatchery at Toomulla in Queensland

Source: Ornatas

Based on ACIL Allen's consultations with stakeholders we expect that commercial sales of lobsters will commence in 2023 and that annual production will increase to 1,000 tonnes by 2032. For our economic analysis, ACIL Allen has assumed that production will be 20 tonnes in 2025 and increase by 10 tonnes each year until 2028. If all goes well, production could ramp up quickly to 1,000 tonnes a year by 2032. Significant investment will be required to expand the annual production of this emerging industry to 1,000 tonnes. Industry estimates suggest that the expansion would require $100 million in investment.

10.7.2 Alignment with government strategic priorities

The research undertaken by UTAS aligns with several National Science and Research Priorities, namely: [180]

- *Food* – the research done by UTAS is expected to lead to a significant increase in Australia's ability to grow and supply lobsters to the domestic and export markets.
- *Advanced manufacturing* – Specialised design and plastic fabrication of rotomolded tank materials to construct lobster mass rearing systems.
- *Environmental change* – The research carried out by the 2 Hubs has had a strong focus on ensuring the environmental sustainability of lobster aquaculture through feed development and onshore lobster culture systems.

The recently released terms of reference for the government's review of its science priorities identifies 3 priorities that could possibly form part of a refreshed set of priorities: [181]

- Supporting stronger action on climate change, including investments in renewable energy, reducing emissions and transitioning to a net zero world.
- Elevating and investing in First Nations perspectives on science, technology and innovation.
- Harnessing the potential of emerging technologies and scientific research in pursuit of not only economic growth but improved Australian wellbeing. [182]

The government has also said that when finalising the revised priorities, it will consider how they:

- Reflect the key challenges and opportunities facing Australia.
- Align with government priorities, such as the National Reconstruction Fund.
- Reflect Australia's competitive and comparative advantages.
- Inform and align government decision making and investment into the future.
- Provide greater certainty and focus for investment, including by industry.
- Be reviewed and updated to ensure they remain contemporary and responsive to Australia's needs.

10.8 Impacts

10.8.1 Economic impacts

Counterfactual

UTAS advised that the ARC grants allowed them to bring nutritionists, engineers, physiologists, aqua culturists, sociologists, geneticists into the research effort. These are multidisciplinary specialists that cannot be brought together to work on a project without significant funding.

[180] Australian Research Council (2022). *Science and research priorities*. Accessed March 2023: https://www.arc.gov.au/funding-research/apply-funding/grant-application/science-and-research-priorities.

[181] In September 2022, the Australian Government announced plans to refresh Australia's National Science and Research Priorities. Australia's Chief Scientist, Dr Cathy Foley AO PSM, is leading a taskforce that will consult with stakeholders and is expected to develop a refreshed set of priorities and a renewed National Science Statement by September 2023.

[182] Department of Industry, Science and Resources (2022). Terms of reference. Accessed March 2023: https://www.industry.gov.au/science-technology-and-innovation/revitalising-australias-vision-science-and-research/terms-reference.

Based on its discussions with stakeholders, ACIL Allen believes that without the research conducted as a result of the 2 ARC grants there would be little to no prospect of any successful lobster aquaculture business being established in Australia in the medium to long term.

In our consultations with Ornatas they noted that

> *ARC funding was critical to getting things started. In particular, having 2 ARC hubs back to back produced a lot of momentum for the commercialisation of hatchery technologies, and Ornatas' parallel investment in infrastructure and operations. That momentum contributed to their ability to access other business grants from government that are critical to fast-track development of the new lobster aquaculture industry.*

Attribution

The attribution describes the percentage of benefits that can be reasonably attributed to the ARC due to their role in the funding of the research.

ACIL Allen believes that it would be appropriate to attribute 50% of the benefits delivered by the lobster aquaculture project to the ARCs funding for the 2 Hubs. Ornatas noted that it would not exist today in the absence of the research supported by the 2 ARC grants provided under the project. However, a 50% attribution recognises the significant history of the research (see Figure 10.3), and the impact of the other organisations involved in this research contributing cash and in-kind, and the in-direct investment by the industry partner to commercialise the science. Ornatas confirmed that a 50% attribution was an appropriate assumption.

Methodology and key assumptions

The cost-benefit analysis (CBA) estimates the costs and identified benefits of Ornatas' lobster production. As discussed above, Ornatas was expressly established to commercialise the University of Tasmania's ARC-funded research. The CBA compares the total costs of the Industrial Transformation Research Hub grants (see Section 8.4) and Ornatas' establishment costs to the benefits to Ornatas in terms of revenue.

The following assumptions underpin the CBA:

— Discount rate of 7% was used in the central case. Discount rates of 3% and 10% were used for lower- and upper-bound sensitivity testing respectively.
— Value of lobster is $100 per kilogram
— The analysis period is from 2012 (from the start of ARC funding) to 2046 (35-year analysis period, inclusive of starting year). This is consistent across all the ARC case study CBAs.
— Ornatas noted that without the ARC funding for the 2 Hubs, the production of aquaculture-grown lobsters in Australia would not have occurred. Therefore, benefits are counted until the end of the analysis period.

Costs

The nominal costs included in the CBA are:

— The cash and in-kind contribution of the ARC Linkage grants (see Section 8.4).
— Ornatas's costs involved in developing and ramping up lobster production facilities.[183]

These nominal costs are adjusted for inflation using the Consumer Price Index by year, which produces the real costs (costs in 2022 dollars).

[183] Ornatas has stated that this includes operational expenditure.

Benefits

The benefit is the revenue generated by Ornatas through its production of lobsters, adjusted for attribution to ARC.

The nominal benefits by year are calculated by taking the tonnes of lobster production, multiplied by the value of lobster per tonne, adjusted for the attribution to the ARC-funded research:

$$Quantiy\ of\ lobster\ produced\ (t) \times value\ of\ lobster\ (\$/t) \times attribution\ to\ ARC\ funded\ research(\%) = Nominal\ benefit\ (\$)$$[184]

These nominal benefits are adjusted for inflation using the Consumer Price Index by year, which produces the real benefits (benefits in 2022 dollars).

Calculation of NPV and CBR

The estimated benefits and costs are provided in Table 10.2 for discount rates of 3%, 7% and 10%.

The benefit-cost ratio (BCR), obtained by dividing the present value of benefits by the present value of costs using a 7% real discount rate, is positive at a value of 3.08. The present value of costs is $96.7 million, the benefits are estimated at $297.7 million, resulting in a NPV of $201.1 million.

Table 10.2 Summary of benefits and costs (2022$)

	Discount rate 3%	Discount rate 7%	Discount rate 10%
Present value costs			
ARC-funded research costs	$51,173,551	$59,015,405	$66,335,174
Ornatas' Costs	$40,225,523	$37,646,565	$36,280,758
Total PV costs	*$91,399,075*	*$96,661,971*	*$102,615,931*
Present value benefits			
Value of lobster production	$627,078,392	$297,724,797	$201,506,061
Results			
NPV	**$535,679,318**	**$201,062,826**	**$98,890,130**
BCR	**6.86**	**3.08**	**1.96**

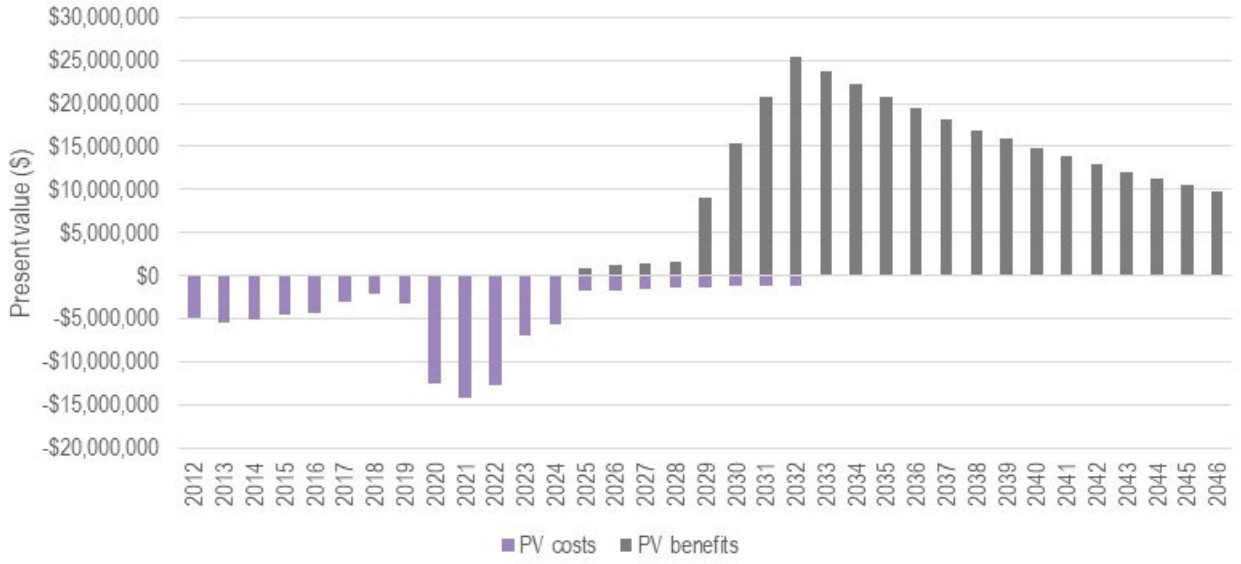
Source: ACIL Allen

Note: All discount rates are real (i.e., discount rates are applied to real costs and benefits)

The present value of benefits and costs of the ARC-funded research by year are shown in Figure 10.5.

[184] For example, in 2025 Ornatas expect to produce 20 tonnes of lobster, at an estimated value of $100 per kilogram, which will result in total production value of $2 million. This figure is adjusted for attribution to ARC of 50%, which results in a nominal benefit of $1 million that can be attributed to the ARC in 2025.

Figure 10.5 Present value costs and benefits by year (7% DR)



Source: ACIL Allen

Sensitivity testing

Sensitivity testing at the 3 and 10% real discount rates[185] was conducted for this analysis (see Table 10.2 above). Sensitivity testing at these 3 rates shows that although the magnitude of the NPV changes at these 3 rates, the NPV remains positive even at a high discount rate of 10%.

Sensitivity testing was also conducted for the value of lobster per kilogram. The central case was $100/kg based on discussions with Ornatas. The CBA results were tested with a lower bound value of lobster of $50/kg (50% below the central case) and an upper bound value of lobster of $75/kg (50% above the central case). The results in Table 10.3 show that the Net Present Value would fall from $201.1 million to $52.2 million and the BCR would fall from 3.08 to 1.54 if the value of lobster fell by 50%. Whereas the NPV would rise to $349.9 million and the BCR would rise to 4.62 if the value of lobster increased by 50%. The NPV remains positive even at the lower bound test of $50/kg. This demonstrates that the estimated benefits of this project outweigh the project costs, even under significantly more conservative assumptions.

Table 10.3 Sensitivity testing value of lobster (7% DR, 2022$)

	Value of lobster $50/kg	Value of lobster $100/kg	Value of lobster $150/kg
Costs	$96,661,971	$96,661,971	$96,661,971
Benefits	$148,862,398	$297,724,797	$446,587,195
Net impact	**$52,200,428**	**$201,062,826**	**$349,925,224**
BCR	**1.54**	**3.08**	**4.62**

Source: ACIL Allen

Sensitivity testing was also conducted for the attribution of benefits to ARC. The central case was an attribution of 50%. The CBA results were tested with a lower bound attribution of 40% and an upper bound attribution of 60%. The results in Table 10.4 show that the NPV would fall from

[185] The 3% and 10% discount rates are the Federal Government Office of Impact Analysis' recommended rates for sensitivity testing. Refer: https://oia.pmc.gov.au/sites/default/files/2021-09/cost-benefit-analysis.pdf

$201.1 million to $141.5 million and the BCR would fall from 3.08 to 2.46 if the attribution is reduced to 40%. Whereas the Net Present Value would rise to $260.6 million and the BCR would rise to 3.70 if the attribution was increased to 100%. The CBA is positive at all 3 discount rates.

Table 10.4 Sensitivity testing attribution to ARC (7% DR, 2022$)

	40% attribution	50% attribution	60% attribution
Costs	$96,661,971	$96,661,971	$96,661,971
Benefits	$238,179,837	$297,724,797	$357,269,756
Net impact	**$141,517,867**	**$201,062,826**	**$260,607,785**
BCR	**2.46**	**3.08**	**3.70**

Source: ACIL Allen

10.8.2 Social impacts

Educational impacts

The ARCs funding of the 2 Hubs has supported the training of 26 PhDs to date (10 in the first Hub and 16 in the second Hub). Of the PhDs from the first Hub, 3 now work for government, 5 continue to conduct research and 2 work for industry in Australia and overseas.

Employment impacts

Ornatas currently has around 27 employees and expects to employ almost twice that number by 2028, and to have over 120 employees in Queensland by 2032. The firm expects that there could be up to 1,000 jobs in total across the entire supply chain by 2032. This includes people employed by feed manufactures, onshore and sea raft grow-out, downstream processing, distribution, and marketing. The bulk of the business activity is expected to occur in Queensland.

10.8.3 Other impacts

Environmental

As discussed above, the research done by the Hubs on feed development and onshore lobster culture systems will help to ensure the environmental sustainability of Australia's emerging lobster aquaculture industry. In particular, this includes ensuring that the feed for the lobsters (throughout their life cycle) is environmentally sustainable.

Collaboration

The ARC funding for this project helped create and strengthen the collaboration between UTAS, PFG and Ornatas. Those organisations continue to collaborate on commercialising the results obtained from the R&D done by the first Hub. Both parties expect that their collaboration will continue into the future.

UTAS also collaborated with a number of other universities as part of the R&D done by the 2 Hubs. For example, the University of the Sunshine Coast researched the genetics of lobsters to look at ways of producing sterile stocks and developing all-male populations (male lobsters grow faster and are therefore, quicker to get to market).

Performance of the ARC

Ornatas noted that this impact evaluation was the first time the ARC has been in touch with Ornatas since establishing the Hub. They believe that businesses/investors would welcome the opportunity to work/communicate more directly with the ARC. They regard this as particularly important since Linkage program grants are meant to support industry - researcher collaboration.

10.9 Potential future impacts

In addition to their own production of lobsters, Ornatas are investigating the opportunities of being a supplier of juvenile lobsters to other aquaculture firms to grow them to market size, at which point Ornatas would buy them back and market them under their brand. Ornatas envisage that if all goes well, the lobster aquaculture sector could become a 1,000 tonne a year industry and the whole emerging sector could have a value of $0.5 billion a year in the longer term.

Collaboration between Ornatas and their research partners is expected to continue. It is possible that the breeding technologies developed for tropical rock lobsters could potentially be applied to other crustacean species.

Changing the Law to Protect Survivors of DFV

11

The following case study presents a body of research focused on domestic and family violence.

Some information may be sensitive and confronting to some readers, and caution is advised.

There are a range of external support services available should you wish to seek support:

— 1800RESPECT on 1800 737 732. 1800RESPECT is the national sexual assault, family and domestic violence counselling service for anyone in Australia who has experienced, or is at risk of, family and domestic violence or sexual assault. 24 hours, 7 days a week.

— MensLine Australia on 1300 789 978. MensLine Australia is a telephone and online counselling service for men with emotional health and relationship concerns, including issues of violence. 24 hours, 7 days a week.

— Lifeline on 13 11 14. Lifeline provides free national counselling, information and support.
24 hours a day, 7 days a week.

11.1 Key Findings

$2.15m invested by ARC and **$1.93m** by participating organisations

1 life would need to be saved for the benefits to offset the research costs

The project has produced
- National Domestic and Family Violence Bench Book, training materials, and a course on DFV
- 2 books, 14 papers, 3 conversation pieces, media & public engagements

2 state laws passed
60K Bench Book users
240 individuals trained

3 PhD & **24** honours students trained as a result of the project

Aligns with priorities:
- National Plan to End Violence against Women and Children 2022-2032
- Queensland Not Now, Not Ever Report
- Queensland Domestic and Family Violence Prevention Strategy 2016-2026

11.2 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to assess the impact and value of research undertaken by many organisations.[186] The results from applying that framework to the Changing the law to Protect Survivors of DFV case study are summarised in Figure 11.1.

[186] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F.

Figure 11.1 Changing the law to Protect Survivors of Domestic Violence – Impact Framework Diagram

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– $2.1 m in cash support from ARC – $2 m in cash and in-kind support from other organisations – Support from DFV organisations	– Identification and analysis of legal decision-making, writing of alternative feminist judgements and assessment of the impact on judicial decision-making – Review of literature and legal responses to DFV – 3-year longitudinal engagement with 65 women involved in legal responses to DFV – Development of the National Domestic and Family Violence Bench Book (Bench Book) and training – Analysis of the gap between judge-made law and lived experiences of Indigenous litigants, writing of alternative judgements – Workshops and engagements	– Bench Book and training materials – 1 book, 3 co-edited collections, 1 monograph, 14 academic papers, 3 conversation pieces and 1 video – At least 12 significant media engagements, 8 events, university and conference presentations and 17 professional development sessions – DFV course for law students – Law and Society Association of Australia and New Zealand Award for best monograph – Member of the Order of Australia and Fellow of the Australian Academy of Social Sciences – New research methodologies	– Development of a robust evidence base on DFV in Australia – Uptake of the Bench Book and training courses – Use of evidence base to inform the introduction of NFS laws in 2 states – Citation of work in state and national policies, strategies and reports – Uptake of education and training by the judiciary, magistrates and tribunal members, and law students – Strengthening of research capacity and connectivity	The research would only need to save the life of 1 woman from DFV for the benefits to offset the research costs Potential impacts on the accuracy, responsiveness and efficiency of the legal system, and in turn, improved outcomes for women and communities Queensland judges better recognise the dangers of NFS and highlight these in their judgments Use of NFS offence by law and justice agencies

Source: ACIL Allen

11.3 Background

This case study relates to projects funded under the following ARC schemes:

— Discovery Program: Discovery Project, Future Fellowships, and Discovery Indigenous.

— Linkage Program: ARC Centres of Excellence.

11.3.1 Domestic and family violence and non-fatal strangulation

Domestic and family violence (DFV) severely damages communities in Australia and across the globe. It is a complex and evolving challenge, which has been defined as:

> *"Domestic and family violence includes any behaviour, in an intimate or family relationship, which is violent, threatening, coercive or controlling, causing a person to live in fear and to be made to do things against their will. This may involve having to significantly modify their behaviour in an attempt to mitigate threats to their safety or wellbeing or the safety and wellbeing of people they care about.... It is often part of a pattern of controlling or coercive behaviour."*[187]

[187] Domestic Violence Service Management (2021). *What is domestic and family violence?* Accessed January 2023: https://dvnswsm.org.au/help-articles-guidelines/what-is-domestic-family-violence/.

DFV may present itself in many ways, including:[188]

- Physical violence and harm
- Sexual and reproductive abuse
- Economic and financial abuse
- Emotional and psychological abuse
- Cultural and spiritual abuse
- Following, harassing and monitoring
- Exposing children to DFV
- Damaging property
- Social abuse
- Animal abuse
- Systems abuse
- Forced marriage and dowry abuse.

DFV can affect any person irrespective of age, gender, socio-economic status or cultural background. However, women and some community groups are disproportionately affected.[189, 190] These groups may also be more susceptible to the impacts of DFV and may require a specific and tailored response by the legal and service system.

Systems abuse (as a form of coercive control) and non-fatal strangulation (NFS) are 2 forms of DFV that are particularly relevant to this case study.

Coercive control involves patterns of behaviour relating to the domination and control of another person, usually within an intimate partner relationship. These behaviours include physical, sexual, psychological, emotional or financial abuse.[191, 192]

NFS is when a person has survived strangulation, which is "a type of asphyxia caused by pressure to the neck, sometimes involving a type of ligature (such as a belt or cord), or more commonly, manual strangulation using hands, arms (e.g., chokehold), knees or feet".[193] NFS is reported by up to half of women who have experienced domestic violence.[194] NFS can be difficult to substantiate legally as there may be no visible injuries.[195] However, victims often report a sore throat, impaired vision and hearing, loss of sensation, memory loss, anxiety and post-traumatic stress disorder, unconsciousness, paralysis and miscarriage of pregnancy.[196] NFS is associated with a 700%

[188] National Domestic and Family Violence Bench Book (2022). *Understanding domestic and family violence*. Accessed January 2023: https://dfvbenchbook.aija.org.au/contents.

[189] Particularly vulnerable groups include people with children, children, young and older people, pregnant people, those with disability, impairment or mental illness, those from culturally and linguistically diverse backgrounds, people living in regional, rural and remote communities, those affected by substance misuse, Aboriginal and Torres Strait Islander peoples, people who are gay, lesbian, bisexual, transgender, intersex and queer, those with poor literacy skills.
National Domestic and Family Violence Bench Book (2022). Op. cit.

[190] National Domestic and Family Violence Bench Book (2022). Op. cit.

[191] Examples of coercive control include the deprivation of liberty and autonomy, isolating an individual from friends, family or wider society, withholding or controlling access to resources (e.g. money), psychological control and manipulation, stalking and intimidation, physical assault or threats of physical assault, sexual assault, reproductive coercion, threatening to take the victim's children away.
NSW Communities and Justice (2020). *Coercive control discussion paper*.

[192] NSW Communities and Justice (2020). Op. cit.

[193] Sharman, L, Douglas, H & Fitzgerald, R (2021). *Review of domestic violence deaths involving fatal or non-fatal strangulation in Queensland.* Brisbane: The University of Melbourne/The University of Queensland.

[194] Douglas, H (2019). *DP200101020 – Australian Research Council, Proposal for Funding Commencing in 2020.*

[195] Sharman, L, Douglas, H & Fitzgerald, R (2021). Op. cit.

[196] Ibid.

higher risk of experiencing attempted homicide and an 800% higher risk of homicide at the hands of an abuser.[197]

The law is recognised as a key mechanism for accountability, prevention and redress of DFV.

Incidence and costs of DFV

In Australia, 1 in 6 women over 15 years are estimated to have experienced DFV by a current or previous partner.[198]

The total costs of violence against women and their children in Australia were estimated at $22-26 billion in 2015-16.[199] However, the costs are challenging to quantify due to the long term nature of the associated social, health, psychological, financial, and economic damages, as well as challenges with accurately capturing the prevalence of the issue due to inconsistent and incomplete reporting and data collection. These costs are likely to have increased in recent years.

NFS is a common form of abuse among women that experience DFV; however, evidence surrounding its occurrence is scarce.[200] A review of the epidemiology of NFS in 9 countries found that between 3 and almost 10% of women reported having been strangled by an intimate partner, with an average of 1% reporting this in the past 12 months.[201] Up to 68% of Australian women using DFV services are estimated to be victims of NFS by an intimate partner.[202] Almost 15% of all family homicides against women are caused by strangulation and/or suffocation.[203]

Policy landscape

There has been growing awareness, advocacy and a culture of change around DFV in recent years. This change has partly been driven by recent high-profile DFV cases (e.g., Rosie Batty and Hannah Clarke), the *me too Movement*,[204] government policy responses and growing government, private sector and philanthropic investment. While this case study focuses on Commonwealth and Queensland government policies introduced to address DFV, it is acknowledged that other jurisdictions have also enacted legislative and policy changes.

The *National Plan to End Violence against Women and Children 2022-2032* (the National Plan) is a joint Commonwealth, state and territory government initiative which outlines and commits to a 10-year plan of sustained action, effort and partnership across sectors and levels of government. Its core vision is to end violence against women and children in one generation.[205] It is implemented through a series of Action Plans and was preceded by the initial 2010-2022 plan. The National Plan builds upon a history of leadership and action by a diverse group of individuals and organisations, including victim-survivors, advocates and women's and community organisations, academics, law enforcement, the justice sector, and all governments and community members.

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[197] Ibid.

[198] Australian Institute of Health and Welfare (2022). *Family, domestic and sexual violence*. Accessed January 2023: https://www.aihw.gov.au/reports/domestic-violence/family-domestic-and-sexual-violence.

[199] KPMG (2016). *The cost of violence against women and their children in Australia Final Report prepared for the Department of Social Services*. Australia: KPMG.

[200] Sorenson, S. B., Joshi, M., & Sivitz, E. (2014). *A systematic review of the epidemiology of nonfatal strangulation, a human rights and health concern*. *American Journal of Public Health*, 104(11), 54-61.

[201] Ibid.

[202] Douglas, H., & Fitzgerald, R. (2021). *Proving non-fatal strangulation in family violence cases: A case study on the criminalisation of family violence*. *The International Journal of Evidence & Proof*, 25(4), 350–370.

[203] Ibid.

[204] me too (2023). *History and inception*. Accessed January 2023: https://metoomvmt.org/.

[205] Commonwealth of Australia (2022). *National Plan to End Violence against Women and Children 2022-2032.* Brisbane: Queensland Government.

The 2022 Federal Budget announced $1.3 billion in funding for women's safety, including $222 million in prevention initiatives.[206]

Our Watch and Australia's National Research Organisation for Women's Safety (ANROWS) were established in 2013 as major organisations in Australia's DFV landscape. Our Watch focuses on prevention through embedding gender equality and changing culture, behaviours and attitudes that underpin and create violence against women and children.[207] ANROWs is a national research body that coordinates research on DFV, develops an evidence base that supports ending violence against women and children in Australia and underpins the National Plan.[208]

The Special Taskforce on Domestic and Family Violence in Queensland developed the *Not Now, Not Ever: Putting an end to domestic and family violence in Queensland* (*Not Now, Not Ever*) Report in February 2015.[209] The publication contained 140 recommendations and set the vision and direction for Queensland's strategy to end DFV and ensure that victims are safe and supported.[210] In August 2015, the Queensland Government formally accepted all 121 recommendations directed at government and supported the 19 recommendations for non-government bodies.

The Queensland Government outlined its plan to drive change and set the direction for ending DFV in Queensland in the *Domestic and Family Violence Prevention Strategy 2016-2026* (the Strategy). The Strategy outlines a shared vision for Queensland and principles to guide action across the community. The vision of the Strategy is "a Queensland free from domestic and family violence". The 3 foundational elements of the Strategy are[211]:

1. a significant shift in community attitudes and behaviours.
2. an integrated response system that delivers the services and support that victims and perpetrators need.
3. a stronger justice system response that will prioritise victim safety and hold perpetrators to account.

These elements reflect the themes from the Not Now, Not Ever Report.

11.3.2 ARC-funded research

Professor Heather Douglas' work has focused on a range of topics under the broad theme of DFV, including NFS and coercive control. Her career began in legal practice as a lawyer, which guided her interest in criminal law in her academic and research career from 2001. She was a former Commissioner for the Queensland Law Reform Commission.

As overviewed in Figure 11.2, Prof Douglas' first ARC grant was *Discovery Projects - Australian feminist judgments project: jurisprudence as praxis* (2012-15). While this did not directly lead to subsequent research in DFV, the project explored feminist issues that have been deeply

[206] Australian Government Department of Social Services (2022). *Women's Safety measures*. Accessed January 2023: https://www.dss.gov.au/sites/default/files/documents/04_2022/fact_sheet_-budget_22-23_womens_safety.pdf.

[207] Our Watch (2023). *About us*. Accessed January 2023: https://www.ourwatch.org.au/about-us/.

[208] ANROWS (2021). *Who we are*. Accessed January 2023: https://www.anrows.org.au/about/.

[209] Queensland Government Department of Justice and Attorney-General (2021). *Not now, not ever report.* Brisbane: Queensland Government.

[210] Ibid.

[211] Queensland Government (2021). *Domestic and family violence prevention strategy 2016-2026*.

Accessed March 2023: https://www.publications.qld.gov.au/dataset/not-now-not-ever/resource/008db60d-06e9-4702-bb87-48be367edf93.

considered in case law, feminist analysis and law reform. The project enhanced Prof Douglas' track record, supporting her success with subsequent funding.

Prof Douglas was awarded a *Future Fellowship – Using law and ending domestic violence: Women's voices* (2015-20). The project undertook the first Australian longitudinal study examining how women of diverse backgrounds who experience DFV engage with law and use it to help them live a life free of violence. The objectives of the grant were to identify:

- When women use the law as a response to DFV and how this use changes over time.
- Factors influencing women's choice of certain legal interventions and how these change over time.
- The unintended consequences of engaging with the law, whether these change over time and for what reasons.
- Factors impacting women's changing levels of satisfaction with legal interventions over time.

The research ultimately aimed to inform community education and policy and legal reform to improve the efficacy of DFV laws and reduce the physical, social and economic harm caused by DFV. A key outcome of this work (discussed further in section 11.7) was the introduction of NFS laws in Queensland in 2016.

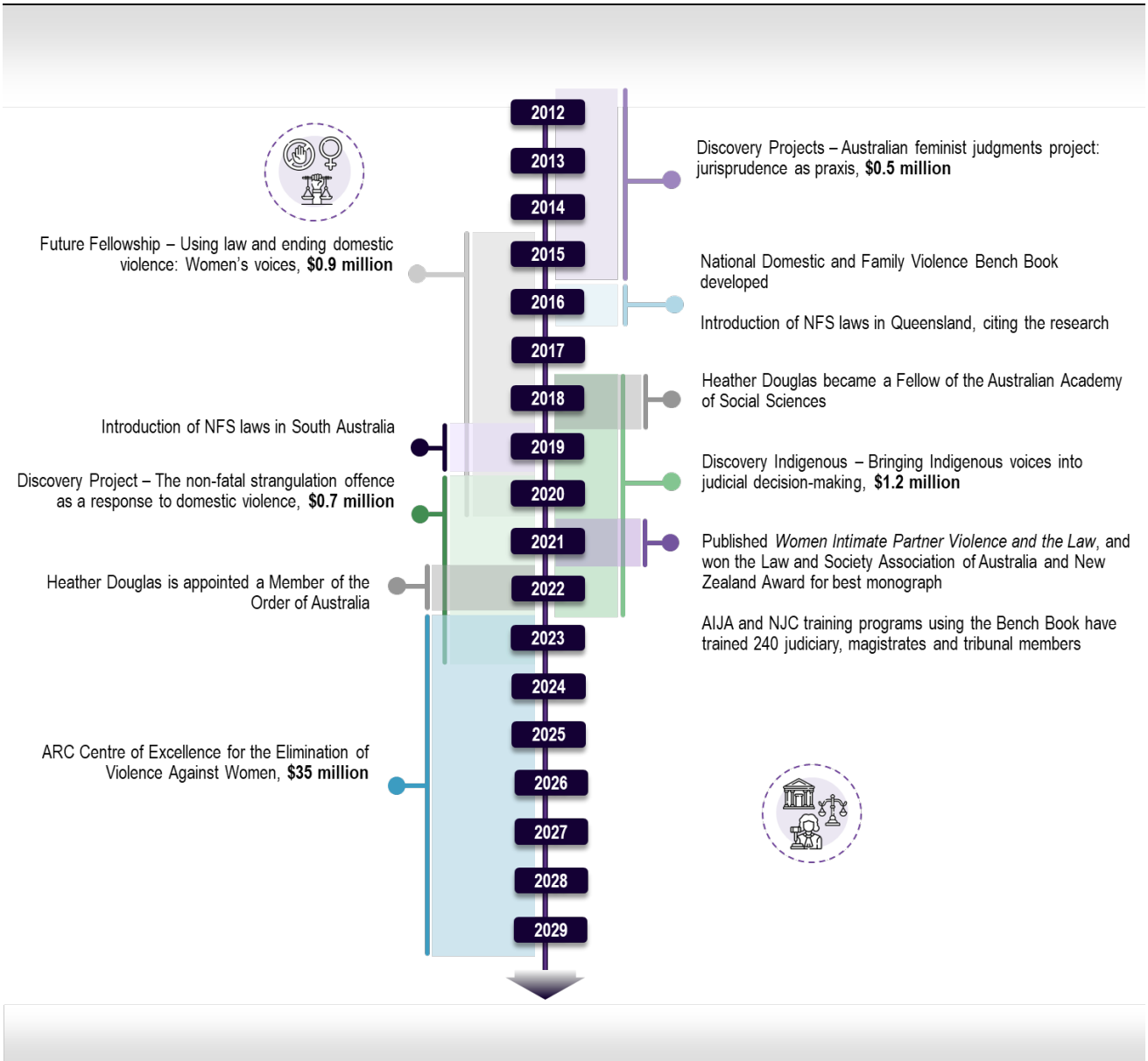
The Future Fellowship grant and introduction of NFS laws led Prof Douglas to conduct further research through another *Discovery Project – The non-fatal strangulation offence as a response to domestic violence* (2020023).

This project reviews the application and experience of the NFS law in practice. The outcomes are expected to include law reform and policy recommendations to improve the operation of the NFS law, enhance service responses and develop professional education. The grant objectives focus on: the prevalence of NFS charges, prosecution and outcomes for the new offence in Queensland; understanding how criminal justice actors build the prosecution case, approach defence, and sentence cases; understanding how victims, perpetrators and service providers view the offence; and developing new theories for understanding the nature of NFS and its construction through criminal law, the role of discretion in responding to DFV, and the processes and impacts of law reform.

Prof Douglas was part of a consortium of researchers recently awarded the *ARC Centre of Excellence for the Elimination of Violence Against Women*. This will enable continued research on the role of law as a response to DFV.

Prof Douglas was also a chief investigator on a project led by Dr Nicole Watson, *Discovery Indigenous – Bringing Indigenous voices into judicial decision-making* (2018-22). The project focused on how judges' decisions can be written to include Indigenous peoples' voices and histories. In this research, Prof Douglas worked with Dr Watson to manage workshops with contributors, co-edit the collection of re-written judgments and co-author an introduction to the collection. Prof Douglas has also been involved in at least 3 presentations explaining the collection's role in reshaping legal education.

Figure 11.2 Overview of the suite of research



Source: ACIL Allen, various sources

11.4 Inputs

ARC and other institutions (including the University of Queensland (UQ), University of Sydney (USYD), University of Kent (United Kingdom), Australasian Institute of Judicial Administration (AIJA), National Judicial Council (NJC) and the Commonwealth Bank) provided $3.4 million in cash contributions for these projects (see Table 11.1).

Prof Douglas did not rely on any existing research infrastructure, yet used librarian, technical and administrative support provided by UQ.

The total value of *Discovery Projects – Australian feminist judgments project: jurisprudence as praxis* was $480,001 (cash). The ARC provided 35% of this funding (2012-14), 48% from UQ and 17% from the University of Kent (both 2012-15). Prof Douglas collaborated with the Australian Association of Women Judges and Women's Legal Services Australia to deliver the project with Dr Francesca Bartlett, Dr Trish Luker, and Prof Rosemary Hunter.

The total value of *Future Fellowship – Using law and ending domestic violence: Women's voices* was $944,347 (cash and in-kind). 100% was provided by ARC (2014-18). Outputs from the Future Fellowship included collaborations with Associate Prof Paul Harpur, Associate Prof Robin Fitzgerald, Katherine Kerr, Associate Prof Bridget A Harris, Associate Prof Molly Dragiewicz, Emma Fell, Elizabeth Price, Dr Leah S Sharman, Dr Nicola Sheeran, Professor Genevieve Dingle and Laura Tarzia.
In-kind contributions were provided by DFV organisations, including Domestic Violence Action Centre, Domestic Violence Assistance Program, Galang Place, Immigrant Women's Support Service, Queensland Indigenous Family Violence Legal Service, Women's House, Women's Legal Service (Brisbane), Working Against Violence Support Service and WWILD Sexual Violence Prevention Association. In-kind contributions for these projects have not been quantified and are detailed below.
$533,975 was provided by the AIJA between 2015-2022 to fund the development of the DFV bench book.
$30,000 was provided by the National Judicial Council (NJC) to develop training materials based on the bench book in 2017.

The total value of *Discovery Indigenous – Bringing Indigenous voices into judicial decision-making* was $1,226,640 (cash and in-kind) (2018-22). 55% was provided by ARC, 10% from ANU, 14% from UQ and 21% from USYD. This project was led by Dr Nicole Watson from USYD and conducted together with Prof Asmi Wood.

The total value of *Discovery Projects – The non-fatal strangulation offence as a response to domestic violence* was $683,229 (cash and in-kind). 52% was provided by ARC and 48% by UQ (2020-23). Prof Douglas is collaborating with Associate Prof Robin Fitzgerald to deliver this project.

Table 11.1 Cash and in-kind contributions for the project

Contributor / Type of support	2012-2014	2015-2017	2018-2020	2021-2023	Total Contributions
Cash					
DP120102375 - Australian feminist judgments project: jurisprudence as praxis					
ARC	$170,000				$170,000
Academic partners (UQ, University of Kent)	$232,501	$77,500			$310,001
FT140100796 - Using law and ending domestic violence: Women's voices					
ARC	$125,211	$712,876	$106,261		$944,347
Non-academic partners (AIJA, NJC)		$399,148	$89,306	$75,522	$563,976
IN180100021 - Bringing Indigenous voices into judicial decision-making					
ARC			$678,640		$678,640
DP200101020 - The non-fatal strangulation offence as a response to domestic violence					
ARC			$146,000	$208,000	$354,000
Academic partners (UQ)			$20,697	$62,091	$82,788
National Domestic and Family Violence Bench Book and training					
Non-academic partners (AIJA, NJC)		$100,795	$102,390	$50,790	$253,975
Coercive control training materials					
Non-academic partners (AIJA)				$50,000	$50,000
In-kind					
IN180100021 - Bringing Indigenous voices into judicial decision-making					
Academic partners (UQ, USYD)			$251,644	$167,762	$419,406
DP200101020 - The non-fatal strangulation offence as a response to domestic violence					
Academic partners (UQ)			$61,610	$184,831	$246,441
Total	**$527,712**	**$1,290,319**	**$1,456,548**	**$798,996**	**$4,073,574**

Source: ***ACIL Allen, research project applications and personal communications with Prof Douglas***

11.5 Activities

The activities associated with the research are centred on projects funded by the ARC since 2012. They include:

- Reviewing current literature and legal responses
- Identifying existing judgements and the influence of feminist and Indigenous perspectives
- Re-writing judgements to incorporate feminist and Indigenous perspectives, and considering the impact these perspectives could have on judicial decision-making in Australia
- Analysis of court administrative data and sentencing outcomes
- 3-year longitudinal interviews DFV victims, and interviews with prosecution and defence lawyers, and perpetrators
- Dissemination of results, and collaboration and partnerships.

11.5.1 Discovery Project – Australian feminist judgments project: jurisprudence as praxis

This project investigated how feminist theory can be applied to legal decision-making in Australia. It aimed to highlight the possibilities, limitations and implications of a feminist approach to judging through analysis of existing decisions and practices and the production of a collection of imagined feminist judgments in significant cases.

The project:

- Mapped existing Australian jurisprudence to identify judgments influenced by feminist thought and explored the subjectivity of feminist judicial officers in Australia
- Built on and extended international feminist judgment-writing projects by identifying key Australian judgments calling for revision, drawing on feminist theoretical insights, writing alternative feminist judgments, and inquiring into and reflecting on the methods and reasoning employed by authors in re-writing judgments from a feminist perspective
- Investigated whether feminist theoretical insights make a difference to judicial decision-making in Australia, or could do so.

11.5.2 Future Fellowship – Using law and ending domestic violence: Women's voices

This project explored women's engagements with the law after experiencing DFV. The project engaged 65 women over 3 years to build evidence for how perpetrators can use the law to further abuse and how legal responses might better prevent this and support women.

This research reviewed current literature and legal responses to DFV and focused on Queensland's civil protection orders, criminal law, family law, immigration law and child protection.

The second component of the method involved 3 annual longitudinal interviews with 65 women who had experienced intimate partner violence. These focused on women's choices about legal engagement and their experiences with and perceptions of the legal system. DFV organisations were critical in supporting engagement with participants (see section 11.4). Family law solicitors and academic partners also contributed to the research. Researchers from other disciplines (e.g., psychology and digital technology) broadened the research's scope, application and impact.

The research concluded with a write-up and dissemination of results, workshops at UQ to connect researchers with DFV organisations, and ongoing monthly meetings at UQ to discuss responses to, and research needs, regarding DFV.

The research found that women's engagement with the legal system changes over time: civil and criminal matters are prominent in the first year after separation, and engagement with family law continues throughout. Women's choice of legal engagements is affected by their access to financial support and lawyers, which fluctuates significantly and is available for only some areas (i.e. protection orders). Perpetrators were found to abuse legal systems and responses as a form of coercive control (i.e., systems abuse).

11.5.3 Discovery Project – The non-fatal strangulation offence as a response to domestic violence

This project reviews the application and experience of the NFS offence. It aims to contribute to the development of law reform and policy recommendations to improve the operation of the offence, enhance service provisions and develop professional education.

The project has to date, involved a comprehensive analysis of administrative data held by courts in the 5 years since the implementation of the Queensland NFS law. The analysis has explored temporal and geographic variation in incidents, victims, offenders and legal variables. This will be followed by an analysis of court files and sentencing remarks to assess the context in which NFS cases are charged, processed and interpreted. This involves interviews with prosecution and

defence lawyers from 4 court regions to understand the legal professionals' experience with and understanding of the offence, and its limitations or benefits to prosecution. This will also analyse sentencing outcomes in higher courts, to understand the judicial consideration of relevant factors, including aggravating and mitigating circumstances.

The third component has involved interviews and focus groups with survivors and perpetrators of NFS, service workers and men's behaviour change workers to understand their perspectives on the implementation and operation of the offence.

11.5.4 Discovery Indigenous – Bringing Indigenous voices into judicial decision-making

This project aimed to demonstrate how legal judgements can be written to be inclusive of the voices and histories of Indigenous people. The project built upon Prof Douglas' first Discovery Project, *Australian feminist judgments project: jurisprudence as praxis*, which corrected for the absence of women's voices in legal judgements, to write the missing Indigenous perspective in 20 Australian superior courts decisions. The project identified gaps between judge-made law and the lived experience of Indigenous litigants by examining 4 test cases and workshops held in Sydney and Brisbane.

11.6 Outputs

11.6.1 Publications

The research resulted in many publications. One of the more significant outputs from the research is the National Domestic and Family Violence Bench Book (the Bench Book), discussed in section 11.7. Prof Douglas developed the Bench Book for the Australian Institute of Judicial Administration (AIJA) with funding from the Commonwealth Attorney-General's Department.

Other significant publications include:

- 1 book titled Women, Intimate Partner Violence and the Law[212] (2021) 3 co-edited collections titled Australian Feminist Judgments[213] (2014) Indigenous Legal Judgments: Bringing Indigenous Voices into Judicial Decision Making[214] (2021),Young People using Family Violence (2021),[215] 8 book chapters on co-option of children in relation to intimate partner violence, the use of technology, violence and the law for general medical practitioners, mothers and step-mothers engaging with the law in response to adolescent family violence, and protection orders and personal security.
- 14 academic papers on NFS and legal responses, coercive control, reproductive coercion, policing of DFV, technology-facilitated DFV, DFV in the context of mental health and intellectual disabilities.
- 3 conversation pieces on migrant women and technology-facilitated DFV, reparations for police negligence, and the role of technology in safety and abuse.
- At least 12 significant media engagements about intimate partner violence and systems abuse, migrant women and technology-facilitated DFV, stalking, women who kill violent men, proposed new strangulation laws in Victoria and the criminality of psychological or emotional DFV. Prof Douglas also called for a review of deaths associated with the family law system

[212] Douglas, H. (2021). *Women, intimate partner violence, and the law*. Oxford University Press.

[213] Douglas, H., Bartlett, F., Luker, T., & Hunter, R. (Eds.). (2014). *Australian feminist judgments: Righting and rewriting law*. Bloomsbury Publishing.

[214] Watson, N., & Douglas, H. (Eds.). (2021). *Indigenous Legal Judgments: Bringing Indigenous Voices into Judicial Decision Making*. Routledge.

[215] Fitz-Gibbon, K., Douglas, H. & Maher, J.M. Eds. (2021). *Young People Using Family Violence: International Perspectives on Research, Responses and Reforms*. Springer Nature.

(where she was referred to as one 'of the nation's leading experts on family law and domestic violence').

- 1 video on technology, privacy and DFV.
- 9 presentations at conferences and 5 at universities.
- 17 professional development sessions in the form of workshops, panel discussions and reflection events. These were undertaken with organisations including the Victorian Department of Justice, Judicial Council of Victoria, Department of Youth Justice and Child Protection Queensland, Network to Eliminate Violence in Relationships, Women's Legal Services Network, Legal Aid NSW, and Legal Aid ACT.
- At least 8 significant public events, including an Annual General Meeting Address at the Australian Academy of Forensic Sciences, panel discussions at Feminist Writer's Festivals, Annual Social Justice Lecture at James Cook University and an expert panel discussion at Queensland Parliament House.
- 2 papers were published with Prof Douglas' honours students on DFV and child support and child maltreatment as coercive control.

Prof Douglas also developed a course on DFV for final-year law students (implemented in 2022 at the University of Melbourne Law School). Approximately 15 students will undertake the course each year.

11.6.2 Awards

In 2018, Prof Douglas became a Fellow of the Australian Academy of Social Sciences in recognition of her contributions to research in DFV. She was appointed a Member of the Order of Australia in 2022 to recognise her services to tertiary education and the community.

Her book, *Women Intimate Partner Violence and the Law*, was published in 2021 and won the Law and Society Association of Australia and New Zealand Award for best monograph in 2021.

11.6.3 Innovation / commercialisation

Prof Douglas' has used innovative research methodologies to support her research. For example, the Future Fellowship project was one of the first studies to apply a qualitative longitudinal approach to the study of women's engagement with law. The research applying feminist theory to legal decision-making was a first in the Australian context, as was the re-writing of legal judgements to include the voices and histories of Indigenous people.

There have been no commercial outcomes from the research, noting that the Bench Book has been made freely available by AIJA to encourage uptake by end users.

11.7 Outcomes

11.7.1 Adoption

The research developed a robust evidence base with advanced knowledge of DFV in Australia. Many organisations have used this to deliver significant outcomes, including developing and using the Bench Book, informing policy and legislation, and guiding education and training.

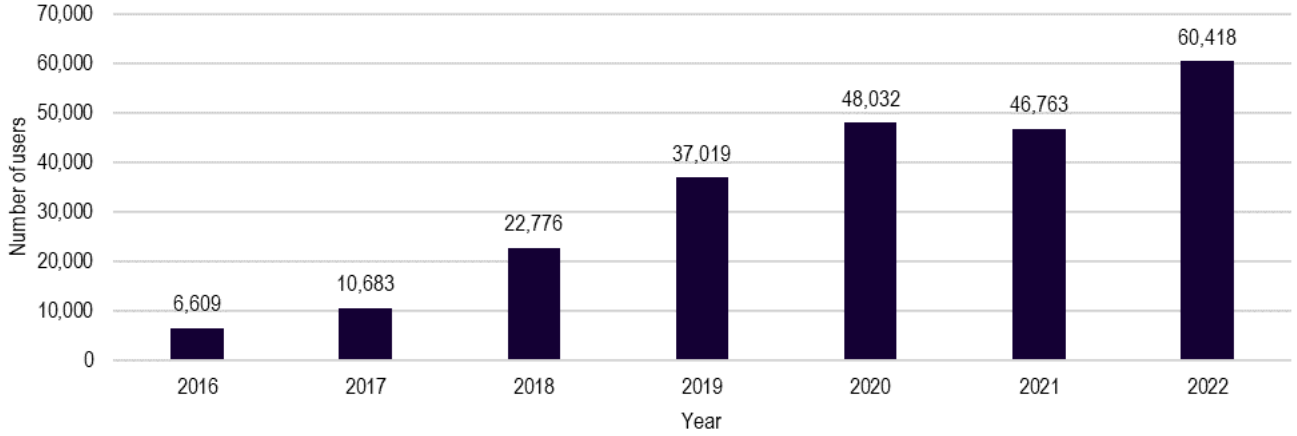
National Domestic and Family Violence Bench Book

Prof Douglas' research on DFV directly contributed to the development of the Bench Book. The Bench Book is a centralised, national resource that guides magistrates, judges and other legal professionals through the sensitivities and complexities of DFV.[216]

The Bench Book draws on the knowledge and experiences of Australian lawyers, judiciary, police officers and case workers to promote greater understanding of the dynamics and behaviours associated with DFV.[217] The Bench Book aims to harmonise the treatment of these issues across jurisdictions and assist with decision-making and judgement writing processes.[218] The Bench Book contains a number of case studies drawn from interviews undertaken as part of Prof Douglas' Future Fellowship, which help users develop a greater understanding of DFV and how these issues present themselves. The Bench Book is housed, maintained and routinely used by the AIJA. The AIJA runs training using the Bench Book for the judiciary, magistrates and tribunal members. The training has been run 8 times since September 2021, with approximately 240 individuals trained. Prof Douglas has also conducted training twice per year with magistrates in Queensland and Victoria since the development of the Bench Book.

Use of the Bench Book has grown steadily by 37% per year since its release in 2016, as shown in Figure 11.3. Prof Douglas has been funded to conduct annual reviews of the Bench Book since its release in 2016.

Figure 11.3 Total number of bench book users each year



Note: statistics were not available for 3 months in 2021.

Source: Google analytics National Domestic and Family Violence Bench Book – site visits

[216] Magistrates Court off Queensland (2022). *Domestic and Family Violence Protection Act 2012.* Accessed January 2023: https://www.courts.qld.gov.au/__data/assets/pdf_file/0020/435026/dv-benchbook.pdf#page=12&zoom=100,92,342.

[217] National Domestic and Family Violence Bench Book (2022). Op. cit.

[218] Ibid.

Informing policy and legislation

— Prof Douglas' suite of DFV research has been highly influential in informing policy and legislation.

— This research was cited in the Not Now, Not Ever Report[219] through a submission to the Taskforce and academic literature. This provided expert advice, which supported the Taskforce in delivering recommendation 120:

The Taskforce recommends that the Queensland Government considers the creation of a specific offence of strangulation.[220]

— An NFS law was introduced in Queensland in 2016, the first in Australia. This made NFS and suffocation a separate criminal offence with a maximum penalty of 7 years imprisonment.[221] Before the introduction of this offence, cases of NFS were treated as common assaults, which are associated with a lesser punishment and fail to encompass the severity of the act. Prof Douglas' contribution to the law reform was directly recognised by members of Queensland parliament in 2020, who stated:

"The new law, section 315A of the Criminal Code, owed much to the campaigning work of Sonia Anderson, whose 22-year-old daughter, Bianca, was strangled to death by her boyfriend in 2010. Another woman, Professor Heather Douglas of the University of Queensland, was also instrumental in the passage of the legislation. Her research revealed the full extent of this horrific but often hidden form of violence. The professor established that a woman who is subjected to attempted strangulation by a partner is 8 times more likely to be murdered by that partner. As well as the psychological trauma, the consequences of nonlethal strangulation can include memory loss, miscarriage and permanent damage to vision, hearing and vocal cords. I wish to again publicly thank Sonia Anderson and Heather Douglas for their work. Their campaign not only changed the law in Queensland; it changed the law across Australia."[222]

In January 2019, a similar law was introduced in South Australia. This stand-alone offence criminalised the act of choking or strangulation in a domestic setting, also posing a maximum penalty of 7 years imprisonment. While the offence cannot be entirely attributed to Prof Douglas' research, the South Australian law has clear parallels to and was modelled from the Queensland law. Both laws are explicitly applicable and limited to the domestic relationship context, have the same maximum penalty, and require that the prosecuting authority prove that the victim did not provide consent.[223]

Other states have introduced or are planning similar legislation.

Prof Douglas' research has prompted greater recognition of systems abuse as a form of DFV. The *National Plan*[224] cites the research article, '*Legal systems abuse and coercive control*',[225] which

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[219] Sharman, L, Douglas, H & Fitzgerald, R (2021). Op. cit.

[220] Queensland Government Department of Justice and Attorney-General (2021). Op. cit.

[221] Queensland Health (2017). *A Health Response to Non-Lethal Strangulation in Domestic and Family Violence*. Brisbane: Queensland Government.

[222] Queensland Parliament (2020). *Record of proceedings. First session of the fifty-sixth parliament*. Accessed January 2023: https://documents.parliament.qld.gov.au/events/han/2020/2020_05_20_WEEKLY.PDF.

[223] Douglas, H & Fitzgerald, R (2020). Women's stories of non-fatal strangulation: Informing the criminal justice response. *Criminology & Criminal Justice*, 22(2), 270-286.

[224] Commonwealth of Australia (2022). Op. cit.

[225] Douglas, H (2018). *Legal systems abuse and coercive control. Criminology and Criminal Justice* 18 (1) 84-99.

explores how legal systems and processes can be used to exercise coercive control over a former intimate partner. Prof Douglas' Future Fellowship supported this research.

Prof Douglas' research also influenced Recommendation 58 of the *Abortion: A Review of South Australian Law and Practice*.[226] report. This recommendation acknowledges that reproductive coercion is a form of DFV and urges that this be added to the definition of DFV in the *Intervention Orders (Prevention of Abuse) Act 2009* (SA).[227] Implementing this recommendation would better align the Act with *Commonwealth Family Law Act 1975* and *Queensland's Domestic and Family Violence Protection Act.* In 2022 new provisions were introduced into the South Australian *Intervention Orders (Prevention of Abuse) Act 2009* (s8(4)(od) and (oe)) identifying coercing a person to have or not to have an abortion is a form of domestic abuse.

Guiding education and training

Key discoveries included that in domestic violence cases, women's engagements with the legal system focus on specific personnel, such as the judiciary, magistrates and tribunal members. These personnel must be appropriately trained to ensure women do not experience secondary abuse by the legal system. The development and ongoing renewal of the Bench Book have been central to training the judiciary, magistrates, and tribunal members to ensure they can appropriately consider and respond to DFV matters.

Prof Douglas was subsequently funded to produce materials on coercive control for training. This resulted in releasing a report, video and material that magistrates could adapt to present to their colleagues. The material is publicly available and has been used in training sessions with Queensland magistrates.[228]

The research has been highly influential in developing and providing education and training programs. *Indigenous Legal Judgments: Bringing Indigenous Voices into Judicial Decision Making* was published in 2021 as part of Prof Douglas' Discovery Indigenous grant and is used as a resource for all first-year law students at the Australian National University, the University of Melbourne, the University of Southern Queensland and the University of Technology Sydney. This is bringing Indigenous voices and issues into the law school curriculum, in line with the Council of Australian Law Deans objective to redesign law school curriculums.[229]

Alignment with government strategic priorities

The research does not specifically align with the National Science and Research Priorities. However, it relates to several other Australian and State and Territory Government priorities, such as those outlined in the National Plan, the Strategy and the Not Now, Not Ever Report (see section 11.3.1).

Research capacity building

Prof Douglas supervised the completion of 1 PhD candidate on migration and DFV, with 2 ongoing candidates focused on NFS and coercive control, and investigating, prosecuting and defending cases of NFS in Queensland. A total of 24 honours students were supervised.

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[226] South Australia Law Reform Institute (2019). *Abortion: A Review of South Australian Law and Practice.*

[227] Ibid.

[228] Australasian Institute of Judicial Administration (2023). *New - Coercive Control*. Accessed January 2023: https://aija.org.au/education-hub/.

[229] Council of Australian Law Deans (2020). *Working Party on First Peoples Partnership: Terms of Reference*. Accessed January 2023: https://cald.asn.au/wp-content/uploads/2020/12/Terms-of-Reference-Working-Party-on-First-Peoples-Partnership-3-Dec-2020.pdf.

Prof Douglas has consistently sought to connect those from research, government, legal, justice and non-profit sectors and to improve communication and understanding across the sectors, and raise awareness of the research findings and its implications for the broader community. This has generated significant social benefits and built the capacity of researchers to engage with end users and the capability of members of the justice system to fulfil their roles better.

11.8 Impacts

11.8.1 Economic impacts

Counterfactual

Without ARC funding and support from research partners and end users, it is highly unlikely that Prof Douglas' suit of research would have been funded or been able to progress.

No other funding bodies in Australia provide the substantial funding amounts awarded to this work. For example, ANROWS, a major funder in this area, commissions research (funded by Commonwealth and State/Territory Governments) to build the DFV evidence base and support the implementation of the National Plan. However, this research is targeted/priority driven (rather than researcher-led discovery research), is periodic and much smaller in quantum (e.g., the 2020-22 Core Grant Research Program allocated $1.157 million across 8 researchers[230]). Some state governments also provide funding for priority-driven research, which is also typically smaller in quantum. In particular, one of the key advantages of the Future Fellowship program is that it allowed for a longitudinal study over 3 years. This allowed for developing and testing a novel research methodology in the context of exploring legal responses to DFV and produced new information and understanding. As such, Prof Douglas strongly believes that the research would not have been conducted without ARC funding.

In-kind contributions from DFV organisations were critical in supporting engagement with research participants. Without these organisations, Prof Douglas would not have been able to conduct longitudinal engagements with women for her research.

AIJA and NJC were essential in supporting research translation, by funding the development of the Bench Book and related training courses for judiciary, magistrates and tribunal members.

UQ was also necessary for the research and supported research capacity building by enabling PhDs and honours students to participate in the research. Prof Douglas moved to the University of Melbourne in 2021 and has received strong support for her research since then. Most of the Discovery Project work on NFS has been undertaken while at the University of Melbourne, and the University's support was pivotal for the successful Centre of Excellence proposal.

Attribution

The ARC provided 63% of the total amount of cash contributions (or 51% of total amount of cash and in-kind contributions). The funding has been essential for this research to occur. However, funding sources from non-academic partners were critical in applying the research, through development of the Bench Book and training and education materials. As such, it is estimated that at least 63% of the benefit delivered by this research is attributable to the ARC, noting that the in-kind contributions would not have been made without ARC funding.

[230] ANROWS (n.d.). *2020–2022 ANROWS Core Grant Research Program*. Accessed January 2023: https://www.anrows.org.au/research/2020-2022-anrows-core-grant-research-program/.

Calculation of NPV and breakeven analysis

As discussed above, the program of research has delivered many significant impacts, including raising awareness of DFV (including NFS, coercive control, legal systems abuse), contributing to a culture change movement, contributing to the education and training of legal professionals in the DFV sector and influencing the establishment and implementation of legislation relating to DFV. These changes are likely to lead to greater need for resources and funding in the short to medium term, rather than savings. However, in the longer term, the ultimate aim is for the research to save lives.

Given the nature of this research, a cost-benefit analysis (CBA) was not considered to be appropriate for assessing the benefits it has delivered. The benefits are not amenable to easy quantification due to:

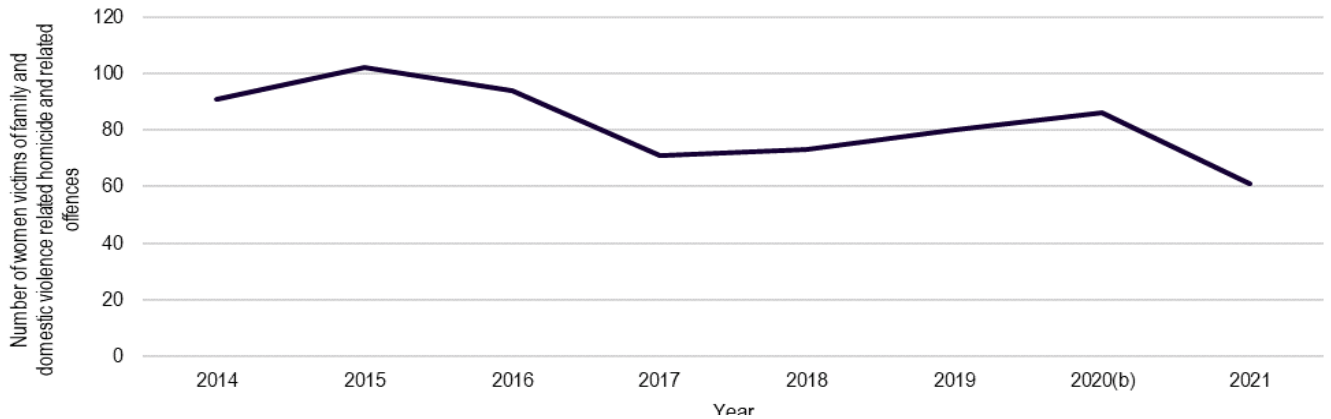
— Limited data available to comprehensively demonstrate the link between the increased awareness, the introduction of new offences and improved training of the judiciary, magistrates and tribunal members and reductions in risk to women's health and lives
— The impracticability of measuring the scale of *marginal* avoidable harm that could be attributed to research in a robust way
— The ongoing nature of the research.

Instead, a breakeven analysis was undertaken to illustrate the potential scale of the benefits of the research. Breakeven analyses are common practice in situations where the costs of a project can be quantified, but the benefits are less certain. In this context, the breakeven analysis sets a baseline whereby the net benefit test is satisfied — that is, it sets a level of benefit beyond which it can be concluded that the research will achieve a net benefit across the community. Setting this target for benefits allows a judgement to be made on the basis of experience and reasonable expectations.

As discussed in Section 11.3.1, DFV poses a range of threats to the health and lives of victims. In 2021, 61 women lost their lives due to DFV in Australia.[231] The number of lives lost due to DFV was steady between 2017-20, and decreased in 2021 (see Figure 11.4). This does not consider the male lives due to DFV (e.g. as new partners and fathers who are killed by the woman's previous abusive partner) nor the loss of life by suicide as a result of DFV.

[231] Australian Bureau of Statistics (2021). *Recorded Crime – Victims. Victims of family and domestic violence related offences, Table 31*. Accessed February 2023: https://www.abs.gov.au/statistics/people/crime-and-justice/recorded-crime-victims/latest-release#victims-of-family-and-domestic-violence-related-offences.

Figure 11.4 Women victims of DFV related homicide and related offences, Australia, 2014–2021



Victims of selected offences have been determined to be DFV related where the relationship of offender to victim, as stored on police recording systems, falls within a specified family or domestic relationship, or where an DFV flag has been recorded, following a police investigation.
(a) Homicide and related offences include murder, attempted murder and manslaughter. Excludes driving causing death.
(b) 2020 data for Tasmania revised.
(c) Includes syringe, bottle/glass, bat/bar/club, chemical, and other weapons.
(d) Weapon used data for Queensland overstated prior to 2020.
Source: ACIL Allen analysis of ABS data

The most significant costs of DFV are the costs associated with:[232]

- Pain, suffering and premature mortality (incurred by victims and the economy): $10.4 billion.
- Private and public health systems (incurred by victims, communities and government): $1.4 billion.
- Productivity and the business sector: $1.9 billion.
- Economic opportunities (incurred by victims and their children): $4.4 billion.
- Second generational impacts (incurred by the Australian economy): $333 million.
- Justice, services and funeral sectors (incurred by the Australian economy): $1.7 billion.
- Transfer costs, including loss of income tax, additional social welfare payments, victim compensation payments and other government services (incurred by Australian economy): $1.6 billion.

The breakeven analysis compares the costs of the ARC-funded research to the value of a statistical life (as determined regularly by the Commonwealth Government)[233] to provide an estimate of the number of lives that would need to be saved to offset the costs of the research. The value of a statistical life is the most appropriate way to estimate how much society is willing to pay to reduce the risk of dying. It is defined as:

> *"The value of a statistical life is an estimate of how much society is willing to pay to reduce the risk of death. By convention the life is assumed to be the life of a young adult with at least 40 years of life ahead. It is a statistical life because it is not the life of any particular person."*

In other words, the breakeven analysis answers the question 'How many lives would the research have to save for the research to break even to society in cost-benefit terms?'

[232] KPMG (2016). *The cost of violence against women and their children in Australia Final Report prepared for the Department of Social Services*. Australia: KPMG.

[233] The Office of Impact Analysis (2021). *Best Practice Regulation Guidance Note: Value of statistical life*. Accessed February 2023: https://oia.pmc.gov.au/sites/default/files/2021-06/value-of-statistical-life-guidance-note-2.pdf.

The cost of the research program is $3.9 million in present value terms (in 2022 using a 7% discount rate[234]), and the statistical value of one life in 2022 was estimated to be $5.3 million in 2022. This implies that, if the research helps prevent the death of only one woman from DFV, the benefits of the project would more than offset its costs. Given the breadth and depth of the costs related to DFV detailed above and the positive impacts that this research has and will continue to have on the accuracy, responsiveness and efficiency of the legal system, it is not unreasonable to suggest that it would have helped to save at least the life of one woman in Australia.

To put the potential benefits in context, while it is challenging to make assumptions as to the quantum of benefit that may be delivered by the research due to challenges with data collection and establishing a causal link between the research and the impact of DFV, if the research were to contribute to saving 1 life every year for the next 10 years, this would amount to $53 million in benefit. This does not consider the avoidance of injury, loss of male lives or loss of lives by suicide, nor the increased costs to the service system resulting from the research.

11.8.2 Social impacts

Prof Douglas' research has helped to fundamentally change how government, the legal and justice systems, and society understand and respond to DFV. It has provided evidence to inform a culture change movement.

While many jurisdictions in Australia and other countries (e.g., most states in the United States) have NFS laws, these have not been evaluated to date to determine whether they increase women's safety. This is the focus of Prof Douglas' current grant, *Discovery Projects – The non-fatal strangulation offence as a response to domestic violence*. Further, NFS is one of many risk factors and acts of serious harm, and as such, should be considered in the broader context of DFV.

Prof Douglas' research ultimately aims to impact the accuracy, responsiveness and efficiency of the legal system, which in turn, may lead to long-term impacts on the improved experience of women who seek safety through law, the confidence and perceived credibility of victims testifying in NFS cases; the incidence of NFS and related charges and convictions; women's safety, health and wellbeing; service system response to women reporting NFS; and the quality of women's experiences in navigating the legal system. These aim to reduce the burden on women's (and their family's) health, wellbeing and financial position and enable them to participate in their communities and workforce more fully.

Educational impacts

The introduction of the Queensland NFS offence improved awareness of the direct harms of NFS and of the importance of NFS in identifying a high risk of future serious harm and death. Courts now use NFS as a key consideration for arresting a defendant or granting bail. The charge also signals to victims and services that victims will need safe housing and a health check.[235] The elevated profile of NFS and uptake of education and training materials and use of the Bench Book is evidenced by judges across Australia better recognising the complexity of DFV, systems abuse as a form of coercive control and the dangers of NFS and highlighting these in their judgments.[236] For example, this research refers to 5 cases, 1 law reform report and 2 law journal articles.[237]

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[234] Which is the central discount rate recommended for the calculation of present values by the Commonwealth Office of Impact Analysis.

[235] Douglas, H (2018). *A red flag for homicide: Should non-fatal strangulation be made a stand-alone criminal offence?* Accessed January 2023: https://www.policyforum.net/red-flag-homicide/.

[236] Ibid.

[237] LawCite (n.d.). *Strangulation, Domestic Violence and the Legal Response*. Accessed February 2023: http://www.austlii.edu.au/cgi-bin/LawCite?cit=%5b2014%5d%20SydLawRw%2011.

Prof Douglas' research has also provided an opportunity for the training and development of PhD and honours students, as noted in section 11.7. This is essential for ensuring the building of research capacity and capability among new social researchers and building a workforce pipeline.

Legal impacts

Since its introduction, there have been 4,467 strangulation offences lodged in Queensland (2017-18 to 2022-23).[238] Of these, 1,600 defendants were convicted, with more than 95% of convicted defendants sentenced to imprisonment.[239] An important element of the NFS charge is that NFS is recorded on the individual's criminal record and serves as a clear indicator for police and legal services that they may be particularly dangerous. This is an important consideration for any future charges.

While it is noteworthy that the suite of research has led to important changes for the legal system, the impact of these changes is unknown and currently being explored through the grant *Discovery Projects – The non-fatal strangulation offence as a response to domestic violence.* This will determine the benefits and limitations of the NFS law in Queensland and beyond.

11.9 Potential future impacts

Prof Douglas' research has paved the way for future DFV research, by herself and others, across a number of areas, including reproductive coercion, NFS, legal systems abuse and legal ethics for lawyers working in DFV.

As noted above, current and future research on *Discovery Projects – The non-fatal strangulation offence as a response to domestic violence* is extending the suite of research by assessing the impact of the NFS law in Queensland.

Prof Douglas was recently awarded an ARC Centre of Excellence for the Elimination of Violence Against Women (2023-29) as part of a consortium of researchers. Her research has been supported by $160,000 in funding from Commonwealth Bank of Australia. This will be used to progress research into financial abuse as a form of coercive control and provide a greater understanding of financial systems abuse. Women's legal Services Australia, AIJA, Australian Women Judges Association and DV Connect have promised in-kind contributions for the research.

The successful development and implementation of the Bench Book set the standard for how the judiciary, magistrates and tribunal members could be educated and trained. AIJA, funded by the Commonwealth Attorney-General's Department, since commissioned Prof Douglas to develop the *National Bench Book on Aboriginal and Torres Strait Islander Peoples and the Legal System*, which will be a practical and readily accessible resource for those working in the criminal and civil justice systems that provide justice and legal assistance services to Aboriginal and Torres Strait Islander peoples.[240]

[238] Queensland Courts (2022). *Queensland Courts' domestic and family violence (DFV) statistics*. Accessed January 2023: https://www.courts.qld.gov.au/court-users/researchers-and-public/stats.

[239] Ibid.

[240] Australian Government Grant Connect (2022). *Archived Grant Opportunity View - GO5545*. Accessed January 2023: https://www.grants.gov.au/Go/Show?GoUuid=a9fdb376-058f-44c9-b0ff-c5f043268c5a.

12 Indigenous Persistence in Formal Learning

12.1 Key Findings[241]

$693,000 invested by ARC (with funding from other ARC grants and participating organisations supporting related projects)

$105.3m NPV of present and anticipated economic impacts and. BCR of 2.48.

The project has produced
- Transitional Academic Pastoral Support Indigenous learning model

- 5 journal articles, **3** conference presentations, **2** case studies, **1** book on *Supporting Indigenous Students to Succeed at University*

~6,000 Indigenous students impacted by the research

Up to 90 fully funded PhD/MPhil and 42 postdoctoral fellows trained

Alignment with Government priorities

- Closing the Gap

12.2 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to assess the impact and value of research undertaken by many organisations.[242] The results from applying that framework Indigenous Persistence in Formal Learning case study are summarised in Figure 12.1.

[241] The Discovery Indigenous grant was the main support for the impacts described in this case study. However, description of the activities, outputs and outcomes of other prior and follow-on ARC funding from various schemes have been included, as these were important for the researcher in supporting the delivery of impact.

[242] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F.

Figure 12.1 Indigenous Persistence in Formal Learning – Impact Framework Diagram

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– $693,000 in funding from ARC[243]	– Developed research partnerships – Reviewed literature and developed data collections – Developed case studies and psychosocial measures of persistence – Launched transdisciplinary research programs, developed Indigenous students and researchers, and conducted community engagement – Integrated Indigenous knowledge	– 5 journal articles – 3 conference presentations – 2 case studies – 1 book entitled *Supporting Indigenous Students to Succeed at University* – Transitional Academic Pastoral Support (TAPS) Indigenous learning model – WillowSoft commercial application software	– Adoption of TAPS at Edith Cowan, Griffith University, James Cook University (JCU) and UNSW and implementation of wrap around support for Indigenous students – Purchase of WillowSoft licences by a university and 3 secondary schools – JCU implemented an Indigenous Student Services Centre – Workforce development and capability	– $105.3 million NPV of present and anticipated economic impacts identified – BCR of 2.48 – Improved graduation and completion rates – Improved Indigenous student satisfaction – Promising evidence for scalability emerging in high schools and other priority cohorts – Reduced failure rate for pre-requisite diplomas – Only the costs of the ARC Discovery Indigenous – Indigenous persistence in formal learning grant was included as it is the key grant that supported the research behind TAPS

Source: ACIL Allen

12.3 Background

This case study relates to projects funded under the following ARC schemes:

- Discovery Program: Discovery Projects and Discovery Indigenous.
- Linkage Program: ARC Centres of Excellence and Linkage Infrastructure, Equipment and Facilities.

The Discovery Indigenous grant was the main support for the impacts described in this case study. However, description of the activities, outputs and outcomes of other prior and follow-on ARC funding from various schemes have been included, as these were important for the researcher in supporting the delivery of impact.

12.3.1 Closing the gap

The gap between the life outcomes of Indigenous and non-Indigenous Australians is underpinned by a myriad of intersecting forms of entrenched disadvantage. Overcoming this gap is a complex challenge facing our communities, governments, legal systems, and public institutions (like universities).

The National Agreement on Closing the Gap (the National Agreement) was developed in 2020 as part of a broad agreement between the Coalition of Aboriginal and Torres Strait Islander Peak

[243] The Discovery Indigenous grant was the main support for the impacts described in this case study. However, description of the activities, outputs and outcomes of other prior and follow-on ARC funding from various schemes have been included, as these were important for the researcher in supporting the delivery of impact.

Organisations, the Commonwealth Government and each State and Territory Government. The National Agreement focuses on areas where Indigenous Australians are more likely to experience disadvantage, such as education, health, employment, and criminal justice.[244] These disadvantages can be the result of interpersonal or systemic factors and are deeply interconnected. They can compound to generate large differences between Indigenous and non-Indigenous Australians in a broad range of life outcomes.

Indigenous learning outcomes

This case study focuses on Indigenous learning outcomes, mostly within higher education, and the impact that ARC-funded research has had on these outcomes.

The National Agreement contains 17 targets for the next decade. 4 goals relate to educational outcomes. The targets are:[245]

- By 2025, increase the proportion of Aboriginal and Torres Strait Islander children enrolled in year before fulltime schooling early childhood education to 95% (Goal 3).
- By 2031, increase the proportion of Aboriginal and Torres Strait Islander people (age 20-24) attaining year 12 or equivalent qualification to 96% (Goal 5).
- By 2031, increase the proportion of Aboriginal and Torres Strait Islander people aged 25-34 years who have completed a tertiary qualification (Certificate III and above) to 70% (Goal 6).
- By 2031, increase the proportion of Aboriginal and Torres Strait Islander youth (15-24 years) who are in employment, education or training to 67% (Goal 7).

The gap in some outcomes, such as early childhood educational enrolment, are on track to close by 2025.[246] For example, Indigenous student enrolment in early childhood education, increased by almost 10% from 2016-18, from 76.7 to 86.4%. This compares with 91.3% of non-Indigenous children.[247]

However, progress in primary and secondary school attendance rates has been limited. In the 5 years to 2019, school attendance for years 1-10 declined by 2%,[248] and by a further 0.5% by 2021.[249] The Indigenous school attendance rate was 82%—about 4 days a week on average and 10% below that of non-Indigenous students.[250] The gap in attendance widens in secondary education, with Indigenous attendance rates falling to just over 70% by year 10 while non-Indigenous attendance declines slightly to just over 90%.

This varies by state and territory, with attendance rates far higher in NSW, Victoria and Queensland, than WA and NT. Attendance also varies by remoteness, with Indigenous school attendance in outer regional, remote and very remote areas substantially lower than that of major cities and regional Australia, while non-Indigenous attendance is relatively consistent. In outer regional parts of Queensland, for example, Indigenous attendance rates in secondary education declined to 3 to 4 days per week in 2019.[251]

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[244] Australian Government (2023). *Closing the gap: targets and outcomes*. Accessed February 2023: https://www.closingthegap.gov.au/national-agreement/targets.

[245] Ibid.

[246] Australian Government (2020), p. 24. *Closing the Gap Report 2020*. Canberra: Australian Government.

[247] Ibid.

[248] Ibid, p. 34.

[249] ACARA (2021), p. 6. National report on schooling in Australia.

[250] Australian Government (2020), p. 34. *Closing the Gap Report 2020*. Canberra: Australian Government.

[251] Australian Government (2020), p. 41. *Closing the Gap Report 2020*. Canberra: Australian Government.

The gap in high school completion rates has narrowed, with two thirds of Indigenous Australians aged 20-24 having completed year 12 or equivalent.[252] Importantly, research shows that when Indigenous students reach the same educational achievements as non-Indigenous students by age 15, there is no difference in educational outcomes like enrolment in university or vocational training.[253]

Indigenous students made up 1.8%[254] of those enrolled in higher education in 2018. In 2017, Indigenous students were also less likely to complete higher education, with 35% dropping out of study, compared to 23% for non-Indigenous students. Furthermore, about 40% of Indigenous students enrolled in 2010 had completed a degree by 2015, compared with just over 66% of non-Indigenous students.[255]

The Bradley Review

The 2008 Review of Australian Higher Education: final report (Bradley Review) was established to determine whether the higher education sector is "structured, organised and financed to position Australia to compete effectively in the new globalised economy".[256] The Bradley Review identified significant threats requiring financing and regulatory attention. In relation to Indigenous students, the Bradley Review found that:

— Higher Education providers should ensure that the institutional culture, the cultural competence of staff and the curriculum's nature, recognises and supports Indigenous students' participation.

— Indigenous knowledge should be embedded into curriculum to ensure that all students understand Indigenous culture.

Further, its strategic goals to 2020 included the need for a national higher education system that supports access, including better support for institutions to assist students from a wide range of backgrounds, particularly Indigenous students.[257]

The Bradley Review enabled a discussion on equity, including special entry measures and funding for Indigenous students, and enabled greater access for Indigenous students to the university sector.

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[252] This is in large part driven by progress in major cities, where the gap fell sharply from 26% in 2012-13 to 6% in 2018-19. The gap was widest in remote areas, at 52%.

Ibid, p. 60.

[253] Australian Institute of Health and Welfare (2020). *Determinants of health: educational participation and attainment of adults*. Accessed February 2023: https://www.indigenoushpf.gov.au/measures/2-06-educational-participation.

[254] Note Aboriginal and Torres Strait Islander people comprise 3.8% of Australia's population. Australian Bureau of Statistics (2021). *Estimates of Aboriginal and Torres Strait Islander Australians*. Accessed February 2023: https://www.abs.gov.au/statistics/people/aboriginal-and-torres-strait-islander-peoples/estimates-aboriginal-and-torres-strait-islander-australians/jun-2021.

[255] The Conversation (2018). *To really close the gap we need more Indigenous university graduates*. Accessed February 2023: https://theconversation.com/to-really-close-the-gap-we-need-more-indigenous-university-graduates-91493.

[256] Bradley, D., Noonan, P., Nugent, H., & Scales, B. (2008). *Review of Australian higher education: final report [Bradley review]*. Canberra: Australian Government.

[257] Ibid.

A national Review[258] of higher education access and outcomes for Aboriginal and Torres Strait Islander people was conducted in 2012 and with a focus on approaches having an impact on the participation and completion rate of higher education degrees by Aboriginal and Torres Strait Islander students.

Education's link to health and other important outcomes

It is well established in the literature that educational outcomes are interconnected with the achievement of other life outcomes. The Australian Institute of Health and Welfare has identified education as a key social determinant of health and labour market outcomes.[259] At the same time, improving health and wellbeing, among other gaps, can lead to improved participation and outcomes in education.[260]

The level of schooling and the attainment of education qualifications beyond school, along with employment, income and housing adequacy, account for just over a third of the gap in health outcomes between Indigenous and non-Indigenous Australians. Cultural and historical outcomes and differences in access to health services comprise 47% of the gap, and 19% is attributed to health risk factors like alcohol consumption, weight, smoking, and nutrition.[261] Consequently, the health gap between Indigenous and non-Indigenous Australians reflects interrelated forms of disadvantage.

12.3.2 Models to support student learning

Indigenous learning support is an active area of research that aims to improve Indigenous participation, retention and learning outcomes. Research has historically focused on teaching style and content taught. Supports are typically provided through personal and cultural support by Indigenous Education Units at higher education institutions and academic learning support in the form of individual supplementary tutorials provided by Commonwealth and higher education faculties.[262] Other approaches have sought to incorporate Indigenous topics, insights and culture into formal education and within institutes (e.g., Indigenous artworks), and to explore racism and cultural change. For example, in 2020, 14 universities claimed to have an Indigenous-specific graduate attribute, indicating a greater focus on incorporating initiatives, ideas and resources to embed Indigenous content and perspectives into courses.[263]

Broadly speaking, these approaches have had limited success. For example, less than 30% of Indigenous students complete degrees after 4 years of study, and this rate of completion has been the same since 2005.[264] There is a clear gap in our understanding of how to improve Indigenous learning outcomes in higher education.

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[258] See National Report at https://www.education.gov.au/aboriginal-and-torres-strait-islander-higher-education/review-higher-education-access-and-outcomes-aboriginal-and-torres-strait-islander-people

[259] Australian Institute of Health and Welfare (2022). *Determinants of health for Indigenous Australians*. Accessed February 2023: https://www.aihw.gov.au/reports/australias-health/social-determinants-and-indigenous-health.

[260] Australian Institute of Health and Welfare (2023). *Aboriginal and Torres Strait Islander Health Performance Framework: Summary report 2023*. Accessed February 2023: https://www.indigenoushpf.gov.au/report-overview/overview/summary-report.

[261] Australian Institute of Health and Welfare (2022). Op. cit.

[262] Nakata, M., Nakata, V., Day, A. and Peachey, M. (2017). Closing Gaps in Indigenous Undergraduate Higher Education Outcomes: Repositioning the Role of Student Support Services to Improve Retention and Completion Rates. The Australian Journal of Indigenous Education, 48(01), pp.1–11.

[263] Universities Australia (2020*). Indigenous strategy annual report*. Canberra: Universities Australia.

[264] See 4-year cohort report of Indigenous degree completions at https://www.education.gov.au/higher-education-statistics.

This ARC-supported study of Indigenous academic persistence focuses on an approach to improving learning outcomes in higher education for Indigenous students that is fundamental to established norms in the literature and past practices within universities. The approach focuses on building an understanding and culture of learning (learner identities) among Indigenous students to support persistence in learning. Higher education institutes are often unfamiliar, leaving Indigenous students with a diminished sense of belonging. This is particularly the case when students are the first in their families to participate in higher education. The model is underpinned by the philosophy that building learning capabilities through institutional interventions and supports outside the classroom leads students to develop a pattern of intellectual behaviours and dispositions that enable them to be more effective in their learning engagements.

12.3.3 ARC-funded research

Professor Nicholas Martin Nakata was the first Torres Strait Islander to receive a PhD in Australia. He graduated in 1998. His research has focused on a range of topics under the broad theme of Indigenous education for more than 20 years. He has been funded by a number of ARC research grants, overviewed below.

Prior to beginning his research career, Prof Nakata worked with the Commonwealth Department of Education to support Indigenous students studying at boarding schools. He found students were very excited when they began their initial journey to boarding school at the beginning of each year and was interested to learn how their initial enthusiasm for school diminished by Easter. His early research education initially aimed to understand how to better represent Indigenous student issues using policy-based approaches. Following this, he investigated the preparation of Indigenous students for classroom learning, explored ways to better support Indigenous students in their learning, and worked to build a pathway to impact for this work.

As overviewed in Figure 12.2, one of Prof Nakata's first ARC grants was funded by the inaugural ARC Indigenous Researcher's Development Scheme (IRDS) – *Curriculum and Learning Pathways for Indigenous learners: Urban Adelaide*. This project was designed to build on from his doctoral research work into studies of curriculum pathways for Indigenous learners (1998-99).

Following several failed attempts at winning further grants in the education areas, he joined other projects to build his research track record:

Discovery Projects – Understanding and working with anger in male Indigenous people in prison settings (2004-06). This project explored the nature and consequences of anger in Australian male Indigenous imprisoned offenders to develop an intervention to improve wellbeing, adjustment of Indigenous men in prison and rehabilitation outcomes.

Linkage Infrastructure, Equipment and Facilities (LIEF) – Australian Social Science Data Archive (ASSDA): Provision of Advanced Research Infrastructure and Collaborative Environment (2009) grant was awarded to a consortia of researchers to advance the social science and humanities knowledge base for use by the general public, media, and government and non-government organisations in developing strong evidence-based policy.

LIEF – Establishment of the Australian data archive: an integrated research facility for the social sciences and humanities (2011-12) grant established an open-access data archive to address social, economic and environmental challenges, and provide greater transparency and data access for government, media and the public.

In 2006, he again attempted to submit an ARC Indigenous Discovery grant for his educational projects and without success.

In 2011 he was granted funding to pursue his research interest in education and persistence. The *Discovery Indigenous – Indigenous persistence in formal learning* (2012-17) aimed to understand

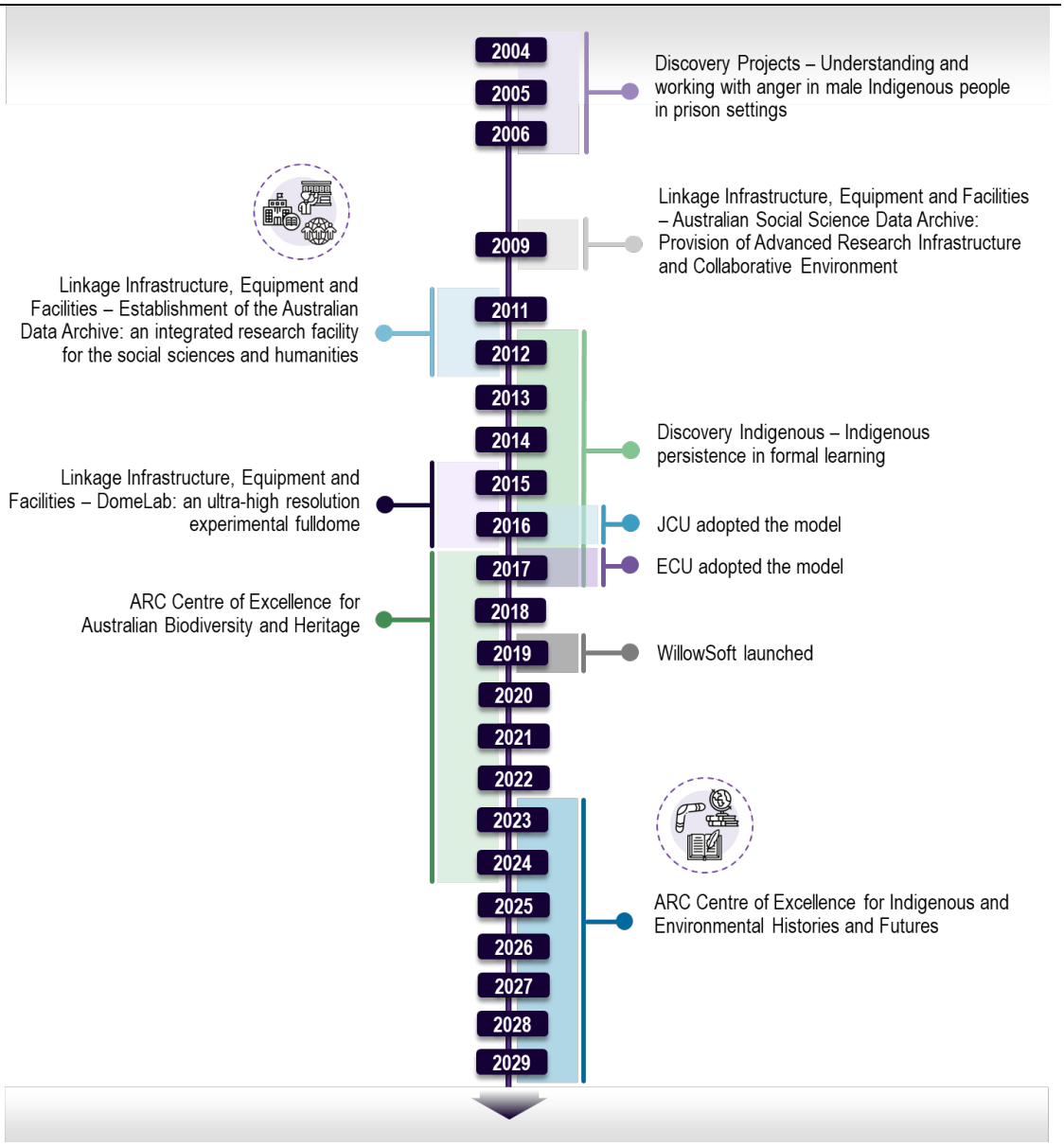
the learning experiences of Indigenous students as they transition to university, how they persist in academic learning (and what enables or impedes this), how this impacts academic performance and whether persistence varies between Indigenous and non-Indigenous students. The research ultimately aimed to identify ways to better support Indigenous students throughout their studies and ensure they experience higher quality learning experiences and outcomes.

He, by this time, had a substantial network of colleagues across the disciplines and was actively supporting their projects.

LIEF – DomeLab: an ultra-high resolution experimental fulldome (2015-16) developed the first ultra-high resolution experimental fulldome in Australia, an immersive video projection environment. It aimed to benefit researchers nationally, as a 'touring' system.

ARC Centre of Excellence (CoE) for Australian Biodiversity and Heritage (2017-24) aims to improve our understanding of Australia's Indigenous heritage and environmental past, the factors that influence change, and the impacts on society. This is investigating the processes that shaped Australia and the story of its inhabitants, future-proofing Australia's unique biodiversity and cultural heritage, and building researcher capability. The education and engagement strategy for this CoE included a focus on supporting schools to improve the STEM education of Indigenous students, which Prof Nakata led.

Figure 12.2 Overview of the suite of research



Source: ACIL Allen, various sources

12.4 Inputs

The Discovery Indigenous grant was the main support for the impacts described in this case study (see Table 12.1). However, description of the other prior and follow-on ARC funding from various schemes have been included, as these were important for the researcher in supporting the delivery of impact.

The total value of *ARC Indigenous Researchers Develop Scheme (IRDS) – Curriculum and Learning Pathways for Indigenous learners: Urban Adelaide* was $24,000.

The total value of *Discovery Projects – Understanding and working with anger in male Indigenous people in prison settings* was $399,214. This included $133,000 in cash from ARC and $266,214 cash from academic partners.[265]

[265] The partner organisation contributing cash support was the University of South Australia.

The total value of *LIEF – ASSDA* was $1,564,000. This included $550,000 in cash from ARC, $525,500 cash from academic and $25,000 cash from non-academic partners. In-kind support included $464,000 from academic partners.[266]

The total value of *LIEF – Establishment of the Australian data archive* was $1,943,479. This included $600,000 in cash from ARC and $480,000 cash from academic partners. In-kind support included $863,479 from academic partners.[267]

The total value of *Discovery Indigenous – Indigenous persistence in formal learning* was $693,000, provided in cash by ARC. This grant was only part funded, as proposed funding for teaching relief and PhD stipends was unfunded by ARC. The grant provided a stipend for Prof Nakata and field costs.

The total value of *LIEF – DomeLab* was $1,687,492. This included $220,000 in cash from ARC, $299,804 cash from academic and $26,938 cash from non-academic partners. In-kind support included $854,570 from academic and $286,180 from non-academic partners.[268]

The total value of *ARC Centre of Excellence for Australian Biodiversity and Heritage* was $62,124,922. This included $33,750,000 in cash from ARC, $10,742,500 cash from academic and $340,000 cash from non-academic partners. In-kind support included $12,787,873 from academic and $4,504,549 from non-academic partners.[269]

Table 12.1 Cash and in-kind contributions for the project

Contributor / Type of support	2004-06	2009-11	2012-14	2015-16	2017-24	Total Contributions
Cash						
IN120100021 - Indigenous persistence in formal learning						
ARC			$693,000			$693,000
Total			**$693,000**			**$693,000**

Source: ACIL Allen, research project applications and personal communications with Prof Nakata

12.5 Activities

The activities associated with the *Discovery Indigenous – Indigenous persistence in formal learning* include:

— Studying Indigenous academic persistence in higher education courses.

[266] The partner organisations contributing cash and in-kind support were Griffith University, Australian Consortium for Social and Political Research Inc, The Australian National University (ANU), The University of Melbourne (UMelb), The University of Queensland (UQ), The University of Western Australia (UWA), University of Technology Sydney (UTS).

[267] The partner organisations contributing cash and in-kind support were ANU, UMelb, UQ, UWA, UTS.

[268] The partner organisations contributing cash and in-kind support were: AARNet Pty Ltd, Australian National Maritime Museum, City University of Hong Kong, Intersect Australia Ltd, Museum Victoria, National Museum of Australia, RMIT University, UNSW, UWA, The Walter and Eliza Hall Institute of Medical Research, University of Canberra, University of Tasmania, Western Sydney University.

[269] The partner organisations contributing cash and in-kind support were: the Australian Museum, ANU, Bioplatforms Australia Ltd, Indonesian National Centre for Archaeology, James Cook University, Max Planck Institute for the Science of Human History, Monash University, Natural History Museum of Denmark, Papua New Guinea National Museum and Art Gallery, Queensland Museum, Scarp Archaeology Pty Ltd, South Australian Museum, State Library of New South Wales, The University of Adelaide, UNSW, University of Colorado (Boulder), University of Papua New Guinea, University of Savoy, University of Tasmania and University of Wollongong.

— Developing 2 case studies on services to improve Indigenous persistence in learning, including student interviews.
— Dissemination of results, and collaboration and partnerships.

Additional activities associated with research projects funded by the ARC since 1998 include:

— Exploration of curriculum pathways for Indigenous learners in the South Australian school curriculum.
— Studying understanding and expressions of anger with Indigenous men.
— Developing research infrastructure and creating collaborative platforms for the ARC Centre of Excellence for Australian Biodiversity and Heritage (CABAH).
— Reviewing literature, and developing data collections and computational models that address gaps in existing datasets for CABAH.
— Conducting scenario testing, forecasting and sensitivity analysis on Australian Biodiversity and Heritage (CABAH).
— Developing Indigenous students and researchers, leadership training and community engagement (CABAH).
— Conducting longitudinal studies of a partnership with remote and regional schools to improve the Indigenous students' performance in math and science (CABAH).
— Integrating Indigenous knowledges into national data bases.

12.5.1 Indigenous Researchers Development Scheme - Curriculum and Learning Pathways for Indigenous learners: Urban Adelaide

This project used qualitative methods to study the South Australian school curriculum and the learning pathways for Indigenous students.

12.5.2 Discovery Projects – Understanding and working with anger in male Indigenous people in prison settings

This project used qualitative and quantitative methodologies to explored the nature and consequences of anger in male Indigenous imprisoned offenders, focusing on the constitutive, regulatory, procedural and other aspects of anger.

12.5.3 LIEF – ASSDA

Researchers developed the infrastructure to house a collection of data sources in an open access platform. The integrated knowledge data base stores data across a wide range of economic, social, political and cultural areas.

12.5.4 LIEF – DomeLab

Researchers developed first ultra-high resolution (4000 x 4000 pixels) experimental fulldome. This involved collaboration with national research services AARNet and Intersect to access research data storage infrastructure and extend Australia's pioneering research in aesthetic frameworks and frontier technologies. DomeLab is designed as a touring system and was installed throughout the country at leading institutions.

12.5.5 LIEF – Establishment of the Australian data archive

This project focused on enhancing HASS research capabilities by creating new research infrastructure that supports modelling, computation and data analysis functions. This project upgraded and acquired data storage hardware to develop a high-end research, analysis and visualisation platform; and created collaborative platforms and established sub-archives.

12.5.6 Discovery Indigenous – Indigenous persistence in formal learning

This project is the focus of this case study.

The Indigenous academic persistence project sought to improve research knowledge of the learning experiences of Indigenous students transitioning from schools and TAFEs to university studies in order to improve support for Indigenous students and their learning experiences and outcomes. It was conducted across 5 universities (UNSW, James Cook University (JCU), Murdoch University, Edith Cowan University (ECU) and Deakin University) by Prof Nakata and 2 Cis, Prof Andrew Day and Dr Gregory Martin, and involved interviews with both Indigenous and non-Indigenous students. The research highlighted focal points for intervention and provided an evidence-based approach to support services that can deliver lasting impact to Indigenous student higher education completion rates.

Two case studies were also undertaken to test strategies of persistence and their effects on progression and completion rates. The first case study (2012-15) drew on a sample of 400+ Indigenous students at a Go8 university. The results showed major improvements in progression and completion rates.

The second case study (2016-21) focused on strategies to raise the levels of persistence, self-regulation and self-efficacy of 800 Indigenous students at a regional university. The results saw a halving of the attrition rate, higher progression rates and a doubling of the graduation rate over a 5-year period.

An industry partner with data engineering expertise, WillowSoft, was recruited to the second case study to help refine the measures and data sets, and to gain predictive capabilities to help the support team to mount early intervention campaigns.

12.5.7 ARC Centre of Excellence – Australian Biodiversity and Heritage (CABAH)

This project is generating knowledge and records of past environmental and archaeological patterns of change, drivers of change and their impacts on society. It will build transdisciplinary research capabilities in Indigenous heritage. It is:

- Generating computational models that identify and fill gaps in existing datasets
- Explaining data patterns using scenario and sensitivity analysis, modelling, and climate hindcasting
- Conducting leadership training, cross-institutional collaborations and community engagement to build researcher capacity and improve Indigenous and female representation in research leadership
- Creating a communication, education and engagement strategy at local, regional, national and international levels.

The project is being conducted by Prof Richard Roberts. It involves Prof Nakata and 17 other CIs and 9 PIs, as well as collaboration with partners in Denmark, England, France, Germany, Indonesia, Papua New Guinea and the United States.

CABAH's education and schools' engagement plans were led by Prof Nakata and his small team to improve the math and science performance of students in regional and remote areas. 42 presentations on the math and science work undertaken by the Centre have been delivered. These include keynote addresses, plenaries, symposia, workshops, and seminars to professional associations in education, Principal's conferences, Teacher conferences, Qld Education Departments forums, Federal and State Ministers and Senators, ACARA, and a range regional and remote communities.

12.5.8 ARC Centre of Excellence – Indigenous and environmental histories and futures

This project is developing an Indigenous and Western knowledge framework for modelling environmental, social, cultural and historical change over the last 1,000 years. The research will:

- Develop and communicate an integrated history of Australian change, framed by Indigenous knowledges and science.
- Integrate Indigenous knowledges into regional land and sea Caring for Country activities, strategies, and policies.
- Forecast the 100 trajectory of socio-ecological change under land-use, management, and climate change scenarios.
- Recruit, empower, inspire and train the next generation of Indigenous researchers and students to close the gap in higher education and research, and train research leaders in culturally appropriate methods and protocols.
- Catalyse recognition and uptake of Indigenous-led understandings of and approaches to managing Country, to influence public perceptions and evidence-based policy-making.

The Centre is led by Prof Sean Ulm, along with Prof Nakata and 18 other CIs and 14 PIs. The research includes international partners in the United States, Canada and Papua New Guinea.

Prof Nakata will again lead the education and engagement plans of the Centre to extend the empirical work with math and science to a greater number of schools in regional and remote areas for both Indigenous and non-Indigenous students.

12.6 Outputs

This section describes outputs for the *Discovery Indigenous* and *LIEF* grant as these have both concluded. The 2 Centres of Excellence are ongoing.

12.6.1 Publications

Several publications were produced from the above research, including the following outputs from the Discovery Indigenous grant:

- Notable journal articles on Indigenous students' persistence in higher education, teaching at the cultural interface, and closing gaps in Indigenous undergraduate higher education outcomes
- 1 study of Indigenous and non-Indigenous students across 5 universities (2012-15), and 2 case study of renewed learning support services at a Go8 university (2010-2015) and a regional university (2016-2022).
- 1 book entitled, *Supporting Indigenous Students to Succeed at University*, on Indigenous persistence in education published by Routledge in 2022.
- 3 Queensland universities are currently contemplating adoption of the improved learning support services.
- Regional offices of the Queensland Education Department in Cairns and the Catholic Education in Townsville are also considering how Prof Nakata's approach to building learner capabilities could be adapted for use in their schools.

Additional publications associated with research projects funded by the ARC since 1998 include:

- More than 70 publications.
- More than 60 keynotes and plenary sessions in over 20 countries.

— 4 edited volumes of works entitled, Indigenous peoples, racism, and the UN (2001), Australian Indigenous Knowledge and Libraries (2005), Indigenous men and anger (2008), and Politics of identity (2013).
— 1 edited volume, Special Issue of the Australian Journal of Indigenous Education, *Indigenous Studies (2009).*
— 1 co-authored treatise on the teaching of English to diverse global communities*, A pedagogy of Multiliteracies*, published by Harvard Educational Review in 1996 has 3,500 citations.

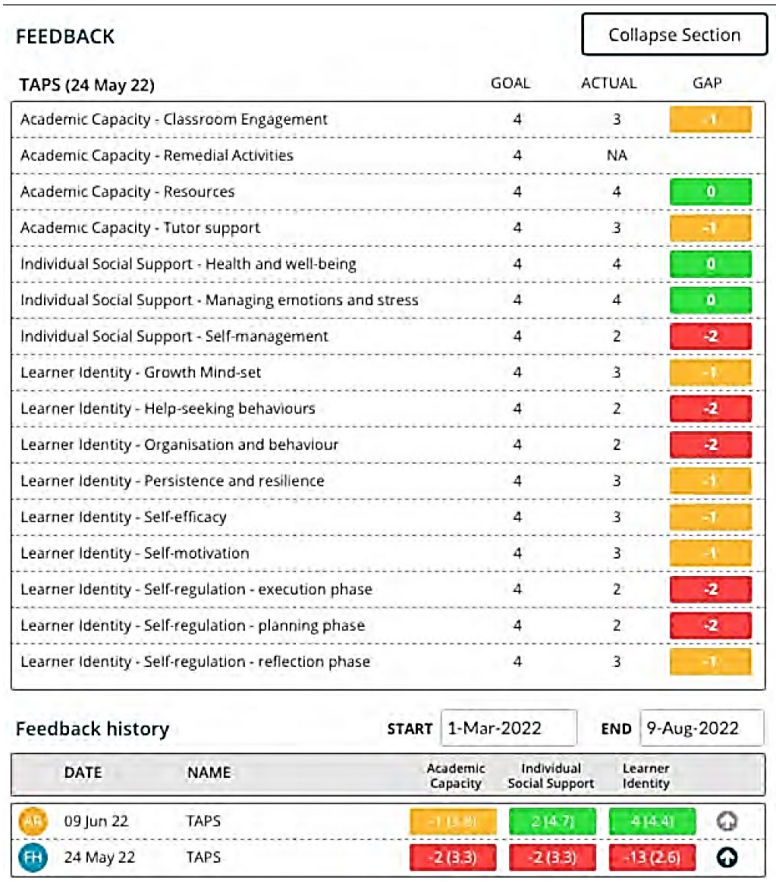
12.6.2 Models or tools

The most significant output is the Indigenous learning model. This learner identity model is based on established research knowledge of the high correlation between self-efficacy in learners and academic performance, and the detailed knowledge of the forms and types of persistence in learning that leads to levels of self-regulation and self-efficacy from Prof Nakata's ARC-supported study of Indigenous academic persistence.

Stakeholders consulted for this case study suggest that the TAPS strategy (Transitional, Academic, Pastoral, Support) Prof Nakata built to develop the learner identity is transformational because it demonstrates that there is no need to wait for universities to change the teaching and learning space or curriculum, rather that staff at the Indigenous Centres can do a lot now to support and engage students to improve their capabilities as learners. TAPS focuses on building the capabilities needed for success, including academic persistence, self-efficacy and performance.

Figure 12.3 shows the key metrics assessed through TAPS, along with the goal rating (on a scale from 1 (poor) to 5 (good)), the actual rating and the gap. Larger gaps between goal and actual ratings identify areas of focus for university support staff.

Figure 12.3 Example of tracking trends and outcomes through TAPS



FEEDBACK — Collapse Section

TAPS (24 May 22)	GOAL	ACTUAL	GAP
Academic Capacity - Classroom Engagement	4	3	-1
Academic Capacity - Remedial Activities	4	NA	
Academic Capacity - Resources	4	4	0
Academic Capacity - Tutor support	4	3	-1
Individual Social Support - Health and well-being	4	4	0
Individual Social Support - Managing emotions and stress	4	4	0
Individual Social Support - Self-management	4	2	-2
Learner Identity - Growth Mind-set	4	3	-1
Learner Identity - Help-seeking behaviours	4	2	-2
Learner Identity - Organisation and behaviour	4	2	-2
Learner Identity - Persistence and resilience	4	3	-1
Learner Identity - Self-efficacy	4	3	-1
Learner Identity - Self-motivation	4	3	-1
Learner Identity - Self-regulation - execution phase	4	2	-2
Learner Identity - Self-regulation - planning phase	4	2	-2
Learner Identity - Self-regulation - reflection phase	4	3	-1

Feedback history — START 1-Mar-2022 — END 9-Aug-2022

DATE	NAME	Academic Capacity	Individual Social Support	Learner Identity
09 Jun 22	TAPS	-1 (3.8)	2 (4.7)	4 (4.4)
24 May 22	TAPS	-2 (3.3)	-2 (3.3)	-13 (2.6)

Source: Prof Nakata, personal communication.

LIEF – Establishment of the Australian data archive generated 4 sub-archives of curated data for research-intensive networks: Centre of Excellence for Policing and Security, the National Criminal Justice Research Data, the Australian Housing and Urban Research Institute, and the Ageing Well Research Network. This has supported more than 1,000 researchers to develop publications. *LIEF – ASSDA* developed an open access platform to house a collection of social sciences and humanities data sources and *LIEF – DomeLab* developed a mobile ultra-high resolution experimental fulldome. Prof Nakata's contribution to these grants focused on how to recognise, document and store Indigenous knowledge and how to use Indigenous guides and protocols in the management of, as well as access to, data.

During the *Discovery Projects* grant, Prof Nakata laid out a *Cultural Interface* theory,[270] developed during his PhD studies, and published in his book, *Disciplining the savages: Savaging the disciplines*. This work fundamentally shifted the thinking on Indigenous contemporary situations. This theory was used in another *Discovery Project* to disrupt the psychological basis of anger issues. It required researchers to look at anger not just as something 'in the head' but also where it forms viz., in a given social environment. This led researchers to seek deeper understandings of the ways men were not able to engage the dynamics of the social environment, and to then find that men had poor language abilities for expressing their emotions and feelings in that context; made more difficult when confronted by an angry situation. A situation whereupon hitting back becomes the only option. The rehabilitation framework was reconfigured to help men build facility with language to better manage encounters that may lead to angry behaviour.

[270] 8Ways (n.d.). *Interface Theory*. Accessed February 2023: https://www.8ways.online/interface-theory.

12.6.3 Innovation / commercialisation

The research has been highly innovative. At the time the Discovery Indigenous grant commenced, research funding was spent on curriculum issues and curriculum reform, and policy and institutional approaches focused on changing pedagogical practice, incorporating Indigenous topics, insights and culture into education (see section 12.3.2). As such, the research took a novel approach to understanding how to build Indigenous persistence in learning and to the study of Indigenous learning outcomes. Additionally, this project leveraged student information systems and analytics to identify bespoke platforms for managing student learning.

Prof Nakata helped develop WillowSoft Student Success platform [271] in 2018 with industry partner WillowSoft Pty Ltd. This commercial application now supports his university to apply the TAPS strategy. A subscription license can be purchased for just over $120,000 per year. As noted on the WillowSoft website:

> *WillowSoft is the only software platform in the world to incorporate over 20 years of Australian academic research in identifying and managing the levers for Indigenous student success. This knowledge is encapsulated in the design of the assessment tools and prescriptive case plan activities.*

WillowSoft provides 4 components:

- Case Management methodology, which incorporates programs, case plans and tasks to support universities to assess and allocate student cohorts to staff
- Discovery, for assessment tools and prescriptive case plan activities
- Insights, for live dashboards of metrics of student cohort performance, and machine learning to identify problem areas and patterns of contributing factors for success or failure
- Engagement support, which equips Indigenous education support staff with a holistic view of the student.

WillowSoft enables cross-campus student monitoring and engagement, particularly helpful for large or dispersed campuses.

Universities can implement TAPS without WillowSoft but will require a much more robust Customer relationship management (CRM) system to support the engagement with students. Prof Nakata has worked with this same industry partner to also develop a version for the school sector to support Indigenous students to arrive at university better prepared for study (see section 12.9).

12.7 Outcomes

12.7.1 Adoption

Adopting the Indigenous learning model TAPS

TAPS fills a gap in available models of support services and provides an evidence base for many stakeholders on how to support Indigenous students. It has been adopted variously by UNSW, ECU and JCU. There are discussions amongst practitioners in other universities (UQ, Griffith, Murdoch, and Sunshine Coast universities) about the potential for a broader rollout of TAPS. A national conference in July 2023 will likely see other interest as knowledge of the case studies are shared with all universities for the first time.

ECU adopted TAPS in 2017. ECU employs non-academic and academic (aligned with student's study fields) support staff to implement TAPS. Indigenous students now receive a pre-orientation survey before they enrol to provide the university with an understanding of their caring

[271] WillowSoft (2019). *WillowSoft Student Success*. Accessed February 2023: https://www.willowsoft.com.au/.

responsibilities, living location, hours worked per week, whether they are the first in their family to attend university, and whether they have studied and completed elsewhere. The university identifies matters that may impact student engagement and completion, and tailors the support provided. This includes a specific introduction to the available Indigenous services, an individual success plan, a 4-weekly phone check-in and an annual student experience/satisfaction survey. Prof Nakata meets with ECU every 6 months to contribute emerging insights on TAPS.

JCU adopted TAPS in 2016 and purchased a WillowSoft subscription in 2019. 50% of JCU's Indigenous student population is from low socio-economic backgrounds, and 75% are first in family to undertake higher education. Since adopting TAPS, JCU implemented an improved learning support service and brought in an industry partner, WillowSoft Pty Ltd, to help measure student progress and outcomes. JCU has 12 academic and pastoral support staff, that engage with Indigenous students every 3 weeks to check-in and identify emerging issues. JCU also uses WillowSoft's predictive capacity across the student cohort and their study schedules to guide where support is needed, and support staff are alerted to this need much earlier through this process.

The success of students completing degrees at JCU has provided confidence with donors such that more funds are now available to support more Indigenous students in their university studies.

Adopting TAPS has created a shift in the way these universities approach Indigenous student learning engagements. This has largely been a move from a reactionary approach (waiting for students to experience problems) to a proactive response and thus opportunities for much earlier intervention (staff regularly engage with students and understand where issues are likely to emerge).

Adopting other research outputs

The book, *Supporting Indigenous students to success at university,* was written as a guide for all universities on how to manage and support under-prepared students.

The Australian New Zealand School of Governance (ANZOG) requested details of the Discovery Indigenous research for use as a case study to exemplify progressive empirically driven public policy in Australia.

LIEF – Establishment of the Australian data archive and *LIEF –ASSDA* resulted in the development of new data protocols for the major social science databases. This revolutionised the way that data is stored and curated. The NSW State Library and World Library and Information Congress adopted this research. Changes were also made to Australian and international policies on managing Indigenous knowledge and data. Prof Nakata also worked with indigenous library associations.

The *LIEF – Establishment of the Australian data archive* grant supported evidence-based policy, developed new data-sharing partnerships with government and researchers, and supported collaboration between research-intensive networks. New data curation since 2012 has led to the development of new content in each sub-archive, resulted in more than 1,000 datasets in the collection. The archive has been used by notable studies such as the Australian Election Study, with the supporting data cited more than 200 times.

12.7.2 Alignment with government strategic priorities

The research aligns with the strategic objectives of the National Agreement on Closing the Gap (see section 0),[272] in particular Goals 6 and 7. Outcome 6 is focused on higher education completion rates, and its 2031 target is to increase the proportion of Indigenous people aged 25-34

[272] Australian Government (2023). Op. cit.

with a completed tertiary qualification to 70%.[273] Outcome 7 focuses on the proportion of Indigenous people aged 15-24 engaged in employment, education or training. Its 2031 goal is to increase this proportion to 67%.[274] This suite of research focuses on improving Indigenous learning outcomes, and key measures of the research (enrolment, retention and completion) align with government priorities.

The research also relates to the strategic goals of Australia's peak university body, Universities Australia, which in 2022 launched a 5-year sectoral strategy for closing the gap in higher education.[275] This includes priorities to improve enrolment and completion rates.

12.7.3 Research capability building

The 2 ARC Centres of Excellence (see section 12.9) will support Higher Degree research students, with the *Indigenous Environmental Histories* supporting up to 90 fully funded PhD and MPhil candidates and up to 42 postdoctoral fellows over its life. Centres of Excellence also provide a means for capacity building across a researcher's career, with training for post-doctoral, early-, mid- and late-career researchers through the opportunity to work on large-scale problems over longer timeframes.

12.8 Impacts

12.8.1 Economic impacts

Counterfactual

This research could not have been conducted without the ARC. No large research grants were available from other sources for research of this nature. The funding also provided the legitimacy for this research and for Prof Nakata to allocate time amongst teaching and other university responsibilities.

Attribution

Noting the counterfactual above, there is a clear role for other funding sources in translating the research. This includes universities, industry and other government funding sources. Without this funding, there would be less uptake and awareness of TAPS.

Given the important role of this funding in conducting this research, ECU and Murdoch university have noted that 75% of the benefits are attributable to the ARC, while JCU has stated that 100% of the benefits can be attributed to the ARC. A central attribution rate of 75% was selected. This parameter is tested in the sensitivity testing section below.

Methodology and key assumptions

The cost-benefit analysis (CBA) estimates the identified costs and benefits relating to the retention of indigenous students in tertiary education. The CBA compares the total costs of the Discovery Indigenous – Indigenous persistence in formal learning grant (see Section 8.4) to the estimated benefits of the additional income accrued by the indigenous learners post-graduation. This model also assumes that university fees are minimised by assuming that students who receive support

[273] Australian Government (2023). Op. cit.

[274] Ibid.

[275] Universities Australia (2022). *Indigenous Strategy 2022-25*. Accessed February 2023: https://www.universitiesaustralia.edu.au/wp-content/uploads/2022/03/UA-Indigenous-Strategy-2022-25.pdf.

and are retained graduate after 4 years of university rather than prolonging their studies and increasing costs due to retaking subjects.[276]

It should be noted that even with the consideration of these 2 areas of benefit, the analysis is still likely to be conservative as it does not quantify broader benefits that may come with increased education levels, such as improving health outcomes.

The following assumptions underpin the CBA:

- Discount rate of 7% was used in the central case. A discount rate of 3% was used as a lower-bound sensitivity and a discount rate of 10% was used as an upper-bound sensitivity.
- The difference in retention rate between indigenous students in the support program and those not in the support program is based on the increase in retention of indigenous students at ECU, based on trial data from 2017 to 2022.
- The number of indigenous students in the model is 1086, which is based on the number of indigenous students who have been part of the program at ECU (286) and JCU (800). This number has been sensitivity tested with a lower bound of 286 (just ECU students) and 2000 (approximately double the central case).
- Indigenous Bachelor and sub-bachelor graduate income assumptions are based on analysis conducted by the Department of Education, Skills and Employment.[277] The dataset underpinning their analysis uses graduates' taxation returns based on records collected to administer the Higher Education Loan Program
- Income growth estimation based on the Department of Education, Skills and Employment analysis and other sources.[278]
- Cost of university is $24,000 per annum. This cost was selected as it is the average of the lower and upper bound costs of a bachelors degree in Australia (AUD $15,000 - $33,000 per annum).
- Length of a bachelor degree is 3 years
- Students who drop out of university do so in their first year of study (based on stakeholder consultation)
- The analysis period is from 2010 (from the start of ARC funding) to 2044 (35-year analysis period, inclusive of starting year). This is consistent across CBAs.

Costs

The nominal costs included in the CBA are:

- The cash contribution of the ARC Discovery Indigenous – Indigenous persistence in formal learning grant (see Section 8.4). Only this grant has been included because it is the key grant that supported the research behind the tertiary education support program.
- Cost of a bachelor degree per retained student. Note that the difference between retained and non-retained students is 2 years of fees. For example, the costs counted for a student who graduates at the end of 2019 would be their annual fees in 2018 and 2019, hence $48,000.[279]

[276] Professor Nakata noted that this was an important part of the support program, to ensure that students are able to graduate with their student debt minimised.

[277] QILT (2021). *Graduate incomes data*. Accessed March 2023: https://www.qilt.edu.au/general/article/2021/11/04/graduate-incomes-data.

[278] Other sources with income estimation sources include https://www.payscale.com/research-and-insights/peak-earnings-data-visualization/ and https://theconversation.com/three-charts-on-teachers-pay-in-australia-it-starts-out-ok-but-goes-downhill-pretty-quickly-122782.

[279] The reason that 2 years of fees is counted rather than 3 (the assumed average length of a bachelor's degree in this model) is because it is assumed that the non-retained students will pay one year of fees before

These nominal costs are adjusted for inflation using the CPI by year, which produces the real costs (2022 dollars).

Benefits

The benefit is the additional income generated by the indigenous graduates that were retained through the support program. The additional income is counted to the end of the analysis period.

The nominal benefits by year are calculated by estimating the number of retained students by graduation cohort and then counting the additional income by year that they would generate compared to if they had dropped out and were on a sub-bachelor education. This is done by taking the number of Indigenous students (the assumed number is based on the number of students supported by ECU and JCU), multiplied by the difference in retention due to the support program, multiplied by the difference in income between bachelor and sub-bachelor graduates. Note that in the model, each cohort experiences income growth rates (over the analysis period) that are aligned with Commonwealth Department of Education and publicly available estimates. This figure is adjusted for attribution to the ARC to identify the nominal benefit in that year.

$$Difference\ in\ income\ between\ \text{bachelor's and sub} - \text{bachelor's graduates}(\$) \times (difference\ in\ retention\ rate\ due\ to\ program\ (\%) \times number\ of\ indigenous\ students\ in\ cohort) \times\ attribution\ to\ ARC\ (\%) = Nominal\ benefit\ (\$)$$ [280]

These nominal benefits are adjusted for inflation using the Consumer Price Index by year, which produces the real benefits (benefits in 2022 dollars).

Calculation of NPV and CBR

The estimated the benefits and costs are provided in Table 12.2 for discount rates of 3%, 7% and 10%.

The benefit-cost ratio (BCR), obtained by dividing the present value of benefits by the present value of costs using a 7% discount rate, is positive at a value of 2.48. The present value of costs is $71.3 million. The benefits are estimated at $176.5 m, resulting in a NPV of $105.3 m.

Table 12.2 Summary of benefits and costs (2022$)

	Discount rate 3%	Discount rate 7%	Discount rate 10%
Present value costs			
ARC-funded research costs	$1,091,710	$1,540,502	$1,979,091
Educational expenses	$90,651,687	$69,754,544	$60,033,901

dropping out, and the cost model only counts the difference between retained and non-retained student costs.

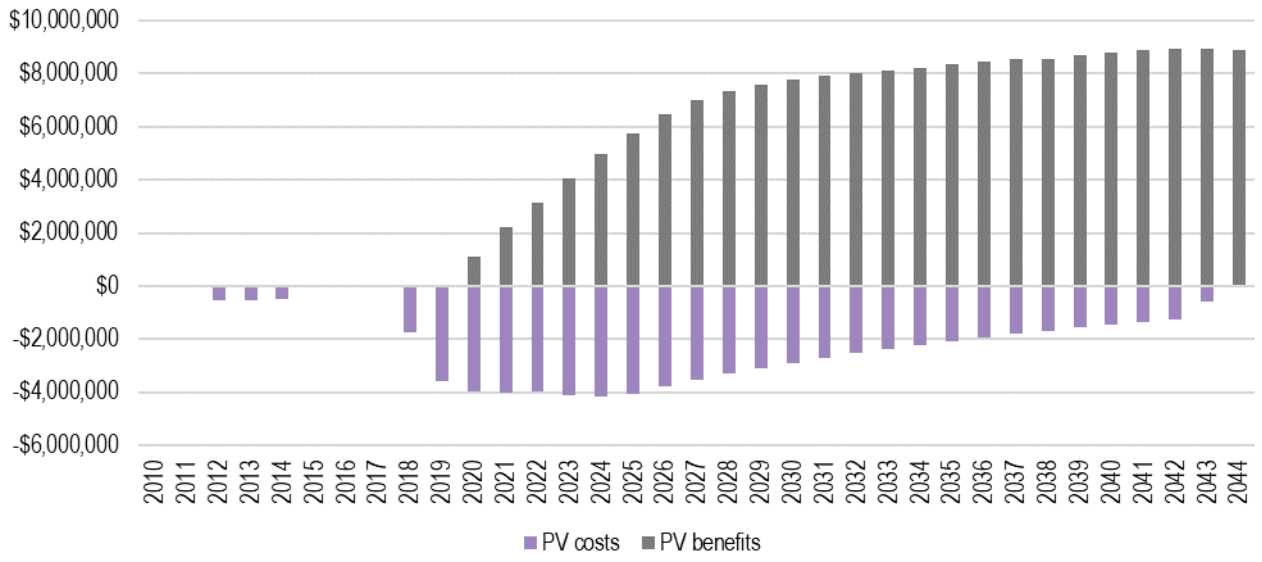
[280] To illustrate how the model works, we will take a student who graduates at the end of 2019 and begins working in 2020. Based on Commonwealth Department of Education analysis, it is estimated that the student's income will grow from $58,000 in year one to $82,000 in year ten of employment, and by 25 years of employment their income would have grown to $103,950. This is compared to a sub-bachelor's degree income, which is estimated to be $40,300 in year one, $73,100 in year 10, but plateaus at $76,755 by year 20 and does not increase over the remaining analysis period. The difference in income each year is multiplied by the number of students retained in that graduate cohort. The number of students retained is found by identifying the difference in retention rate between the counterfactual (scenario with no support program) and reference case (scenario with support program) and multiplying the difference with the number of indigenous students supported by the program (1,086). This gives the additional income generated by the retained student each year and is repeated for every graduate cohort in the analysis period (2020 graduate cohort to 2044 graduate cohort), out to the year 2044. The nominal benefit counted in 2020 is the additional income generated by the retained students in their first year of employment, which is $1,185,803 in total.

	Discount rate 3%	Discount rate 7%	Discount rate 10%
Total PV costs	*$91,743,397*	*$71,295,046*	*$62,012,992*
Present value benefits			
Additional income generated through retained students	$286,923,289	$176,540,606	$128,838,433
Results			
NPV	**$195,179,892**	**$105,245,560**	**$66,825,441**
BCR	**3.13**	**2.48**	**2.08**

Source: ACIL Allen

The present value of benefits and costs of the ARC-funded research by year are shown in Figure 12.4.

Figure 12.4 Present value costs and benefits by year (7% DR)



Source: ACIL Allen

Sensitivity testing

Sensitivity testing at the 3% and 10% discount rates[281] was conducted for this analysis (see Table 12.2 above). Sensitivity testing at these 3 rates shows that although the magnitude of the NPV changes at these 3 rates, the NPV remains positive even at a high discount rate of 10%.

Sensitivity testing was also conducted for the number of Indigenous graduates. The central case was 1,086, based on figures provided by ECU and JCU. The CBA results were tested with a lower bound number of students of 50 students (a significantly lower number than the number of enrolled students) and an upper bound number of students of 2,000 (approximately double the central case). The results in Table 12.3 show that the NPV would fall from $105.3 million to $3.4 million and the BCR would fall from 2.48 to 1.71 if the number of students falls from 1,086 to 50. Whereas the NPV would rise to $195.1 million and the BCR would rise to 2.50 if the number of supported students increases to 2,000. The CBA is positive at all 3 discount rates. The CBA is not overly

[281] The 3% and 10% discount rates are the Federal Government Office of Impact Analysis' recommended rates for sensitivity testing. Refer: https://oia.pmc.gov.au/sites/default/files/2021-09/cost-benefit-analysis.pdf

sensitive to the number of students because the costs (university fees) also increase and decrease with the number of students.

Table 12.3 Sensitivity testing number of students (7% DR, 2022$)

	50 students	1,086 students	2,000 students
Costs	$4,752,037	$71,295,046	$130,001,909
Benefits	$8,128,021	$176,540,606	$325,120,821
Net impact	**$3,375,984**	**$105,245,560**	**$195,118,912**
BCR	**1.71**	**2.48**	**2.50**

Source: ACIL Allen

Sensitivity testing was also conducted for the difference in fees between retained and non-retained students. The central case was that the difference between retained and non-retained students was 2 years of university fees ($24,000 for 2 years, i.e., $48,000). That is to say, that non-retained students will pay one year of fees before dropping out. The Cost Benefit Analysis results were tested with a lower bound difference of one year of fees and an upper bound of 3 years of fees (the maximum amount assuming a 3-year undergraduate degree). The results in Table 12.4 show that the Net Present Value would fall from $105.3 million to $66.3 million and the BCR would fall from 2.48 to 1.60 if the difference in fees was 3 years rather than 2 years. Whereas the Net Present Value would rise to $141.4 million and the BCR would rise to 5.02 if the difference in fees was one year rather than 2 years. The CBA is positive at all 3 discount rates. However, it can be seen that the BCR is highly sensitive to the cost of university, given that this is the main contributor to the cost side of the CBA.

Table 12.4 Sensitivity testing difference in fees between retained and non-retained students (7% DR, 2022$)

	1 year of fees	2 years of fees	3 years of fees
Costs	$35,143,715	$71,295,046	$110,233,796
Benefits	$176,540,606	$176,540,606	$176,540,606
Net impact	**$141,396,891**	**$105,245,560**	**$66,306,810**
BCR	**5.02**	**2.48**	**1.60**

Source: ACIL Allen

Sensitivity testing was also conducted for the attribution of benefits to ARC. The central case was an attribution of 75%. The CBA results were tested with a lower bound attribution of 50% and an upper bound attribution of 100%. The results in Table 12.5 show that the Net Present Value would fall from $105.3 million to $69.7 million, and the BCR will fall from 2.48 to 2.45 if the attribution is reduced to 50%. Whereas the NPV would rise to $140.8 million and the BCR would rise to 2.49 if the attribution was increased to 100%. The CBA is positive at all 3 discount rates.

Table 12.5 Sensitivity testing attribution to ARC (7% DR, 2022$)

	50% attribution	75% attribution	100% attribution
Costs	$48,043,531	$71,295,046	$94,546,561
Benefits	$117,693,737	$176,540,606	$235,387,474
Net impact	**$69,650,206**	**$105,245,560**	**$140,840,914**
BCR	**2.45**	**2.48**	**2.49**

Source: ACIL Allen

12.8.2 Social impacts

Educational impacts

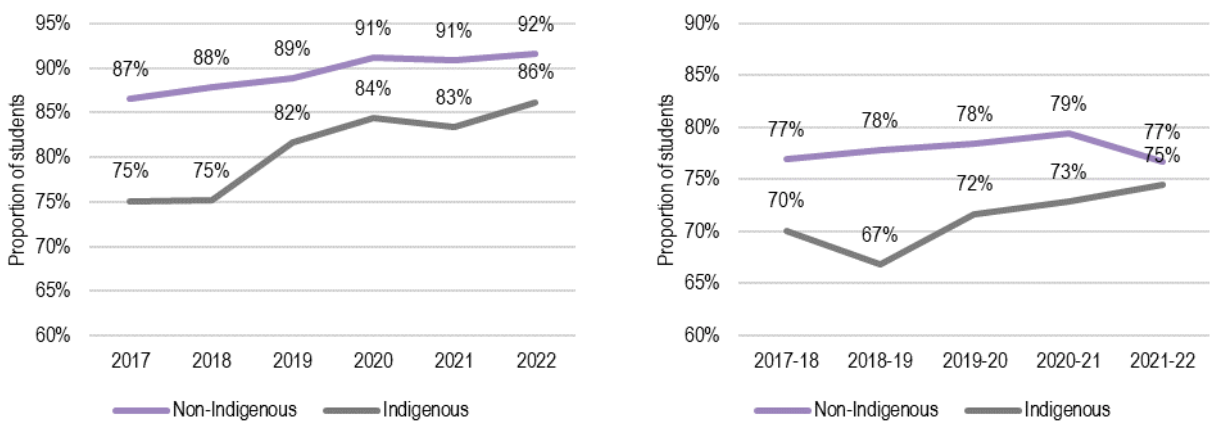
This section discusses the impact of adopting TAPS by 2 universities, ECU and JCU.

This research's primary beneficiaries are Indigenous students, their families and communities, industry, universities and governments. Adopting TAPS has led these universities to shift the way they view priority cohorts: from a transactional or deficit to a relational and empowering manner. The model and evidence base provides guidance on how universities can maximise the effectiveness and efficiency of funding for support services. This is helping close the gap for Indigenous student education.

Since adopting TAPS, ECU has supported approximately 400 students across a range of learning modes and campuses. ECU has seen an improvement in Indigenous student's awareness of where and how to get support, student stress levels, and proactive support-seeking behaviours. As such, students engage with support staff before issues become crises. This has improved success rates (units passed compared with units attempted) and retention rates (progress from semesters and years, see Figure 12.5). TAPS has made their approach to student engagement and support more effective as ECU can prioritise staff support. TAPS has not increased ECU's costs as they had an existing CRM.

This research has also contributed to a national conversation around closing the gap and universities' role in this. These lessons inform how supports are being provided for other non-Indigenous priority cohorts, such as students with disabilities. For example, ECU has implemented TAPS with students with disabilities. This has led their students to transition from being the least satisfied to the second most satisfied student group (second to Indigenous students).

Figure 12.5 Impact of adopting TAPS at ECU on success and retention rates



Note: Success rate is a weighted pass rate, essentially, if a student takes 4 units all of the same weighting and passes 3, their success rate would be 75%. N=365 Indigenous students and 22,393 total domestic students in 2021.

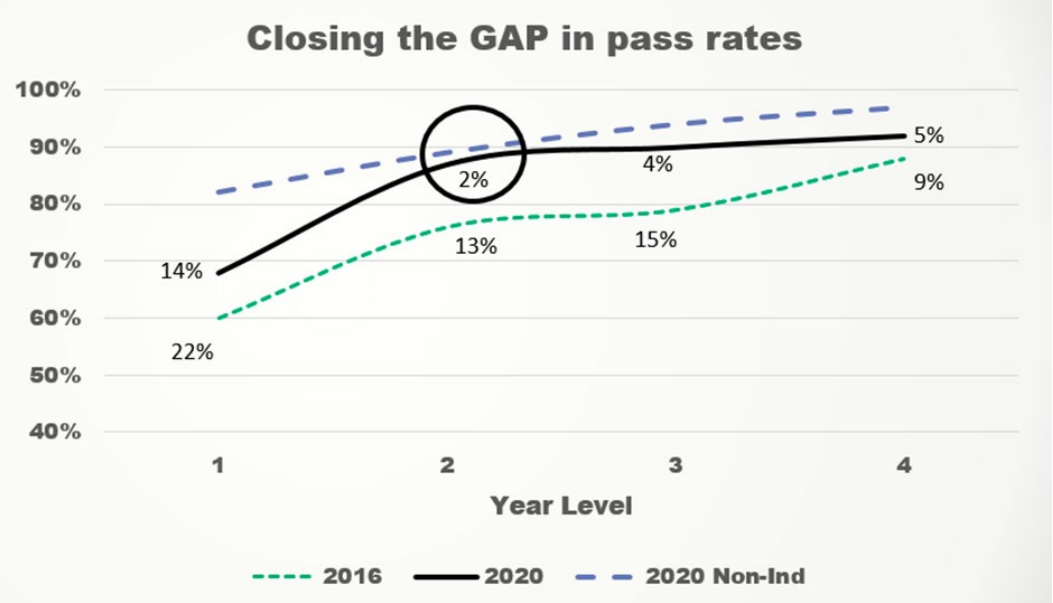
Retention rate measures the proportion of all students enrolled in the given calendar year who re-enrolled (in any course in ECU) the following calendar year. The years on the chart should be read e.g. "from" 2017 "into" 2018. N=286 Indigenous students and 16,158 total domestic students in 2021.

Source: Edith Cowan University

JCU has seen stronger awareness of and engagement with support services from the year the model was implemented. The Indigenous Student Services Centre has enabled more coordinated and focused service delivery across the Indigenous student body. The results have been remarkable as can be seen in Figure 12.6. Graduation rates have also doubled in 5 years from 74 graduates to 130 graduates, a strong improvement. Further, JCU has many Indigenous students

studying diplomas to get an ATAR and the necessary pre-requisites to study an undergraduate degree, and TAPS has supported a decrease in the failure rate for this diploma from 79% in 2019 to 43% in 2020.

Figure 12.6 Impact of TAPS at JCU's pass/fail rates



Source: James Cook University

Employment impacts

By increasing graduation rates, TAPS is likely to have flow on benefits for the employment of Indigenous graduates. There is published research that suggests Indigenous graduates with Bachelor degrees earn higher salaries than those with lower level qualifications (e.g. high school diplomas, certificates). For example, Indigenous graduate income is $58,200 for Bachelors, compared with $40,300 for sub-Bachelors.[282] After 10 years, this research suggests the average income earned is $82,500 and $73,100, respectively.

12.8.3 Other impacts

This program of research has supported the development of collaborative partnerships, most prominently with case study universities and those implementing TAPS and WillowSoft. These were critical to developing the evidence base and translating the research.

12.9 Potential future impacts

This research has made important contributions to our understanding of Indigenous learning capacities and can be applied more broadly across other education types and priority cohorts.

The research knowledge emphasises the importance of developing a learner identity in students from the early years (primary and secondary schools) to improve academic performance, and in these ways strengthen pathways for Indigenous students to participate in higher education studies.

As such, Prof Nakata has been exploring options for TAPS to be used in Queensland schools and a grant submission has been made to the Commonwealth's Regional Participation Project Pool

[282] Quality Indicators for Learning and Teaching (2021). *Graduate incomes data*. Accessed February 2023: https://www.qilt.edu.au/general/article/2021/11/04/graduate-incomes-data.

Program to fund trial sites in communities across all 5 regions of the Queensland Department of Education catchment areas.

He is also currently in partnership with 19 schools in regional and remote Queensland with a student base of 4,000 students to improve the Indigenous students' performance in the math and science curriculum.

16 of these schools are in very remote areas, and where the majority of students speak English as their second language. Performance data from the early trials between 2019 and 2021, in these 16 schools, show improvements in math to levels well above the previous 9-year average achieved by these same schools.

Both the math and science work are now being trialled in 3 regional schools with Indigenous and non-Indigenous students, with early evidence showing that this model also is benefiting non-Indigenous students. However, funding constraints are limiting the extent to which the math and science work can be applied.

Prof Nakata has been exploring opportunities with the Queensland Department of Education, Catholic schools sector and industry partners such as Minerals Council of Australia, BHP, Glencore, Rio Tinto and others.

Prof Nakata was part of a consortium recently awarded an ARC Centre of Excellence for Indigenous and Environmental Histories and Futures (CE230100009). This research aims to improve our understanding of Australia's environmental and Indigenous history before European settlement by enhancing transdisciplinary research capability and creating an integrated history of change. The education and engagement role he has on this project will help in part to support his ongoing research work in math and science.

RRR: Indigenous Remains Repatriation 13

First Nations readers should be aware that this document contains information about the theft and return of ancestral remains that can be confronting and distressing.

13.1 Key Findings

$2.98m invested by ARC and $5.96m by participating organisations

4 PhD students trained as a result of the project (4 students currently completing PhDs)

The project has produced
- The Return Reconcile Renew (RRR) website, Digital Archive and global network

- 'Introduction to Repatriation: Principles, Policy and Practice' course at The Australian National University

Major publications include
- The Routledge Companion to Indigenous Repatriation

- A Repatriation Handbook: A Guide to Repatriation

- Science, Museums and Collecting the Indigenous Dead in Colonial Australia

- A mass of community reports and non-traditional research outputs

32 Masters students and 108 participants in professional development repatriation courses enrolled at ANU over 6 years

Alignment with Government priorities

'Better health outcomes for Indigenous people'

"The Australian Government supports the repatriation of Aboriginal and Torres Strait Islander ancestral remains and secret sacred objects which contributes to healing

13.2 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to assess the impact and value of research undertaken by many organisations.[283] The results from applying that framework to the RRR: Indigenous Remains Repatriation case study are summarised in Figure 13.1.

[283] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F.

Figure 13.1 Repatriation of ancestral remains – Impact Framework Diagram

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– $3 million in funding from the ARC – $5.9 million in cash and in-kind support from other organisations – Ongoing support and collaboration from founding partners the Ngarrindjeri Regional Authority, Kimberley Aboriginal Law and Culture Centre and the Gur A Baradharaw Kod Sea and Land Council Torres Strait Islander Corporation	– Historical research that identifies opportunities for repatriation and builds the evidence base for future practice – The development of a website, a living Digital Archive and associated Indigenous governance arrangements which raise awareness of the meaning and value of repatriation and support an expanding national and international network of repatriation communities – Community engaged theoretical and empirical research that has, for example, advanced understanding of the history of theft, search, and return; Indigenous Digital Archive governance, and the relationship between repatriation, healing, and reconciliation – Empirical mapping of Indigenous ancestral remains around the world – Collaboration exemplifying significant knowledge transfer between researchers, institutions, governments, and community in Australia and internationally	– Publications, conference papers and international symposiums – Practitioner handbooks and guidance material, tool kits, Country Reports and Community Reports – National and internationally recognised Archive and e-research infrastructure – Masters course and professional and practitioner training courses and micro-credentials – World first Graduate Certificate in Repatriation and Restitution planned for delivery at ANU in 2023 – The RRR website provides communities and the general public with access to information that supports repatriation research and repatriation outcomes	– Extensive utilisation of archival information and research outputs – The development of a national and international community of practice for repatriation – Alignment with Government support for the repatriation of Aboriginal and Torres Strait Islander ancestral remains and secret sacred objects, which contributes to healing and reconciliation	– Reduction in the search, research and administrative costs associated with repatriation for all stakeholders – Years of pain and suffering avoided by communities involved in the repatriation of ancestral remains – Professional development and training of practitioners – An international community of practitioners, researchers and government officials – Critical support in the development of a National Resting Place for poorly provenanced ancestral remains

Source: ACIL Allen

13.3 Background

This case study relates to projects funded under the following ARC schemes:

— Discovery Program: **Discovery Projects**.

— Linkage Program: Linkage Infrastructure, Equipment and Facilities and Linkage Projects.

13.3.1 Repatriation research and practice

For more than 2 centuries, Indigenous ancestral remains were removed from their communities of origin to be held in Australian and overseas universities, public museums and private

collections.[284, 285] These remains were collected for the purpose of sale and trade, exhibition, and 'scientific' research into human biological differences.[286]

Although evidence of Indigenous opposition and resistance to the removal of remains dates as far back as the early 19th Century, a global movement began in the 1970s to have them brought home.[287]

The repatriation movement is now a coordinated global effort involving national and regional governments, cultural institutions, research organisations, private individuals and Indigenous communities.

Critical to successful repatriation is information concerning where ancestral remains are located and where they were originally taken from (their provenance). Spread across different archives and institutions and constituted in different types of archival and published resources, such information is hard to locate, particularly for source communities. Before the creation of the RRR Digital Archive (see below), no centralised resource of information was available to repatriation workers and critical questions being posed by Indigenous organisations were as yet unaddressed. Following consultation, recognition of the critical need for a centralised resource of information and identification of research questions about the removal and return of ancestral remains led to the program of work detailed in this impact case study.

ARC-funded research

This case study focuses on the work of an international team of repatriation researchers and practitioners led by Professor Cressida Fforde. Since 2013, this work has contributed to the development of national and international capability (and interconnected communities of research and practice) in repatriation.

Professor Fforde is Senior Research Fellow at the Centre for Heritage and Museum Studies at the Australian National University (ANU). Prof Fforde's primary research area has been the repatriation of Indigenous human remains acquired by museums and other collecting institutions in the long 19th Century. She undertakes applied and scholarly research in this field. She is particularly interested in advancing understanding of the history of the theft and scientific (mis)use of Indigenous ancestral remains, its continuing legacy, and the relationship between repatriation, healing and reconciliation. This work has been driven by the need to celebrate and develop a greater understanding of the efforts made by Indigenous peoples to locate the remains of their ancestors, as well as the need to improve the flow and management of information to support repatriation practice.

While Prof Fforde's research dates to the 1990s with the completion of one of the UK's first PhD on repatriation, our impact story begins with the awarding of the first ARC-funded research grant in 2013. Led by Prof. Fforde, the grant (a Linkage Project entitled *Return, Reconcile, Renew: understanding the history, effects and opportunities of repatriation and building an evidence base for the future*) brought together a multi-sector international team of repatriation researchers and practitioners, including 3 highly experienced Indigenous Australian Partner Organisations. The

[284] Department of Infrastructure, Transport, Regional Development, Communications and the Arts (2022). *Indigenous Repatriation*. Accessed January 2023: https://www.arts.gov.au/what-we-do/cultural-heritage/indigenous-repatriation

[285] Australian Institute of Aboriginal and Torres Strait Islander Studies (n.d.). *Return of Cultural Heritage*. Accessed January 2023: https://aiatsis.gov.au/about/what-we-do/return-cultural-heritage#:~:text=The%20Indigenous%20Repatriation%20Program%20facilitates,communities%20of%20origin%2C%20contributing%20to.

[286] Department of Infrastructure, Transport, Regional Development, Communications and the Arts. Op. cit.

[287] Return Reconcile Renew (2021). *Explainer: What is repatriation*? Accessed January 2023: https://returnreconcilerenew.info/ohrm/biogs/E002082b.htm.

grant provided 3 years of funding to undertake extensive domestic and overseas research to better understand the history of removal and return of ancestral remains. This grant aimed to investigate the effects of repatriation and the opportunities it provides nation building, healing and reconciliation, whilst also providing a greater understanding of the history of Indigenous responses to the initial theft of their ancestors and their campaigns to locate and bring them home. This research, which also formed Stage I of the development of an online resource for the repatriation community, was a critical input to Prof Fforde's second ARC-funded grant in 2017, which continued the collaborations commenced in the original Linkage. With the award of the next grant, a LIEF, the successful partnership in both grants re-conceptualised itself as the Return Reconcile Renew research network, which continues to undertake various repatriation projects funded through ARC and other research income.

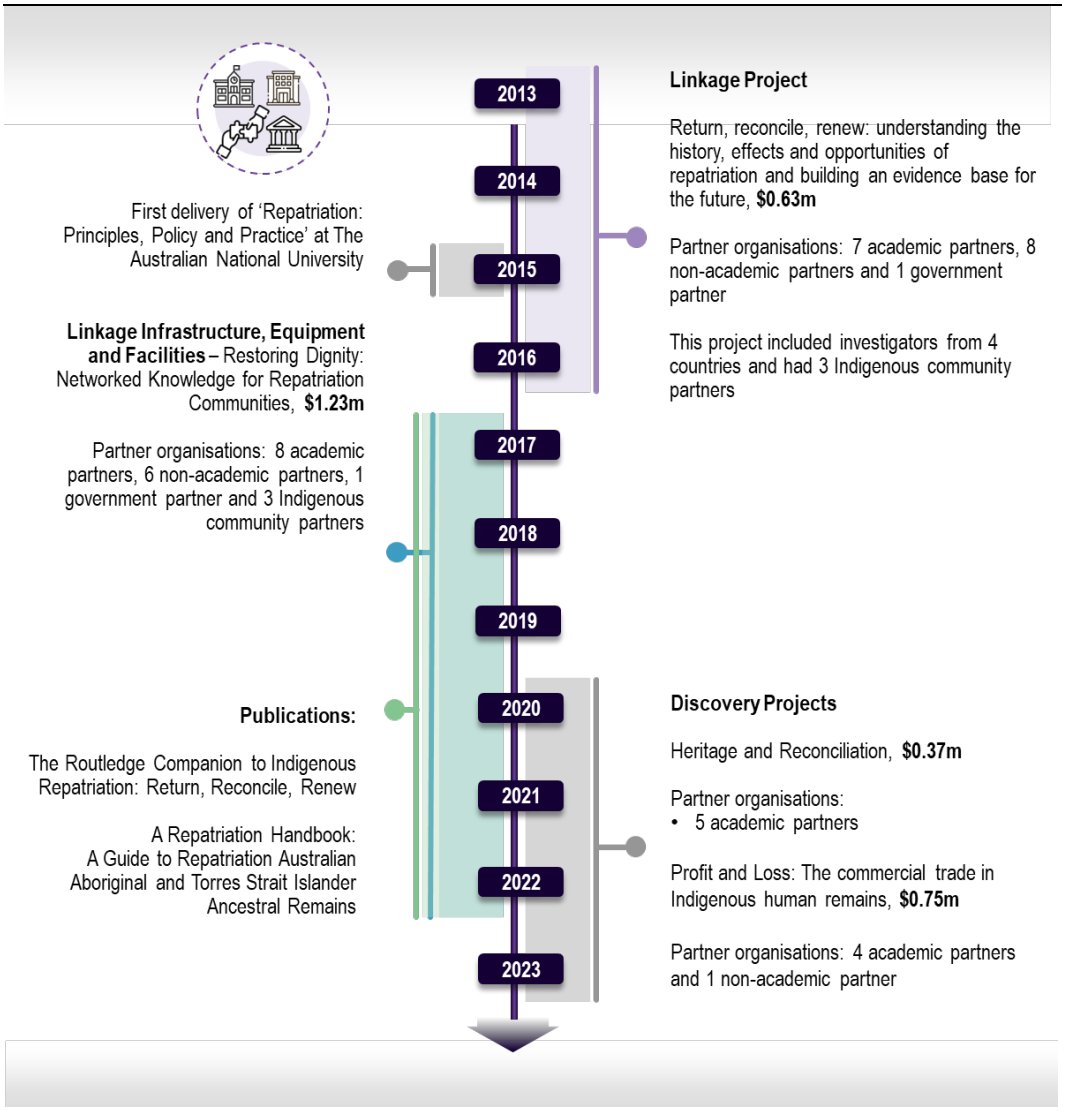
The second grant (a Linkage Infrastructure, Equipment and Facilities (LIEF) grant entitled *Restoring Dignity: Networked Knowledge for Repatriation Communities*) provided 2 years of funding (commencing in 2018) to build a unique digital facility that supports the repatriation of Indigenous human remains and future scholarship on the issue, in a way that would optimise the opportunities for repatriation to deliver social good. The grant provided opportunities to extend the research undertaken on the original Linkage to build major repatriation research infrastructure. The resulting Return Reconcile Renew (RRR) website and Digital Archive is a centralised resource of repatriation information to raise awareness of repatriation's meaning and value and support community-led repatriation practice. The primary objective of the LIEF grant was to develop a national and international resource for repatriation research and practice. This involved developing technical infrastructure, refining the Archive's information management systems, and further developing the Archive's Indigenous governance structure to ensure ethical data management. The grant also aimed to raise awareness of the Archive and increase the number of national and international Indigenous community stakeholders who could access it.

After completing the LIEF grant, Prof Fforde was awarded 2 further ARC grants, this time under the Discovery Program. Both include members of the broader RRR network continuing the successful partnerships commenced in 2013, and explore new research avenues opened up by work undertaken as part of the Linkage and LIEF projects. The first, entitled *Heritage and Reconciliation* (2020-2023) aims to rethink heritage from the standpoint of reconciliation/peacebuilding. One of its major case studies is repatriation. The project proposes using the term 'reconciliation heritage' as a tool to examine how heritage can contribute to reconciliation in settler-colonial contexts. The research involves the intellectual traditions of Aboriginal, Māori and Western cultures and aims to theorise the relationship between heritage and reconciliation to create a model for implementing outcomes in practice.

Prof Fforde's second Discovery Project entitled *Profit and Loss: Understanding the global commercial trade in Indigenous human Remains, today and in the past* (2020-2023), aims to generate new knowledge of the global marketplace for Australian Indigenous human remains in the 19th Century by gathering extensive data on all components, routes and actors in the trade and applying analytical frameworks from a range of disciplines, including data science and economic anthropology. This grant also supports investigation into the economics and valuation mechanisms of the modern commercial trade from the 1950s onwards and examines the broader implications of the commercialisation of Indigenous human remains in terms of moral economy, legality and power.

A timeline of the grants awarded, and the key events related to each grant is provided in Figure 13.2 below.

Figure 13.2 Timeline of ARC grant funding



Source: ARC grants, Prof Cressida Fforde

13.4 Inputs

Between 2013 and 2022, the ARC-supported research attracted $8,937,692 in cash and in-kind contributions (see Table 13.1).

Prof Fforde's first ARC-funded project (a Linkage Project) received $1,045,654 in total cash contributions. This included $629,533 in ARC funding between 2013 and 2016 and $20,121 from academic partners and $396,000 from non-academic partners over the same period.[288] In addition, the first project also received in-kind support from numerous sources. Between 2014 and 2019, the project received in-kind contributions equivalent to $2,200,133 from partner institutions.[289] This included $824,022 from academic partners and $1,376,111 from non-academic partners.

[288] Partner institutions on the first project that contributed funding were ANU, the Office of the Arts, Ngarrindjeri Regional Authority Inc, Australian Institute of Aboriginal and Torres Strait Islander Studies and the National Museum of Australia.

[289] Partner institutions on the first project that contributed in-kind support were the Association on American Indian Affairs, Office of the Arts, Museum of New Zealand Te Papa Tongarewa, ANU, Flinders University, UQ, University of Melbourne, Ngarrindjeri Regional Authority Inc, Kimberley Aboriginal Law and Culture

Prof Fforde's second ARC-funded project (LIEF project) received $2,041,000 in total cash contributions, which stretched beyond the ARC funding period to 2022. This included $1,231,000 in ARC funding between 2017 and 2018 and $450,000 from academic partners and $360,000 from non-academic partners over the same period.[290] This project also received in-kind support from several sources, equivalent to $1,196,188 between 2014 and 2022. This support included $768,616 from academic partners and $427,572 from non-academic partners.[291]

Prof Fforde's third ARC-funded project (a Discovery Project) received $379,392 in total cash contributions to 2023. This support includes $371,400 from the ARC between 2020 and 2023 and $7,992 of co-funding from the Australian National University between 2020 and 2023. In addition, between 2020 and 2023, the project received in-kind support from several academic partners to the value of $587,100.[292]Prof Fforde's fourth project (a Discovery Project) received $766,345 in total cash contributions to 2023. This included $748,829 from the ARC between 2020 and 2023 and $17,516 from the Australian National University between 2020 and 2023. Between 2020 and 2023, the project received in-kind support from several sources, equivalent to $721,882.[293] This support included $607,732 from academic partners and $114,150 from non-academic partners.

Centre, Australian Institute of Aboriginal and Torres Strait Islander Studies, National Museum of Australia and the University of Otago (NZ).

290 Partner institutions on the second project that contributed funding were the National Museum of Australia, Department of Communication and the Arts, ANU, Flinders University, University of Melbourne, Australian Institute of Aboriginal and Torres strait Islander Studies and UTAS.

291 Partner institutions on the second project that contributed in-kind support were the University of Cologne, University of Amsterdam, National Museum of Australia, Ngarrindjeri Regional Authority Inc, Kimberley Aboriginal Law and Culture Centre Aboriginal Corporation, Department of Communication and the Arts, The Australian National University, Flinders University, The University of Melbourne, Gur A Baradharaw Kod Sea and Land Council Torres Strait Islander Corporation, Australian Institute of Aboriginal and Torres Strait Islander Studies, University of Otago and UTAS.

292 Partner institutions on the third project that contributed in-kind support were the ANU, Flinders University, Newcastle University (UK), The University of Melbourne and the University of Otago (NZ).

293 Partner institutions on the fourth project that contributed in-kind support were the University of Virginia (US), National Museum of Australia, QUT, ANU, University of Melbourne and UTAS.

Table 13.1 Research funding

Contributor/Type of support	2013-2015	2016-2018	2019-2021	2022-2023	Total Contributions
Cash					
LP130100131 – *Return, Reconcile, Renew: understanding the history, effects and opportunities of repatriation and building an evidence base for the future*					
ARC	$524,683	$104,850			$629,533
Academic partners	$6,707	$10,061	$3,354		$20,121
Non-academic partners	$132,000	$198,000	$66,000		$396,000
LE170100017 – *Restoring Dignity: Networked Knowledge for Repatriation Communities*					
ARC		$1,231,000			$1,231,000
Academic partners		$150,000	$225,000	$75,000	$450,000
Non-academic partners		$120,000	$180,000	$60,000	$360,000
DP200102850 – *Heritage and Reconciliation*					
ARC			$266,400	$105,000	$371,400
Academic partners			$3,996	$3,996	$7,992
DP200101814 – *Profit and Loss: The commercial trade in Indigenous human remains*					
ARC			$509,591	$239,238	$748,829
Academic partners			$8,758	$8,758	$17,516
In-kind					
LP130100131 – *Return, Reconcile, Renew: understanding the history, effects and opportunities of repatriation and building an evidence base for the future*					
Academic partners	$274,674	$412,011	$137,337		$824,022
Non-academic partners	$458,704	$688,056	$229,352		$1,376,111
LE170100017 – *Restoring Dignity: Networked Knowledge for Repatriation Communities*					
Academic partners		$256,205	$384,308	$128,103	$768,616
Non-academic partners		$142,524	$213,786	$71,262	$427,572
DP200102850 - *Heritage and Reconciliation*					
Academic partners			$293,550	$293,550	$587,100
DP200101814 – *Profit and Loss: The commercial trade in Indigenous human remains*					
Academic partners			$303,866	$303,866	$607,732
Non-academic partners			$57,075	$57,075	$114,150
Total	***$1,396,768***	***$3,312,706***	***$2,882,371***	***$1,345,847***	***$8,937,692***

Source: ACIL Allen, research project applications and personal communications with Prof Fforde

13.5 Activities

The activities described in this section are central to the research projects funded by the ARC since 2013. They include:

— Community engaged participatory research that advances understanding of the history of removal and return of ancestral remains and highlights Indigenous repatriation achievements that have changed disciplinary ideology, policies and legislation in order to bring their ancestors home.

- Scholarly and applied research that empowers community-led repatriation practice, identifies opportunities for repatriation and builds the evidence base for future practice.
- A website of repatriation information which forms a major public knowledge transfer platform that raises awareness of the meaning and value of repatriation.
- A large and expanding Digital Archive of repatriation information with associated Indigenous governance arrangements that supports a growing national and international network of repatriation communities
- An audio-visual record of Indigenous voices in repatriation which bears powerful witness to the social impact of removal and return, celebrating First Nations achievements.
- Theoretical research to explore the relationship between repatriation, healing, and reconciliation.
- Empirical mapping of Indigenous ancestral remains around the world.
- Meaningful collaboration and partnerships.
- Forums for discussion, planning and debate.
- Producing multiple scholarly and applied outputs for a variety of stakeholders.

While these activities reflect the work undertaken on ARC research projects, they are only a proportion of the repatriation research, work and effort that has been undertaken by the RRR team in Australia and overseas since 2013, much of which could not have occurred without the support the ARC has provided to activate this network.

The RRR network has supported a deep and growing level of collaboration amongst researchers, Indigenous communities, museums, and governments to help find and return remains that were taken to museums worldwide. The research funding has helped these collaborators to raise awareness of the issues and importance of repatriation for Indigenous communities across the globe. In some instances, it has supported or contributed to the return of remains to Australia and elsewhere and the development of policy and legislation in several countries.

13.5.1 Understanding the opportunities for repatriation and the evidence base needed for the future

The first ARC-funded project (RRR) involved extensive research to advance knowledge on the removal and return of Indigenous ancestral remains and provided practical support to repatriation and burial practices. The research supported its community Partner Organisations in the Kimberley, Torres Strait and Ngarrindjeri Country, as well as the Federal Government's Indigenous Repatriation Unit, the National Museum of Australia and the National Museum of New Zealand Te Papa Tongarewa. It was the foundation for the development of Indigenous-led protocols for accessing culturally sensitive digital information to be held in the RRR Digital Archive.

The research activities provided important insights which supported developments in knowledge surrounding the effects of repatriation. In particular, they contributed to understanding the interconnection between repatriation, healing and reconciliation, and successful repatriation and cultural governance/nation building. They explored the means by which ancestral remains were taken and how they travelled between institutions.

The research uncovered new collections of ancestral remains in countries such as Japan, India and South Africa. It involved the early-stage development of informatics, Indigenous governance protocols and content for the development of an online archive, 'Return, Reconcile, Renew' (RRR). The research established the foundations for major repatriation research infrastructure. It also conducted over 50 interviews with First Nations people, provided forums for discussion and supported local repatriation practice. Support for local repatriation practice included creating community reports, provenancing remains already returned to community-keeping places and located ancestral remains in domestic and overseas institutions.

The academic partners involved in this project were the Australian National University, the University of Melbourne, Flinders University, the University of Otago, and the University of Tasmania.

Non-academic partner organisations were the Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS), National Museum of Australia, Office for the Arts, Ngarrindjeri Regional Authority Inc (NRA), Museum of New Zealand Te Papa Tongarewa, Kimberley Aboriginal Law and Culture Centre (KALACC), Gur A Baradharaw Kod Sea and Land Council Torres Strait Islander Corporation (GBK) and the Association on American Indian Affairs.

13.5.2 A network of knowledge to support repatriation communities in Australia and elsewhere

The second project (*Restoring Dignity: Networked knowledge for repatriation communities*) was arranged into 3 programs informed by the work in the 'Return, Reconcile, Renew' project. The first program involved the development of the Indigenous data-governance framework, which is essential to the use, sustainability and growth of the Digital Archive. This was achieved by establishing a decision-making body and agreement on rules relating to decision-making, implementation, procedures and provisions. This program involved extensive community and stakeholder engagement, which raised awareness of the research infrastructure.

The second program involved building the Archive's content and was primarily focused on collecting museum information and recording Indigenous repatriation histories and voices. This program focused on overseas collections, particularly Europe and the USA, with some focus also on South America, Japan, India, New Zealand and Russia, undertaking extensive preparatory research and then on-site visits to key holding institutions to source content for the Archive. This process involved utilising *Facility Advisory Group* knowledge and networks, scientific articles, online resources, diaries, museum correspondence, consultation with museums and discussions with relevant holding institutions. To capture Indigenous histories and voices, the program undertook further interviews with Indigenous people involved in repatriation in Australia and internationally.

The final program involved building the infrastructure and delivery platforms required for the Digital Archive. This process included uploading data and testing the access and use protocols of the Archive, in addition to the development of the technical infrastructure needed to optimise use and sustainability. The public website was launched at KALACC in September 2019 (www.returnreconcilerenew.info).

Partner organisations on the project were KALACC, GBK, NRA, AIATSIS, The Australian National University, Flinders University, University of Technology Sydney, The University of Melbourne, the University of Tasmania, the University of Otago and the National Museum of Australia.

13.5.3 Understanding the relationship between heritage and reconciliation

The third project (*Heritage and Reconciliation*) explores the interconnection between heritage and reconciliation. It aims to rethink heritage from the perspective of peacebuilding. Repatriation is one of 2 major case studies in this project. The project is organised into different programs of work (as described below) and is still being completed.

The first program develops a theoretical understanding of heritage from the standpoint of reconciliation. A central (and new) concept being proposed in this project is 'Reconciliation Heritage', which is being trialled as a heuristic tool to enable critical analysis of heritage in which reconciliation is foregrounded. The program involves critical analysis of the proposed concept, which is broken down into 4 categories. The first category is heritage which has been the product of reconciliation. The second is heritage created by the reconciliation process. The third is heritage associated with reconciliation narratives and values and rituals associated with conflict resolution. The fourth is the heritage associated with the representation of Indigenous people. Data relating to

these 4 categories is being collected and compared against the findings of existing scholarship that has understood the building blocks of reconciliation in a similar way. The program also identifies local heritage-making initiatives and explores their interconnection with peacebuilding approaches, with a particular focus on the work of Ngarrindjeri people in their efforts to be built just and peaceful relations with the nation-state.

The project's second program focusses on whether and how World Heritage sites in settler-colonial states may become ambassadors for reconciliation. This involves analysis of visitor experience at World Heritage sites and interviews with staff, as well as analysis of related interpretations in local displays, websites and other forms of media to identify potential themes and values relating to reconciliation. In conjunction with this analysis, the program will involve staff and traditional owners from World Heritage sites in workshops that focus on if and how World Heritage communities can foster awareness of reconciliation. These workshops will involve discussion and questionnaires with broader staff cohorts as well as the co-creation of a low-cost exhibition that can travel to World Heritage sites.

The project's third program focusses on repatriation, and particularly the role of the concept of dignity in successful repatriation practices. It builds upon Prof Fforde's preliminary research into the relationship between dignity and repatriation and draws upon ideas of dignity from Western, Māori and Aboriginal philosophies. It utilises extensive interview data on repatriation and applied literature on the role of dignity in conflict resolution and repatriation processes. In addition, an audit of the repatriation policies in Australia and New Zealand has been conducted to explore the values associated with such instruments through the authorisation process and examine the ways in which these values can initiate constructive dialogue.

The academic partners involved in this project are The Australian National University, Flinders University, the University of Melbourne, the University of Newcastle Upon Tyne and the University of Otago.

13.5.4 Analysing the commercial trade in Indigenous human remains

The fourth project (*Profit and Loss*) is organised into different programs of work that run concurrently. Program 1 primarily focusses on the 19th century trade in Indigenous ancestral remains and how the market operated. This program explores the sale and exchange of ancestral remains in Europe, Australia, New Zealand and the USA, employing a combination of historical research methods, data analytics, museum archives, newspaper reports, ledgers from relevant collectors and businesses, as well as archives of dealers and auction houses. These resources are being compiled to allow for analysis of the history of the trade, its pricing and valuation mechanisms and the influence of different market forces, providing a greater understanding of the economics at play.

Program 1 also involves detailed investigations into the issue of legality, the creation of illicit trade and its impact on commerce, applying insights from empirical scholarship on the concept of 'moral economy'. In addition, this program investigates the commodification of Māori remains, known as 'Toi moko'. This involves consultation with leading Māori knowledge holders and philosophers to support the creation of biographical histories of Toi moko and a greater understanding of the deeper meanings surrounding their post-mortem genealogies. This program is also concerned with the global trade of replica remains and cast skulls and the ways in which they impact the broader market.

Program 2 primarily focusses on mapping and analysing the range of exchange mechanisms and networks through which Indigenous human remains and their replicas were dispersed worldwide. This process involves extensive consultation with museum archives in 'source' countries to uncover the details of exchange, thereby informing the identification of institutions of future research.

Program 3 investigates the nature and extent of the modern trade in Indigenous remains from 1950 to the present. This research element involves extensive analysis of web-based commerce to uncover the interests, motivations and emotions that influence the collectors involved with Indigenous human remains today. This program incorporates social science research and data-mining techniques to analyse information from various sources, including newspaper reports, sales catalogues, online salerooms and auction platforms, and relevant social media groups. The program will also involve interviews with both collectors and those pushing to end the trade, providing significant insight into its nature and extent.

Partner organisations on the project are The Australian National University, The University of Tasmania, The University of Melbourne, Queensland University of Technology, the University of Virginia and the National Museum of Australia.

13.6 Outputs

13.6.1 Publications

The research supported by these 4 ARC grants has resulted in a significant number of publications, which include:

- 3 books, titled Science, Museums and Collecting the Indigenous Dead in Colonial Australia (2017), The Routledge Companion to Indigenous Repatriation (2020), and A Repatriation Handbook: A guide to the repatriation of Australian Aboriginal and Torres Strait Islander Ancestral Remains. National Museum of Australia (2020). There were 55 book chapters published between 2015 and 2022 by the RRR team, as well as an additional 15 book chapters published by invited authors 2 further books resulting from the collaboration are to be submitted for publication in 2023, a book from each Discovery Project are contracted for delivery by the end of 2024, as well as a multi-authored publication on Dignity and Repatriation.
- A significant recent development has been the acceptance by Routledge of the first ever book series focused on repatriation matters, titled *Routledge Studies in the Repatriation and Restitution of Human Remains and Cultural Objects*
- Over 50 unpublished reports, toolkits and guidance materials available through the RRR Digital Archive including summaries of holdings in 40 countries, and 6 reports for RRR community organisations 12 non-traditional research outputs (NTROs), including several consultancy reports for the Australian Institute for Aboriginal and Torres Strait Islander Studies (AIATSIS)
- 3 media articles about the establishment of a new digital resource for repatriation
- 63 conference papers and presentations

13.6.2 Major research infrastructure, models and tools

One of the most significant outputs from this research program is the RRR website and Digital Archive. This Archive is a web-accessible centralised digital database of repatriation knowledge compiled through the Linkage and LIEF-funded grant (*Restoring Dignity* project). It provides a system of information that can be shared sensitively and appropriately. It is underpinned by an Indigenous data governance framework that specifies the guiding principles and philosophies that provide the rationale for the way that data in the RRR Archive are accessed, used, stored and maintained.

The Archive has 3 tiers of information. Tier 1 is public-facing and is intended to raise awareness of the meaning and value of repatriation. Tier 2 provides restricted physical access to authorised users at the Australian Institute for Aboriginal and Torres Strait Islander Studies (AIATSIS).

Functionality to provide remote access to this tier of RRR is currently under development. Tier 3 provides the 3 community partners who have been fundamental to the development of RRR with access to private information relating to their communities. Expansion of Tier 3 to other community organisations nationally and internationally is under development. The public face of the website is www.returnreconcilerenew.info.

13.6.3 Professional and practitioner training

Developing a practitioner-oriented course at The Australian National University (ANU) is another significant research output. Entitled 'Introduction to Repatriation: Principles, Policy and Practice', the course is delivered as a 5-day intensive course to a mixed cohort of masters, professional development, and micro-credential participants. This course has been delivered 6 times.

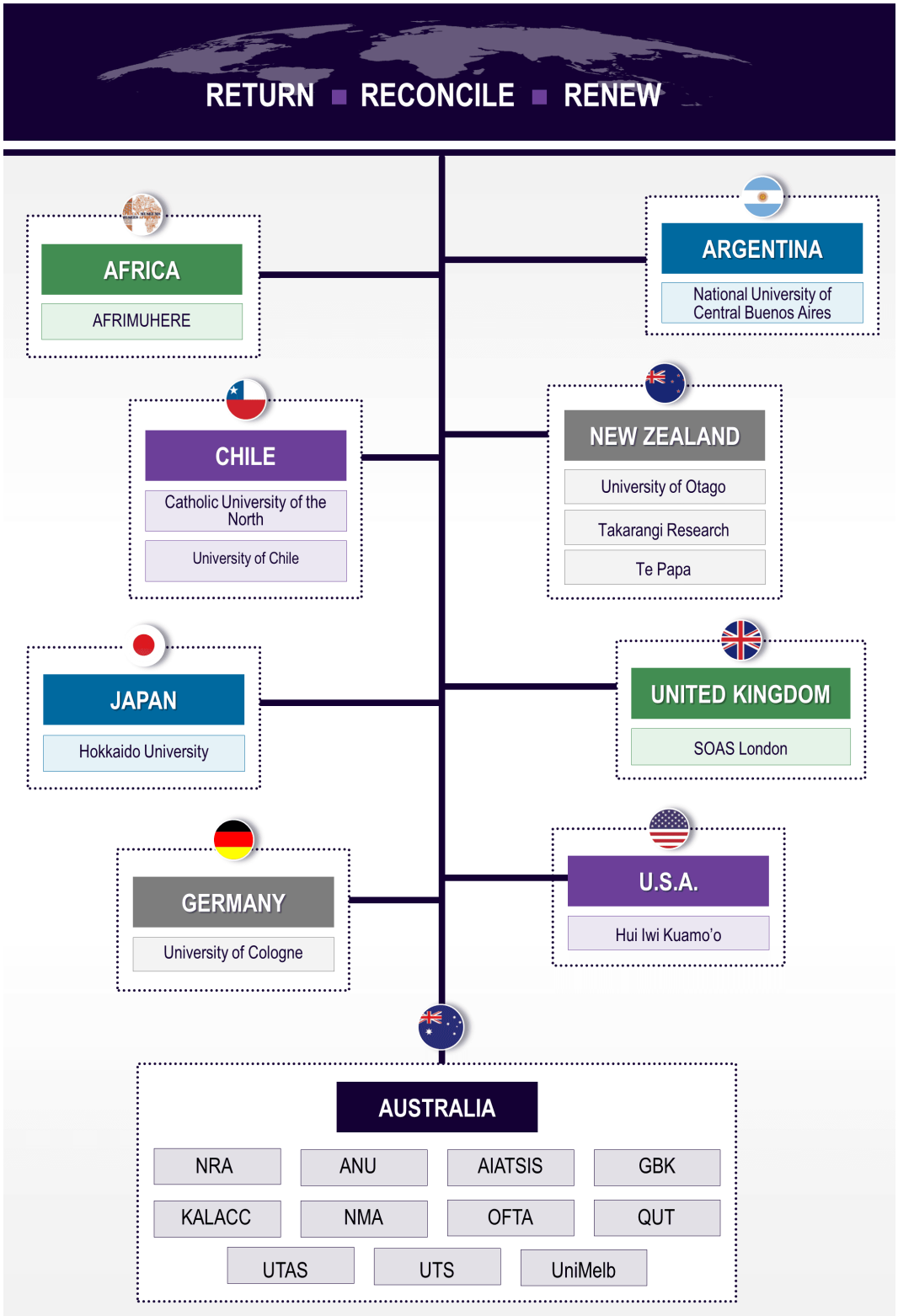
It conceptualises the issues regarding repatriation and explores the interconnections with Indigenous law, ethics, Country and community development. In addition, the course considers the relationship between the reburial debate and museum practice and provides an interpretation of relevant institutional, agency and government policy regimes.

The course was co-created by RRR collaboration and is team-taught by its members. Participants learn from a wide range of Indigenous and non-Indigenous expertise across the various sectors engaged in repatriation. As evidence of growth, is developing 3 further repatriation related masters courses for delivery in 2023 and 2024, each of which will also be available to a mixed cohort. In February 2023, Fforde has applied for these 4 courses to be available through the ANU as a Graduate Certification in Repatriation and Restitution, the first of its kind globally.

13.6.4 Collaborations and partnerships

ARC funding has enabled partnerships and fostered collaboration between a wide range of repatriation scholars, practitioners and communities both in Australia and globally. Since the original Linkage project in 2013, repatriation activity has grown and partnerships in the sector have strengthened. Figure 13.3 is a visual representation of the core RRR network, which is comprised of more than 30 researchers and collaborators across 22 universities and organisations. This network spans more than 10 countries around the world. Again, it shows the global reach of a network that has been supported by ARC-funded research. ARC funding has enabled the establishment of this network, which has culminated in the 2022 setup of *Return Reconcile Renew: an International Centre for Repatriation Training, Practice and Research,* with the Co-ordinating hub at ANU, directed by Fforde. The new Centre has a 5 year plan for growth.

Figure 13.3 Core network of professionals, practitioners and communities connected to RRR



Source: ANU

13.7 Outcomes

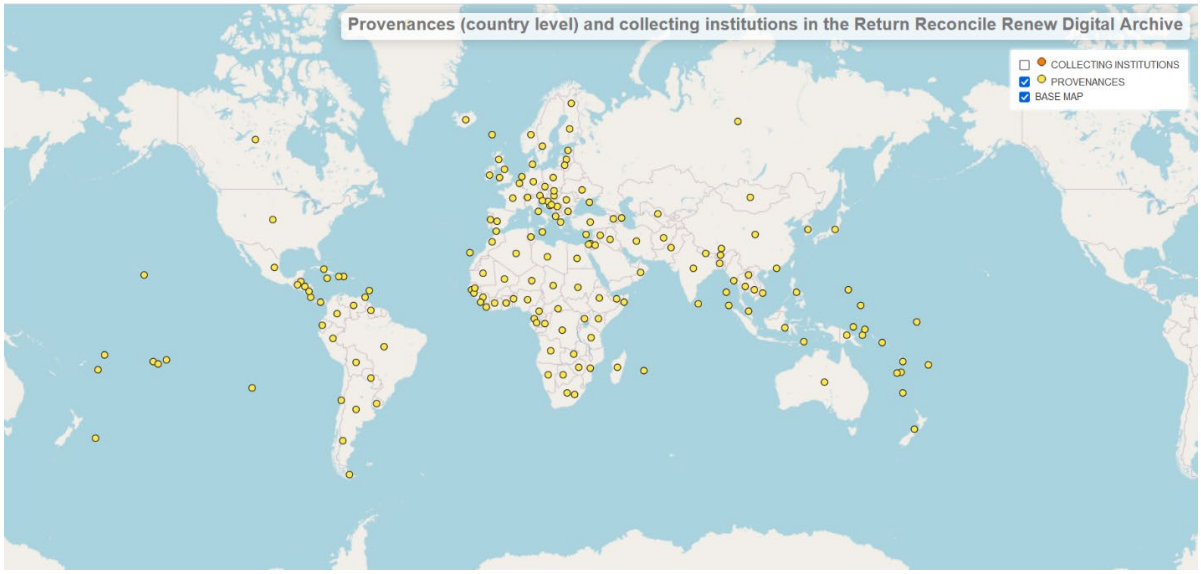
13.7.1 Adoption

The outputs of this research have been adopted by repatriation practitioners and institutions in Australia and elsewhere. They have also assisted communities seeking repatriation outcomes to engage with an international network. Consultations with some participants and collaborators identify the significant benefits it has had on the practice of repatriation.

In particular, the handbooks and guidance materials generated by participants in the research have informed how significant cultural institutions (namely, the National Museum of Australia) have approached repatriation.[294] This guidance has been adopted by institutions overseas and provides a common approach to repatriation that supports effective cross-national discussions between institutions, governments and communities.

The RRR Digital Archive and website currently contains 4454 archival resources and published resources, 417 digital objects, 3964 entries for entities, and 2,333 separate pages for each ancestral remain associated with First Nations represented by 3 Community Partner Organisations. The Archive holds information on over 275 collections and holding institutions and societies across 24 countries, which together are known to have held human remains from at least 11,559 provenances in 165 countries which demonstrates its global relevance (see Figure 13.4), and this number is growing. The Archive contains information relating to 172 repatriation-related policies (including museum collection and repatriation policies, as well as national and international guidelines and codes), 53 pieces of legislation and 191 entries related to repatriation events. The Archive contains 280 entries about people involved in the removal or return of ancestral remains. The Archive also contains information from over 70 interviews. The 3 Community Partner Organisations represent 61 Indigenous Nations.

Figure 13.4 Provenances and collecting institutions in the Return Reconcile Renew Digital Archive



Source: RRR Digital Archive

[294] See for example, Pickering, M. (2020), 'A Repatriation Handbook: A Guide to Repatriating Australian Aboriginal and Torres Strait Islander Ancestral Remains' National Museum Australia, June. Accessed February 2023: https://www.nma.gov.au/about/publications/repatriation-handbook.

13.7.2 Alignment with government strategic priorities

All 4 of Prof Fforde's ARC grants relate to Priority 9 of the National Science and Research Priorities: Practical Research Challenge and its associated challenge, 'better health outcomes for Indigenous people'. A growing body of research and Indigenous testimony to a strong relationship between repatriation, healing and reconciliation. This research also aligns with the Australian Government Office of the Arts' statement that "The Australian Government supports the repatriation of Aboriginal and Torres Strait Islander ancestral remains (ancestors) and secret sacred objects (objects) which contributes to healing and reconciliation."[295]

13.7.3 Counterfactual

Without ARC funding and support from research partners, the scale and scope of this research program would have been vastly reduced. The *Return Reconcile Renew* network and now Centre would not have been established, and the Digital Archive would not exist. Without this funding, it is unlikely the ANU course on repatriation would have been established, at least not in the same impactful format, nor the current expansion to 4 repatriation related courses that are intended to form the new (and world first) Graduate Certificate in Repatriation and Restitution. The ARC funding enabled significant financial distribution to the 3 community partner organisations to facilitate their integral involvement in the initiative and all its outputs. The original thought, research, provenance research and partnerships would have been significantly restricted if ARC funding had not been received. The ARC funding has produced ground-breaking and internationally recognised outputs, most of which would not have been achieved without the ARC grants.

13.7.4 Attribution

All stakeholders consulted for this case study place a high level of attribution on the ARC's funding to the impacts outlined below. They believe that the funding was critical to developing the Archive (i.e., research infrastructure) that drives many of the impacts identified during consultations.

The funding was also critical in providing the foundation and momentum for an international community of research and practice to emerge. This network undertakes vital applied research necessary for successful outcomes, supports resolution of repatriation cases, and provides an international network of support for communities navigating repatriation challenges overcoming the trauma of the theft and scientific misuse of their ancestors' remains. The breadth and global reach of this network (in terms of countries, researcher partners, community organisations and practitioners involved) are illustrated in Figure 13.3.

Moreover, consultations with key stakeholders in Australia and overseas conducted for this case study identify that without funding to develop the RRR Archive and website, repatriation would have remained a highly fragmented eco-system that was difficult to navigate, costly, time-consuming, and did not support the needs of communities. These stakeholders firmly believe that many repatriation outcomes achieved in recent years would not have been possible without the investments in RRR and its associated capabilities and communities of practice.

[295] Australian Government, Department of Infrastructure, Transport, Regional Development, Communication and the Arts. *Indigenous Repatriation*. Accessed February 2023: https://www.arts.gov.au/what-we-do/cultural-heritage/indigenous-repatriation.

13.8 Impacts

13.8.1 Economic impacts

Ancestral remains cannot be reburied or returned to Country without accurate provenance information. Repatriation research methods refined (and now taught) by Fforde and the RRR team produce provenance information vital for informed decision making, and result in historical information about collecting and the post-mortem history of ancestral remains taken from Country that are constantly requested by community members.

If remains are poorly or incorrectly provenanced, institutions, governments and communities can make incorrect decisions about repatriation and reburial. This includes failing to identify that an individual's body parts sent to an institution have been lost or transferred elsewhere. Thus resulting in only the partial return of an ancestors remains, or multiple returns after more remains are sequentially discovered in an institution. Such a lack of informed decision- making generates costs that are then borne by communities, institutions and governments seeking repatriation outcomes.

Over the past 4 decades, provenance research has also revealed a history of colonial theft largely unknown in the Western canon, demonstrating how Indigenous efforts to secure the return of ancestral remains have also resulted in a greater understanding of colonial era practices and their impact. Without the truth-telling that accompanies the revealing of these type of silenced histories, and the way in which Indigenous people have laboured to address the wrongs of the past, reconciliation is hampered, which also has significant costs. The RRR Digital Archive bears witness to this history and is a significant public knowledge dissemination platform for truth-telling.

Through Tier 3 of the RRR Digital Archive, 3 Indigenous partner organisations now each have access at no financial cost to a curated secure and private Digital Archive of critical information about their ancestors remains that is governed by them to support their repatriation work. This would have been impossible to achieve to this standard without ARC and partner funding, and now continues to be maintained without cost to communities through contractual agreement between ANU, AIATSIS, KALACC, NRA, and GBK. RRR is working to expand this Tier 3 option for other Indigenous organisations in Australian and internationally.

While it is difficult to quantify the economic impacts associated with undertaking provenance research, stakeholders have identified a range of financial benefits and cost savings that can be attributed to the presence of the RRR Digital Archive and website. These benefits relate to the operational and program costs associated with essential repatriation research and data management, managing repatriation programs and participating in repatriation events. These benefits include:

- Reduced staffing costs within cultural institutions and Indigenous organisations associated with archival work for repatriation purposes.
- Reduced staffing and research costs as repatriation practitioners do not have to 'reinvent the wheel' or follow research paths already worked through by others.
- Reduction in costs associated with IT environment and Archive curation of data essential for repatriation practice.
- Reduced travel time and expenses for repatriation practitioners and community stakeholders. That is, the need for a practitioner or a community member to travel for a case to determine the provenance of a remain or cultural artifact may be reduced if there are significant digital records to substantiate a claim of provenance. In particular, stakeholder consultation has highlighted how the Archive reduces the time and resources required to provenance ancestral remains located overseas. Consultations have highlighted there is limited funding to support travel and accommodation costs associated with domestic or overseas repatriation research, so access to the Digital Archive and website is critical for some communities and practitioners.

— Reduction in costs associated with community and/or intergovernmental negotiations relating to the provenance of a claim or claims. This will be reflected in a reduction in the staffing and travel costs in Australia and overseas associated with a repatriation case.
— Reductions in the costs associated with providing interim resting places while remains are being provenanced by practitioners or communities.

13.8.2 Social impacts

The social and community benefits in Australia and overseas are the ultimate impacts generated by this ARC-funded research. These benefits can be summarised as a significant reduction in the pain, suffering and trauma experienced by communities seeking to resolve repatriation cases, and the impacts of the research and RRR on creating positive collaborative partnerships that continue to expand.

Reduced pain, suffering and trauma

Stakeholders consulted for this case study have identified significant trauma, pain and suffering individuals and communities involved with repatriation cases experience. They identify the deep sorrow and significant emotional toll placed on individuals involved with repatriation, which can be decades long in some circumstances.

For example, ACIL Allen consulted with one stakeholder from North America who discussed cases that had been unresolved for nearly 30 years. However, with access to the Archive, stakeholders report the ability to progress a repatriation event that has been open for decades in a matter of months or years.

Other stakeholders consulted also discussed "years of pain and suffering avoided" by communities who have benefited from the Archive's presence and the ongoing research program. Again, while this pain is real, it is not quantifiable due to the unique nature of each repatriation and the considerable variance in the time taken to deliver human remains and cultural objects to their final resting places.

Professional development, practitioner and network impacts

The Digital Archive developed by the RRR team serves as a resource for future scholarly work and training. Prof Fforde's ARC research grants have supported 4 PhD students.

The course delivered through ANU, 'Introduction to Repatriation: Principles, Policy and Practice' as masters and professional development, is committed to providing participants with a learning experience that benefits from extensive Indigenous expertise within the RRR network. The course was launched in 2015 and was first hosted by RRR partner organisation, the Ngarrindjeri Regional Authority on Ngarrindjeri Country. The second, in 2018, was hosted by the Kimberley Aboriginal Law and Culture Centre on Yawuru Country (Broome) and Bunuba Country (Fitzroy Crossing). The third, in 2019, returned to Ngarrindjeri Country and was again hosted by the Ngarrindjeri Regional Authority. The last 3 courses have been delivered online. While delivering the course online does not allow for teaching by community partner organisation personnel on their traditional Country, the format significantly increases global reach in teaching and participation. In 2022, a cohort of South American Indigenous participants took the course, with RRR employing a translator to make the course accessible to them.

The course was co-created by the RRR collaboration and is team-taught by its members. Participants learn from a wide range of Indigenous and non-Indigenous expertise across the various sectors engaged in repatriation. 3 additional repatriation courses will be offered in 2023 and 2024, with the total 4 courses being developed to become a graduate certificate in repatriation for delivery in 2023, which will be the first of its kind globally.

Student experiences in the course are highlighted in the testimonials below.

Box 13.1 Student testimonials

"Participation in the Return, Reconcile, Renew 'Introduction to Repatriation' course was a key steppingstone in my career as cultural heritage professional. Having previously studied and worked in the 'aftermath' of repatriation activities, this course provided me with a myriad of practical tools, networks, and case studies that enabled me to more confidently begin work initiating provenance and repatriation projects, building meaningful relationships with recipient communities, proactively caring for material, and engaging in productive conversations with resistant parties."

Madalyn Grant, Repatriation Manager at The University of Queensland

"This course was very intensive and a thorough introduction to the issues surrounding the repatriation of skeletal remains and sacred objects. I was working on a repatriation project at the time and the course introduced me to the concepts of community reports and provenancing. Through this, and the support offered by the RRR team, I was able to get a much better outcome for the family involved and afford them a greater sense of closure. This course gave me confidence around ethical procedures when repatriating skeletal remains and in pursuing repatriation work in the future. I have since assisted in a second repatriation project involving cultural materials and look forward to more work in the repatriation field in the future."

Anonymous, Australian Professional

"Repatriation can be very lonely work, full of uncertainties, soaring highs and deflating lows. Currently, there are no other training courses for repatriation in the world and the Return, Reconcile, Renew course provided me with a unique opportunity to connect with colleagues and swap notes. Hearing from repatriation practitioners from all over the world enabled you to place your work within a global context and I found great value in knowing that others are having a shared experience.

The focus given to developing robust provenance research skills was particularly useful as this isn't taught anywhere else, it is something you need to learn on the job. I left feeling much more confident in my approach, the course validating and confirming my own thinking. It armed me with the right vocabulary and examples to advocate for repatriation in a more articulate way, commanding the space with more confidence.

This course is essential for anyone working in repatriation, and I will be recommending that members of the NZ Repatriation Research Network take this course as part of their own professional and personal development."

Jamie Metzger, Repatriation Project Lead at the Museum of New Zealand Te Papa Tongarewa

Source: Various

Since the course was launched in 2015, 32 students have enrolled as Masters students, and 108 students have enrolled in the professional development course. Of the 108 participants enrolled in the professional development course, c.65 were Indigenous (national and international). Details of enrolments are displayed in Table 13.2 below.

Table 13.2 Enrolment details for 'Introduction to Repatriation: Principles, Policy and Practice'

Year	Combined	Masters students	PD total	Indigenous (national & international) within PD cohort	Countries
2015 (hosted by NRA)	16	1	c.15	c.15	
2018 (hosted by KALACC)	15	5	c.10	c.7	Australia, Japan
2019 (hosted by NRA)	30	6	24	14	Australia, Japan, China
2020 (online)	22	6	16	10	Australia, Canada, Chile, Japan, China
2021 (online)	25	6	19	6	Australia, Nigeria, India, USA, New Zealand, UK, China, Taiwan
2022 (online)	32	8	24	13	Argentina, Australia, Canada, Switzerland, Chile, Ireland, New Zealand, Germany, USA, Uruguay, Saudi Arabia
Total	**c.140**	**32**	**c.108**	**65**	**17 countries**

Source: Prof Cressida Fforde

13.8.3 Other impacts

Advice

The RRR team regularly provides advice to institutions, community organisations, and governments which includes information that has resulted from the work of the collective over the past 10 years. Examples include: the Indigenous Repatriation unit within Commonwealth Government's Office of the Arts (OFTA) has consulted with RRR in relation to at least 6 institutions from who international repatriations have occurred or are part of ongoing discussions. The RRR Archive was used to produce information within a 24-hr turnaround that assisted the repatriation of a Native Hawaiian ancestor. Details of relevant resources within the RRR Archive has been provided to Indigenous organisations in Australia, South America and Africa. Austrian and German museums have benefitted from advice provided by RRR members, including into the review of German repatriation guidelines. Members of the RRR team are also founding members of a German repatriation provenancing network.

Halting the online sale of remains

In May 2020, RRR Partner Investigator C. Timothy McKeown learned that a skull from the Torres Straits was being advertised for sale on eBay by a British Columbia, Canada seller. The skull was advertised as a Melanesian Torres Straits Islander Chief's Ritual Skull from the 19th Century, with an asking price of US$17,500. McKeown contacted Catherine Bell, a law professor at the University of Calgary, to determine whether the sale violated Canadian law. Bell submitted a report to the Royal Canadian Mounted Police (RCMP), alleging that the sale violated several Canadian laws, including s.182(b) of the Canadian criminal code – improper or indecent interference or indignity to human remains – as well as Memorandum D19-9-3 importation and shipment of human body parts and organs. Bell provided the RCMP with an explanation of why the sale violated Canadian law and also provided a biography and contact information for Ned David, chairperson of the Gur a Baradharaw Kod Torres Strait Sea and Land Council. Ned David sent the RCMP a

statement on the gross indignity associated with the sale of the remains of one of his ancestors, who made the statement below.

> *"The indignity is twofold: the first is the desecration of the ancestors themselves. These individuals were highly respected in life. To have their remains treated in this way – as just a thing to be bought and sold – is just appalling. The second is the violation of dignity experienced by Torres Strait Islander people and our culture when our ancestors are treated in this way. It is demeaning in the extreme to have one's ancestors treated as commodities for financial gain." – Ned David, chairperson of the Gur a Baradharaw Kod Torres Strait Sea and Land Council*

The RCMP forwarded the matter to the Crown Prosecutor, and the seller removed the listing when questioned.

This case highlights the impact and reach of the global RRR network.

Impact on the Ngarrindjeri people

Information collected for this case study suggests that the RRR Archive has been particularly impactful for Ngarrindjeri people. Ngarrindjeri care for their repatriated ancestors in their Keeping Place before reburial. Before the RRR Archive, no centralised resource was available to tell them about their ancestors in the Keeping Place or in domestic and international museums. Such a lack of information seriously impacted Ngarrindjeri ability to make informed decisions about caring for their ancestors and planning for their final interment. Other than the funding distributed to the NRA through the RRR project, there has been no significant funding to support repatriation for the Ngarrindjeri. Through collaboration and audit of the Keeping Place, information on each ancestor has been collected and placed in the NRA's private section of the Archive, called the 'NRA Community Partner Extension'.

The Ngarrindjeri now have access to a secure Digital Archive that contains a breadth of information about their ancestors, including reports, images, publications, interviews, film, media, contracts and other forms of information. This information can be searched, sorted and filtered in ways useful for Ngarrindjeri repatriation work and reburial planning. The private area of the Archive also holds information about processes undertaken in past reburials, including photos of past reburials, previous planning documents, and records of conversations with state authorities and museums. This information can serve as a guide for the NRA in repatriating their ancestors.

The NRA Community Partner Extension contains information about at least 1,656 Ngarrindjeri Old People. Ngarrindjeri cares for at least 381 in their Keeping Place, and the rest are housed in domestic and international institutions. These Old People have been repatriated from 4 domestic and 4 international institutions, with some additional Old People handed in by the public.

Impact on the Kimberley Aboriginal Law and Culture Centre (KALACC)

KALACC have a Keeping Place to care for repatriated Old People awaiting final interment, much like the Ngarrindjeri. Unlike the NRA who represent one Indigenous nation (Ngarrindjeri), KALACC represents 30 different language groups and is responsible for supporting the cultural practices and repatriation of each. Despite these significant responsibilities, KALACC had only one repatriation officer. This officer retired in 2022 and there has been no funding to support a replacement position. As with NRA and GBK, KALACC was a community partner on the 2013 Linkage grant and the 2017 LIEF. Funding, supported by the ARC, has enabled on the ground community consultations and repatriation work through engagement with RRR projects and information complied through RRR collaboration.

Prior to collaboration with RRR, KALACC had only limited and paper-based information about the ancestral remains in its care. There was also very limited information related to ancestors from the Kimberley that were to Australian institutions or internationally. In recognition of this, an audit of the KALACC Keeping Place was undertaken by the RRR team to compile and effectively Archive all available information about each ancestor, which was then augmented by RRR provenance research.

RRR has gathered a significant amount of information additional to that already held by KALACC for the majority of over 70 ancestral remains housed in its Keeping Place prior to the start of the RRR collaboration and located information for an additional 114 ancestors from the Kimberley that are known to have been sent to domestic or overseas institutions. This includes 6 detailed reports for ancestral remains repatriated from 4 domestic and 2 international institutions and one detailed report about ancestral remains still present in an overseas institution. By aggregating the information in these reports, it is evident that for a total of 29 ancestors in the KALACC Keeping Place, detailed archival research from RRR has increased the information available to KALACC in 27 of these cases. Since collaboration between RRR and KALACC initiated in 2013, all community repatriation consultations have made use of information located or consolidated through the RRR initiative.

A notable example of the impact of the RRR and KALACC collaboration was in the repatriation of remains from Vienna, Austria. In this example, KALACC had received information relating to Bardi Jawi ancestors held in a museum in Vienna. However, it was not known which individual related to which piece of information. RRR research was critical in the identification of the correct connection. This information was provided in a detailed provenance report to KALACC and it was used as part of community consultations by the KALACC repatriation officer, leading to the reburial of the 2 individuals on Country in 2015 (Figure 13.5).

Figure 13.5 Bardi Jawi repatriation on-Country, One Arm Point, Western Australia (2015)

Source: Pickering, M (2020). A repatriation handbook: a guide to repatriating Australian Aboriginal and Torres Strait Islander Ancestral Remains

Impact on the Gur a Baradharaw Kod Torres Strait Sea and Land Council (GBK)

Alongside KALACC and the NRA, the Gur a Baradharaw Kod Torres Strait Sea and Land Council (GBK) is a founding community partner in the RRR initiative. The Digital Archive contains a dedicated GBK Community Partner Extension, with information organised with the same functionality, governance and security as the NRA and KALACC Partner Extensions. However, the GBK does not yet have a Keeping Place. Consultations across the Torres Strait decided that the initial focus should be on persuading museums to repatriate ancestral remains to Australia, whereby second round consultations would occur to organise the return to Country to the Torres Strait. The RRR initiative will support this process as it occurs. GBK has amassed information about Torres Strait ancestral remains in domestic museums and institutions, while RRR has brought the information together, synthesising and organising it in a manageable manner.

As of February 2023, there are 447 ancestral remains documented in the GBK Partner Extension of the RRR Archive. Of these remains, 129 are held in domestic institutions, 153 are held in overseas institutions and 165 are recorded as missing from collections or their whereabouts currently unknown. There are currently 2923 published resources and 458 archival resources in the GBK Partner Extension. There have been 47 ancestors that have been repatriated from overseas institutions. The information base contained in the GBK Partner Extension will continue to grow and assist in future GBK repatriation and provenance processes.

Ethical engagement and access to funding

Another impact of the research program has been how it has demonstrated ethical engagement with Indigenous people and communities. Indigenous communities have been intimately involved in this program of work and have been key decision-makers. This research has supported and empowered Indigenous communities to undertake provenance research, particularly in the Kimberley, Ngarrindjeri Country and the Torres Strait. Training and step-by-step guides on provenance research are available to support communities to provenance ancestral remains and objects, which can be complex. In addition, this research program has set the bar regarding Indigenous community engagement and participation in research relating to repatriation.

How this research program has empowered Indigenous communities to conduct provenance research has the potential to increase access to funding for the repatriation efforts of these organisations. Once provenance is established, these organisations will have a much stronger case to seek funding from government programs and agencies which support repatriation. These include the Department of Infrastructure, Transport, Regional Development, Communications and the Arts' *Indigenous Repatriation Program* and the AIATSIS-run *Return of Cultural Heritage* initiative. The *Indigenous Repatriation Program* facilitates the return of ancestral remains of Aboriginal and Torres Strait Islander origin, while the *Return of Cultural Heritage* initiative is focused solely on the return of cultural objects.

13.9 Potential future impacts

The *RRR* Archive is a living resource that will continue to grow and be used to support repatriation scholars and practitioners. The RRR team actively seeks funding from multiple sources to continue its content and functionality development and accessibility to repatriation communities globally (see Figure 13.3 and Figure 13.4 as an illustration of RRR's future potential global impacts). This resource has significantly reduced the time required to provenance and repatriate remains and will be of significant future impact in the field. Future impacts could be realised by expanding the contents of the Archive to include details of the ancestral remains of other Indigenous nations throughout Australia. Detailed work in the RRR Archive has largely focused on the Kimberley, the Ngarrindjeri and the Torres Strait, compiled in areas private to each of the associated community partner organisations, aiding the repatriation processes for these groups. This work has drawn

together a large amount of information and records relevant to other Indigenous nations. These records are housed in Tier 2 of the Archive (the Repatriation Extension) which makes them available through restricted access for genuine repatriation practitioners and researchers to do their own research. There are opportunities to expand the Archive, and RRR is actively seeking funding to increase the number of community partners in Australian and overseas because of its global relevance.

This program of work has also improved the ability of partner organisations to secure government funding for different projects. The reputation built from participation and history of engagement with research and deliverables has resulted in an AIATSIS Research Exchange grant with Ngarrindjeri (completed Feb 2023), the Jan 2023 submission of a grant by the Council for Native Hawaiian Advancement (partnering with RRR) to a major US funder, and a number of small and large scale consultancies undertaken by the RRR team for OFTA and AIATSIS. Dr Hilary Howes worked with the RRR team as an ECR and was then successful in achieving an ARC DECRA on holdings of Indigenous ancestral remains in collections of the old Russian empire (DE210101721) that she undertakes at ANU as part of the RRR team. RRR is one case study within an ARC Discovery Indigenous Fellowship (IN220100008) currently being undertaken by Dr Lyndon Ormond-Parker, also at ANU. This research program can potentially influence similar funding decisions in the future.

The RRR research program has been highly impactful for repatriation scholars, practitioners and Indigenous communities in Australia and abroad. However, once you build a national asset as valuable as the RRR Digital Archive, you cannot leave it stranded. This asset must receive ongoing support to exploit its benefits in the future.

National Resting Place

The RRR Archive may become an important underpinning digital infrastructure that supports a future 'National Resting Place'. A future National Resting Place is planned to be a facility within Canberra's Aboriginal and Torres Strait Islander cultural precinct called 'Ngurra'. This facility will house and provide long-term care for limited-provenance ancestors returned from overseas.[296] This program is being led by AIATSIS and will be established alongside a Culture and Knowledge Centre. The RRR Digital Archive will be a critical source of information for the National Resting Place database, and the contents of the Archive could be used extensively, particularly for limited provenance ancestors.

> *"The National Resting Place will be a central place for commemoration, reflection and healing. A place for ancestral remains to rest in honour and peace, where all Australians can celebrate Aboriginal and Torres Strait Islander cultures"*[297] *– The Hon Ken Wyatt MP, Minister for Indigenous Affairs (2019-2022)*

The RRR team has undertaken consultancies for AIATSIS that have informed its business case for a future National Resting Place. Consultations undertaken for this case study suggest that the expertise provided by the RRR team was important in shaping the rationale for future government investment in National Resting Place.

[296] Australian Government, Office of the Arts (2022). *National Resting Place*. Accessed February 2023: https://www.arts.gov.au/what-we-do/cultural-heritage/indigenous-repatriation/national-resting-place.

[297] The Hon Ken Wyatt MP (2019). *Reconciliation WA Speech*. Accessed February 2023: https://www.indigenous.gov.au/news-and-media/announcements/reconciliation-wa-speech-minister-wyatt.

ACIL ALLEN

Supporting information

III

Evaluation framing and terms of reference

A

A.1 Terms of reference

The terms of reference for this evaluation require ACIL Allen to assess:

- the outcomes of NCGP-funded research, including those relevant to the Government's broad strategic priorities
- the economic impact of NCGP-funded research
- the broader impacts of NCGP-funded research, including environmental, social and other impacts
- the effectiveness with which the ARC is supporting, monitoring and reporting on NCGP research impact.
- identify lessons and recommendations on how the impact of ARC-funded research could be better supported, monitored and communicated in the future.

A.2 Evaluation framing

The evaluation framing is provided in Table A.1. This presents the evaluation questions, areas of interest and potential data sources according to the evaluation focus areas of: *outcomes and impacts of ARC-funded research* and *improving the delivery of research impacts and ongoing impact assessment*.

Table A.1 Evaluation framing

Evaluation questions	Indicators
Outcomes and impacts of ARC-funded research	

1. What are the short-, medium- and long-term outcomes and impacts of ARC-funded research? Is the NCGP achieving its intended outcomes?	– Extent to which the research has contributed to (in the short-, medium- and long-term)
	  – the economy
	  – society
	  – the environment
	  – culture
	– Extent to which NCGP research is:
	  – applied to problems/opportunities
	  – licensed or under invention disclosures or patents
	  – used to form companies, spin-offs, start-ups or joint ventures
	  – extending existing findings
	– Extent to which the NCGP is contributing to:
	  – a higher quality workforce
	  – job creation
	  – increased research capacity

Evaluation questions	Indicators
	– knowledge expansion – development of new products – development of improved processes or services – trust in publicly funded research – perceptions of legitimacy of publicly funded research – satisfaction among the Australian public
2. Do the outcomes and impacts delivered by the NCGP align with the Government's strategic priorities?	– Extent to which the NCGP outcomes and impacts align with the Government's strategic priorities
3. What is the Government's return on investment for the NCGP?	– Extent to which the benefits of the NCGP outweigh the costs
4. What are the main factors supporting the delivery of research outcomes and impacts? How does the ARC contribute to these factors? What roles do non-ARC funding sources play in pathways to impact for ARC-funded research?	– Identification of factors supporting the delivery of research outcomes and impacts – Extent to which the ARC contributes to these factors – Nature of the contribution of non-ARC funding sources on the pathways to impact for ARC-funded research
5. How would the capacity of Australian research to support economic, environmental, social and other impacts be affected by the absence of the NCGP?	– Extent to which the capacity of Australian research to support economic, environmental, social and other impacts would be affected by the absence of the NCGP
6. How would the level and nature of the economic, environmental, social and other impacts delivered through Australian research be affected if the level of funding administered through the NCGP were to change?	– Extent to which the economic, environmental, social and other impacts would be affected by changes in NCGP funding levels
Improving the delivery of research impacts and ongoing impact assessment	
7. What, if any, lessons can be learnt to improve the NCGP's effectiveness in delivering outcomes and impacts from the research it funds?	– Identification of lessons to improve the NCGP's effectiveness in delivering outcomes and impacts from funded research
8. What improvements, if any, could be made to the data and/or data collection methodologies the ARC uses to assess the outcomes and impacts of NCGP-funded research? What data points/metrics could the ARC collect to better inform future impact assessment work?	– Identification of improvements to data and/or data collection methodologies to assess the outcomes and impacts of NCGP-funded research – Identification of data points/metrics that the ARC could collect to better inform future impact assessment work
9. What improvements, if any, could be made to the ways the ARC communicates the outcomes and impacts of NCGP-funded research?	– Identification of improvements to ARC communication of the outcomes and impacts of NCGP-funded research

Source: ACIL Allen, RFQ

Beneficiaries of NCGP-funded research

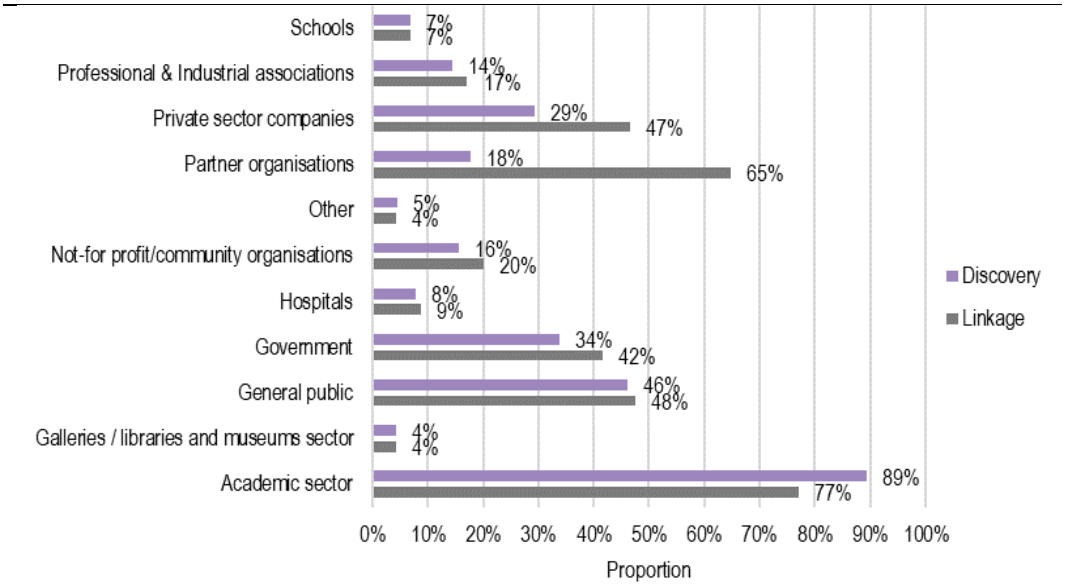
B

B.1 Who benefits?

Who benefits from ARC-funded research is a key consideration underpinning impact. Domestic stakeholders consulted for this considered that the research's end-users and beneficiaries included the government, research, industry, business and non-profit sectors. However, they could not meaningfully articulate the beneficiaries at an aggregate level due to the multitude of projects funded (approximately 29,000), the broad nature of the research conducted across the NCGP, and the diversity in research partners and end-users.

An analysis of final report data supports these stakeholder comments. Figure B.1 provides a breakdown of beneficiaries for Discovery and Linkage Programs. Discovery Program projects commonly reported delivering impacts to recipients in the academic sector, general public and government. Linkage Program projects reported delivering impacts to the academic sector, partner organisations, and private sector companies. Linkage Program projects report a higher proportion of beneficiaries in almost all beneficiary types, except for the academic sector. This also aligns with the survey data discussed in section 2.2, which shows the breadth of sectors that have or are likely to experience commercial outcomes from NCGP-funded research.

Figure B.1 Final report data on the type of beneficiary by Discovery and Linkage Programs

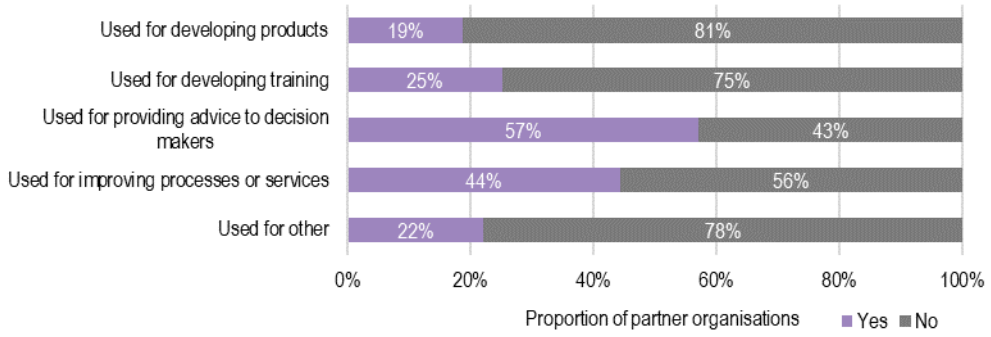


N=3,974 final reports. Note is available from 2014 onwards.

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

End-users benefit from the research in a range of ways (see Figure B.2), including using Linkage Program results to advise decision makers (57% of partner organisations) and improve processes/services (44%).

Figure B.2 Final report data on the proportion of partner organisations that used the results for developing products, training, providing advice, improving processes/services and other

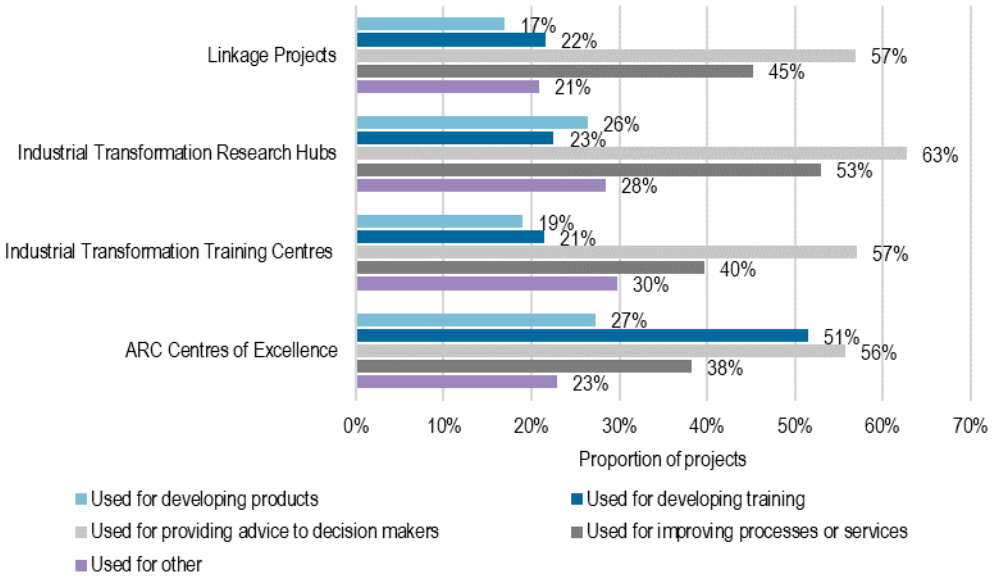


N=664 final reports. Data is only available for Linkage Program (ARC Centres of Excellence, Industrial Transformation Training Centres, Industrial Transformation Research Hubs, and Linkage Projects).

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

Figure B.3 details the usage of project results, by scheme. Note that data was only collected for 4 schemes. Linkage Projects were primarily used to develop advice for decision makers and improvements to processes and/or services, as were Industrial Transformation Research Hubs and Industrial Transformation Training Centres, while ARC Centres of Excellence projects were primarily used to develop advice and training.

Figure B.3 Final report data on the proportion of projects using the results for developing products, training, providing advice, improving processes/services and other by scheme



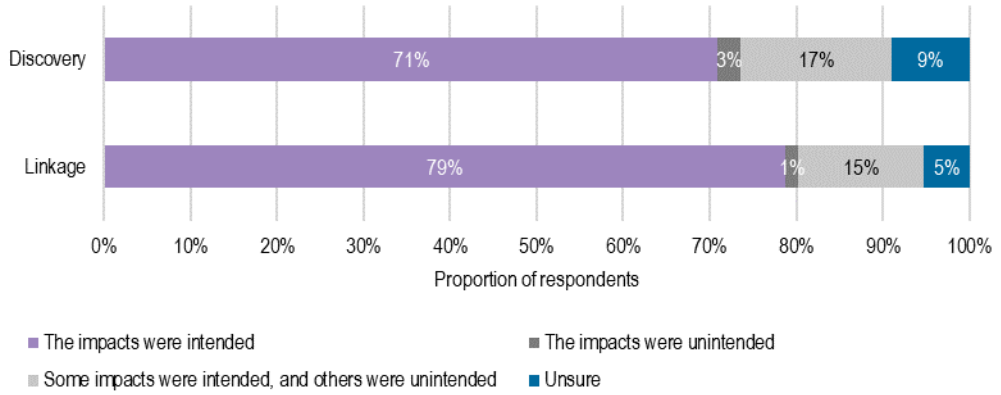
N=664 final reports

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

The case studies also highlight the breadth of beneficiaries and sectors benefiting from the research. 13 FoRs are represented across the 7 case studies, with several case studies having more than one FoR. End-users of the research include government, industry, community and not-for-profit organisations, the general public and the academic sector. The important point to note is that end-users are also often heavily involved in the conduct of research funded by the ARC. This is an excellent outcome for the research sector and the Australian community because it suggests that there is a strong relationship between the research and overall community need.

As shown in Figure B.4, most of both Discovery and Linkage Programs respondents (71% and 79%, respectively) considered that the impacts of their research were intended, while only 3% and 2% reported that the impacts were unintended. 17% and 15% reported it that was a combination of both unintended and intended impacts.

Figure B.4 Survey results on whether the research impact was intended

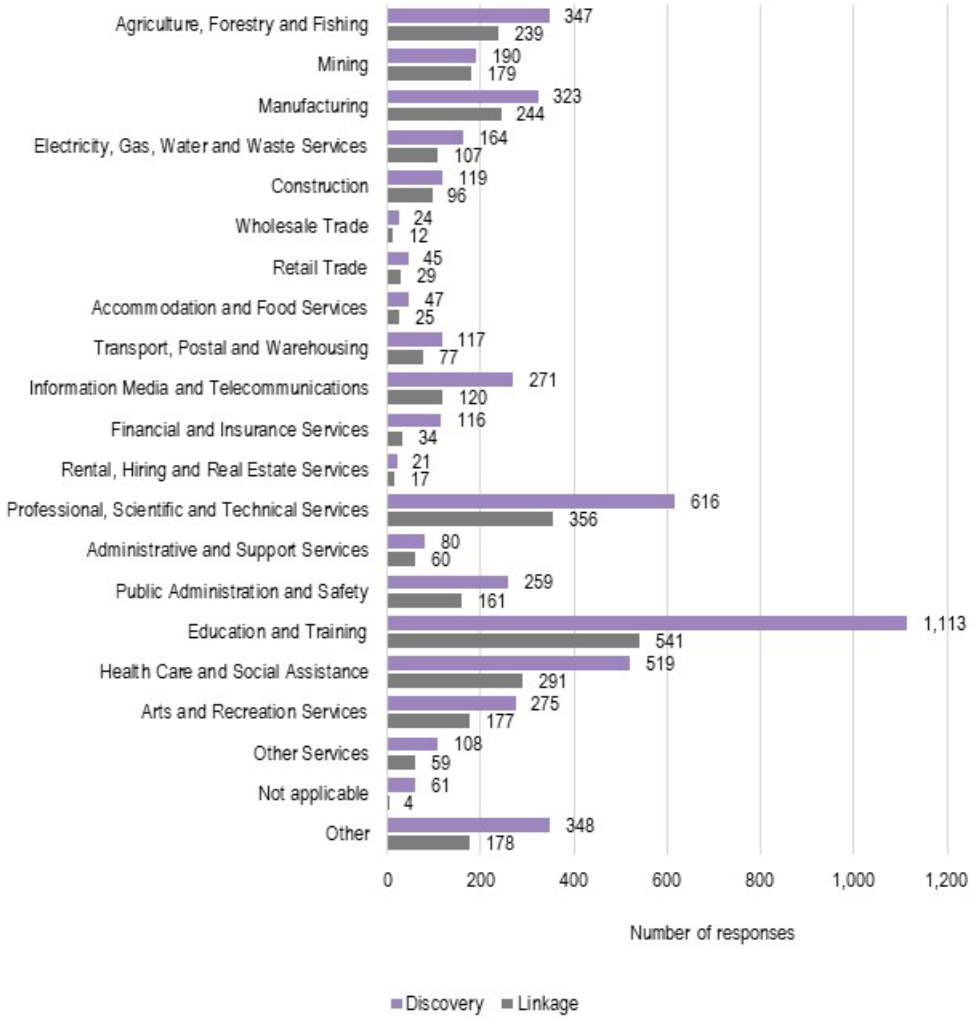


N=3,617

Source: ACIL Allen survey of ARC funding recipients

Outcomes are most likely to be experienced by the Education and Training sector for both Discovery (22% of respondents) and Linkage (18%) Program projects. This was followed by Professional, Scientific and Technical Services (12% for both Discovery and Linkage Program respondents, see Figure B.5).

Figure B.5 Survey results on sectors likely to have experienced/to experience outcomes



N=3,651

Source: ACIL Allen survey of ARC funding recipients

B.2 Examples of excellent research involving end-users

Insights from the case studies (see Part II) highlights the critical role of end-users in shaping research pathways and adopting research outputs and outcomes.

Aquifer Reinjection describes the Curtin University-Water Corporation collaboration. As discussed further in section 3.2, as an end-user, Water Corporation was closely involved in the research and trialling the technology, to ensure that the Scheme would be accepted by state government and community stakeholders. As a result, Water Corporation established the Groundwater Replenishment Scheme in 2016. Similarly, *Irrigation automation* describes the collaboration between University of Melbourne and Rubicon Water, where Rubicon Water incorporated the research into the Total Channel Control algorithm (part of their commercial irrigation automation).

Indigenous persistence in formal learning involved end-users such as Edith Cowan University in trials, to explore the effectiveness of the student support model developed through the research.

Onshore Lobster Aquaculture end-user Ornatas, was specifically created as a start-up company to commercialise and use the technology developed by the University of Tasmania (UTAS) to operate a lobster aquaculture facility. Similarly, *Quantum Computation and Communication Technology* shows that the CQC^{2}T led to multiple spin-off companies who are end-users of the technology.

Changing the law to protect survivors of DFV end-users Australian Institute of Judicial Administration (AIJA) and National Judicial Council (NJC) supported translation, by providing the opportunity, funding and support to develop a training resource and implement a training course.

Stakeholder survey additional information

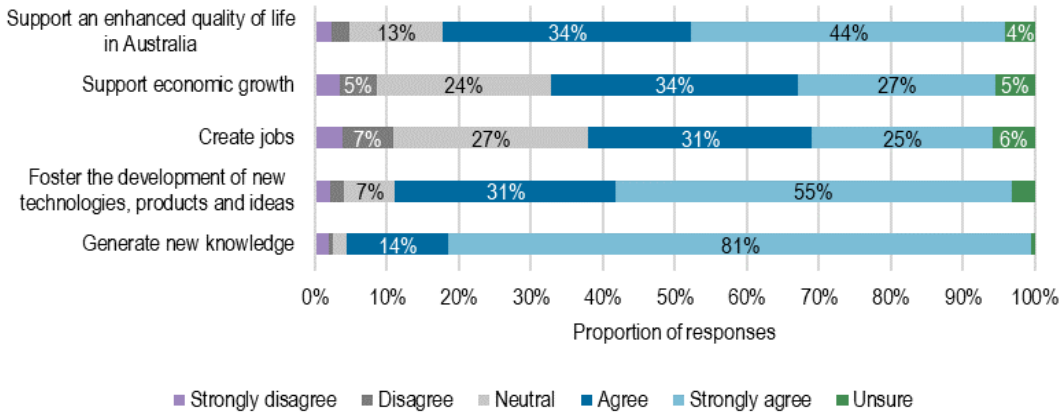
C

C.1 Additional survey analysis

C.1.1 Impact analysis

Survey data also highlights the broad purpose and contribution of NGCP-funded research in building Australia's research and innovation capacity. Most agreed that the NCGPs' primary role was to generate new knowledge (95% strongly agree/agree), foster new technologies, products and ideas (86%) and support an enhanced quality of life in Australia (78%) (see Figure C.1).

Figure C.1 Survey results on the role of NCGP in building Australia's research and innovation capacity

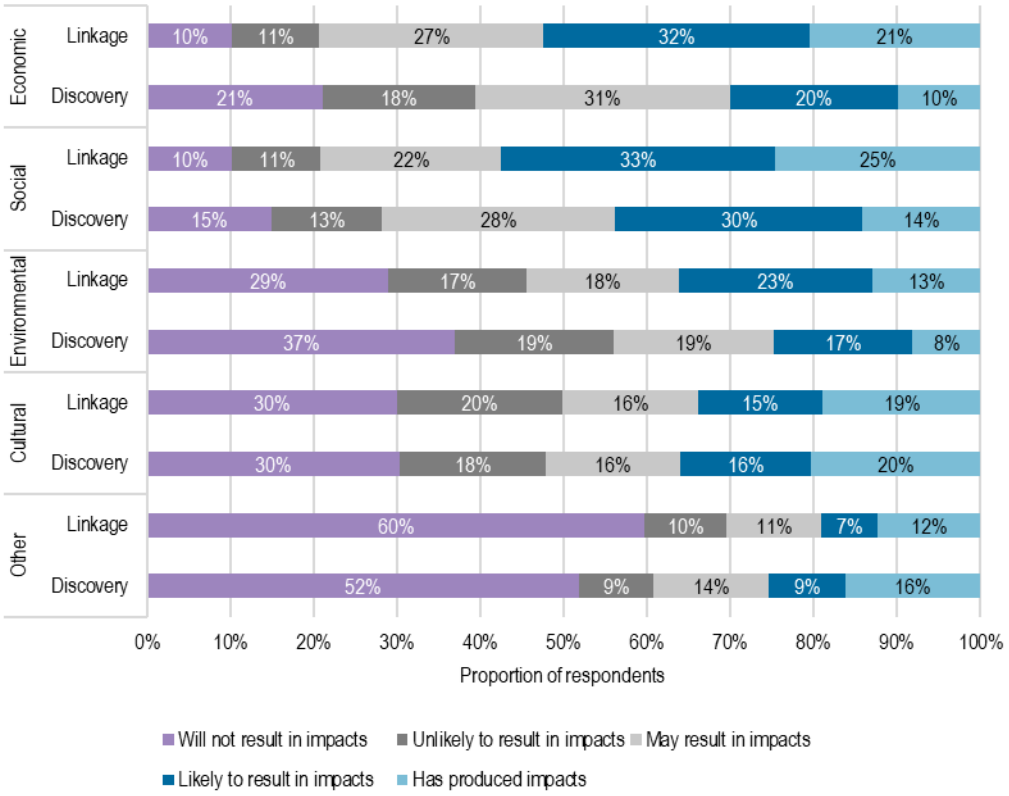


Note: respondents could select more than one answer for the following: Support an enhanced quality of life in Australia N=3,515, Support economic growth N=3,512, Create jobs N=3,508, Foster the development of new technologies, products and ideas N=3,517, Generate new knowledge N=3,524.

Source: ACIL Allen survey of ARC funding recipients

Figure C.2 reports survey respondents perspectives on the impacts that have been/are likely to be delivered by the projects across economic, social, environmental, cultural and other types of benefits.

Figure C.2 Survey results on the impacts that have been/are likely to be delivered by the projects



Economic: Discovery N=2,454, Linkage N=1,331. Social: Discovery N=2,454, Linkage N=1,331. Environmental: Discovery N=2,452, Linkage N=1,328. Cultural: Discovery N=2,454, Linkage N=1,327. Other: Discovery N=2,446, Linkage N=1,317.

Source: ACIL Allen survey of ARC funding recipients

Table C.1 shows respondents reports of the time lags taken to generate returns on the research investment.

Table C.1 Survey results on the time lags taken to generate returns on the research investment

	Discovery	Linkage	Assumed midpoint (years)
During the project	10%	15%	0
Within 1 year of project completion	6%	14%	1
2-5 years from project completion	35%	38%	3.5
5-10 years from project completion	34%	25%	7.5
Over 10 years from project completion	16%	8%	11
Weighted average	**5.6**	**4.2**	

Source: ACIL Allen survey of ARC funding recipients

Table C.2 shows the results of the analysis to the question on the most significant impacts resulting from research projects.

Table C.2 Qualitative analysis of survey results on the significant impacts - top bigrams and trigrams by project type

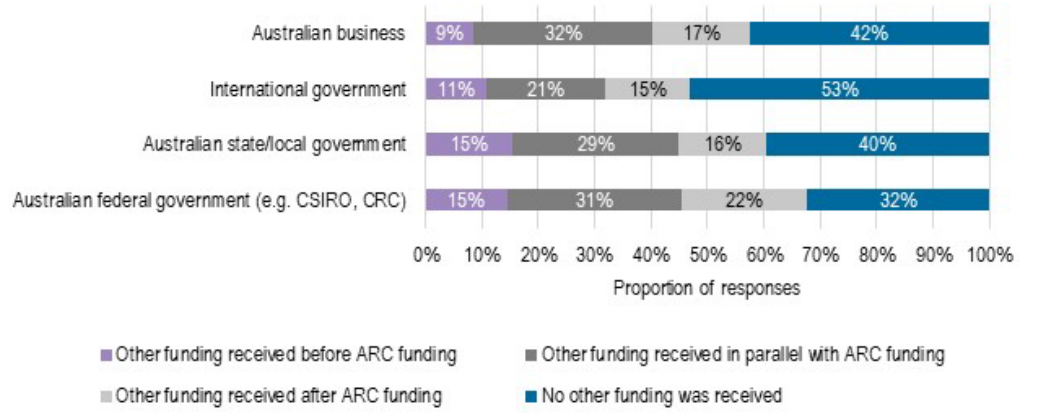
Rank	Discovery		Linkage	
	Bigram	Trigram	Bigram	Trigram
1	'better understanding'	'early career researchers'	'industry partners'	'early career researchers'
2	'climate change'	'saved production costs'	'difficult quantify'	'early childhood education'
3	'new knowledge'	'reduction carbon emissions'	'young people'	'reduction carbon emissions'
4	'phd students'	'great barrier reef'	'better understanding'	'first nations people'
5	'improved understanding'	'sea level rise'	'developed new'	'evidence based training'
6	'difficult quantify'	'people benefited implementation'	'long term'	'children benefitted improved'

Source: ACIL Allen survey of ARC funding recipients

C.1.2 ARC and non-ARC funding sources

When asked about non-ARC funding they received for their most impactful programs, respondents stated that the Australian Federal Government was the most commonly reported source of non-ARC funding that was received, with 68% of respondents reported receiving this funding before, in parallel, of after ARC funding (see Figure C.3).

Figure C.3 Survey results on the origin of non-ARC funding sources



Australian business N=475, International government N=430, Australian state/local government N=486, Australian federal government (e.g. CSIRO, CRC) N=173

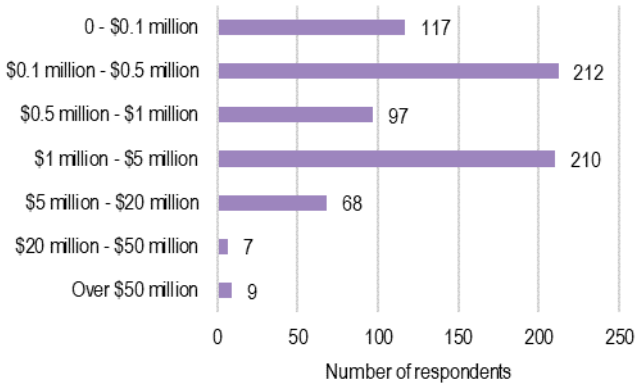
Source: ACIL Allen survey of ARC funding recipients

The value of funding received from other sources was most commonly between $100,000-500,000 or $1-5 million (both 29%, see Figure C.4, left chart). Followed by under $100,000 (16%), $500,000 to $1 million (13%), and $5 million to $20 million (9%). A small proportion of respondents reported that they received $20 million to $50 million (1%) and over $50 million (1%).

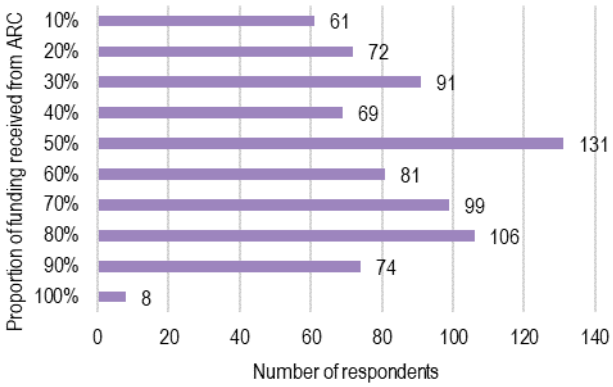
When respondents received funding from non-ARC sources, the majority of their funding was still from ARC. 63% of respondents (499 of 792) received 50% or more funding from ARC (see Figure C.4, right chart).

Figure C.4 Survey results on the distribution of the size of funding received from non-ARC sources and the proportion of funding received from ARC

Size of funding received from non-ARC sources



Proportion of funding received from ARC



N=720 for size of funding. N=792 for proportion of funding.
Source: ACIL Allen survey of ARC funding recipients

Program, funding and other data and methodology

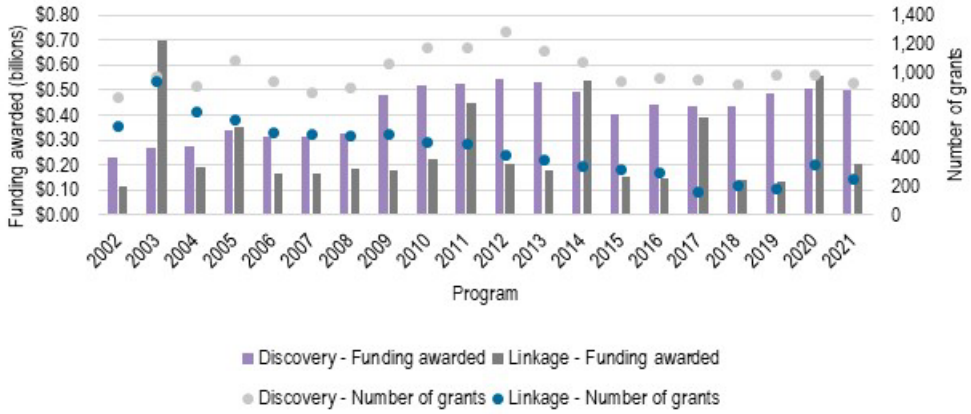
D

D.1 Program and funding data analysis

D.1.1 Funding analysis

Figure D.1 shows the total level of funding and the number of grants awarded from 2002 to 2021, by program. The amount of funding and grants awarded vary across years. Notably, funding for the Linkage Program is higher every 3 years relative to intervening years. This is due in large part to the periodic nature of funding awarded for ARC Centres of Excellence, which has occurred in 2002 (noting this was a small investment of $10 million), 2003 (noting this was a large investment of $559 million), 2005, 2008 (noting this was a small investment of $16 million), 2011, 2014, 2017, and 2020.

Figure D.1 Funding data on funding awarded and number of grants by year and by Discovery and Linkage Programs



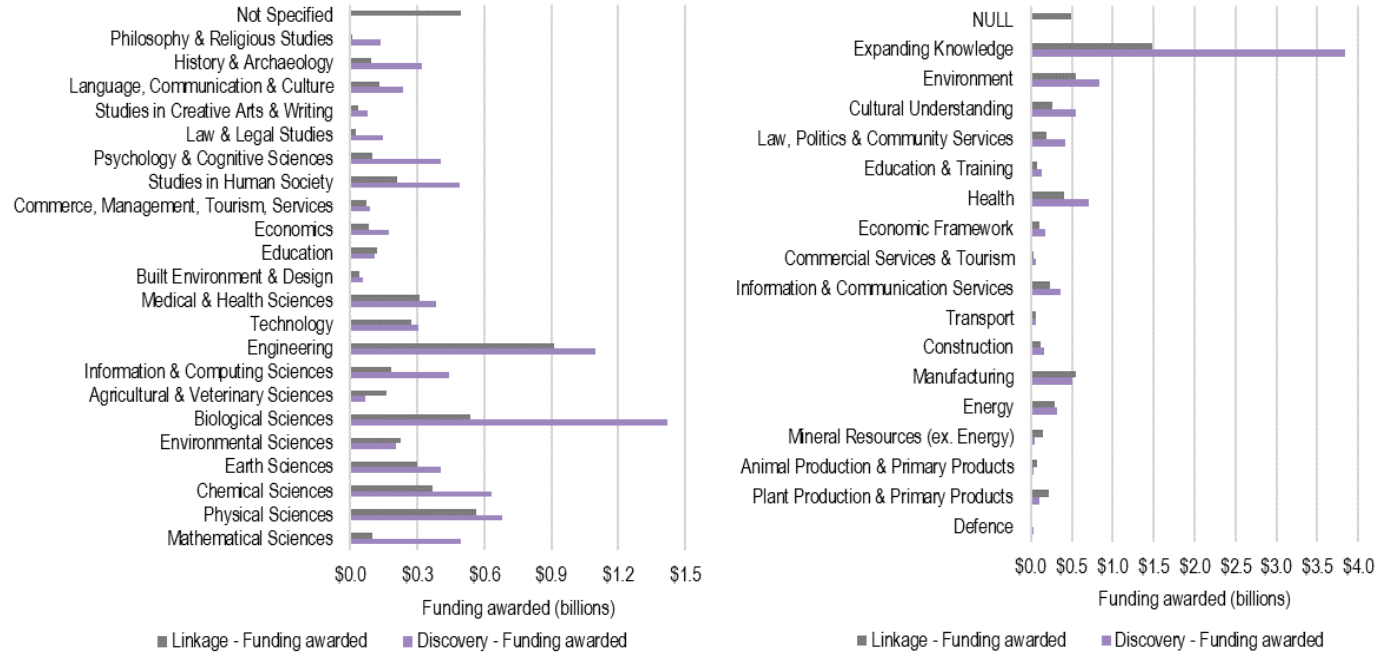
N=29,303 projects

Note: funding amounts are in current dollars (i.e. the value of the funding allocated in the award year, as reported in application data).

Source: ACIL Allen's analysis of ARC funding data for grants awarded between 2002 and 2021.

Figure D.2 shows the total funding allocated to each FoR (left chart) and SEO (right chart) from 2002 to 2021, by program.

Figure D.2 Funding data on funding allocated by FoR and SEO, across Discovery and Linkage Programs



N=29,303 projects

Note: funding amounts are in current dollars (i.e. the value of the funding allocated in the award year, as reported in the final report).

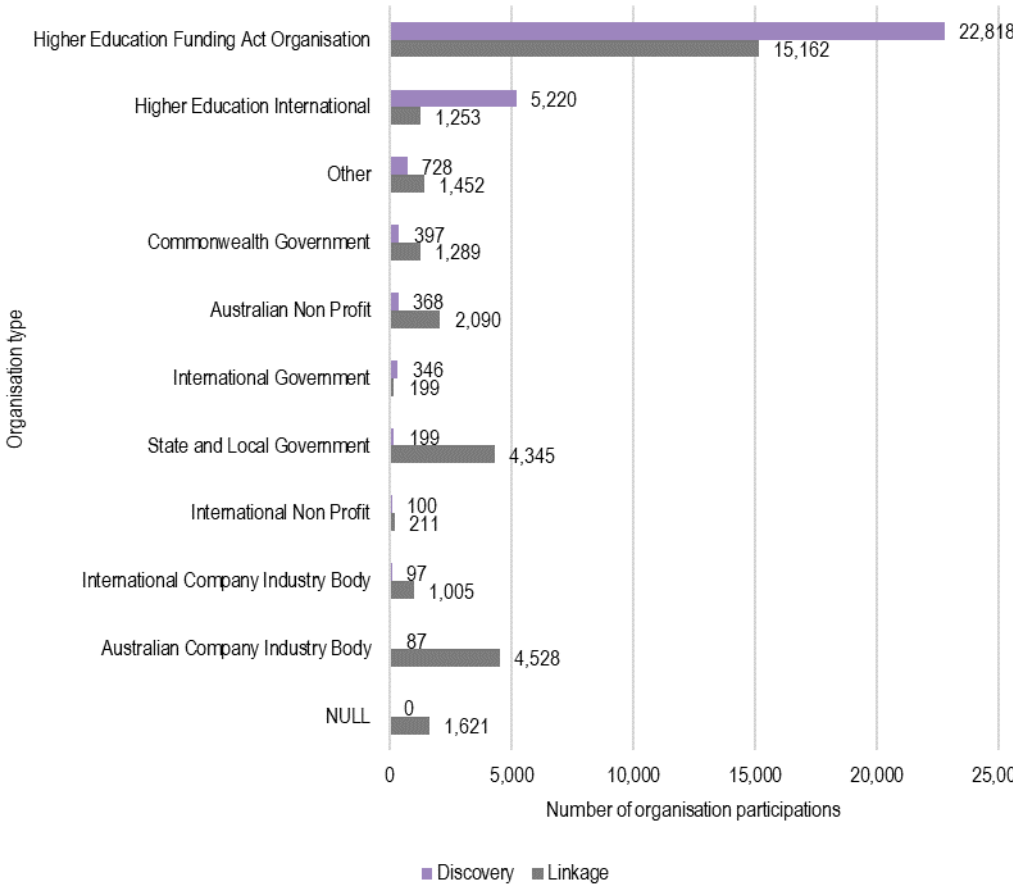
Source: ACIL Allen's analysis of ARC funding data for grants awarded between 2002 and 2021.

The most common participating organisation type is Australian universities (*Higher Education Funding Act 2003* organisations), which contribute most cash and in-kind contributions to projects (see Figure D.3, top chart). Of Discovery Program grants, 22,818 organisations participating were Australian universities, followed by Higher Education International organisations (5,220). Similarly, most organisations participating in Linkage Program grants were Australian universities (15,162), followed by Australian Company Industry bodies (4,528) then State and Local Government (4,345).

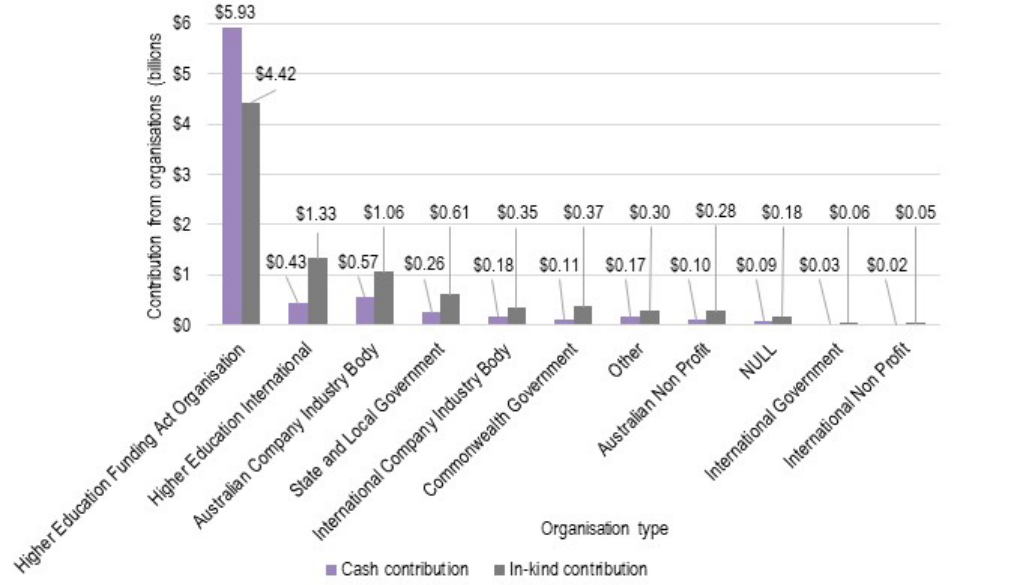
The number of total co-contributions made by each type of organisation (bottom chart) shows that most funding was provided by *Higher Education Funding Act 2003* Organisations, which contributed $10.35 billion. This was followed by Higher Education International ($1.75 billion) and Australian Company Industry Body ($1.63 billion).

Figure D.3 Funding data on the number of organisation participations and contribution amount by organisation type and by Discovery and Linkage Programs

Number of organisations



Contribution amount (cash and in-kind)



N=29,303 projects

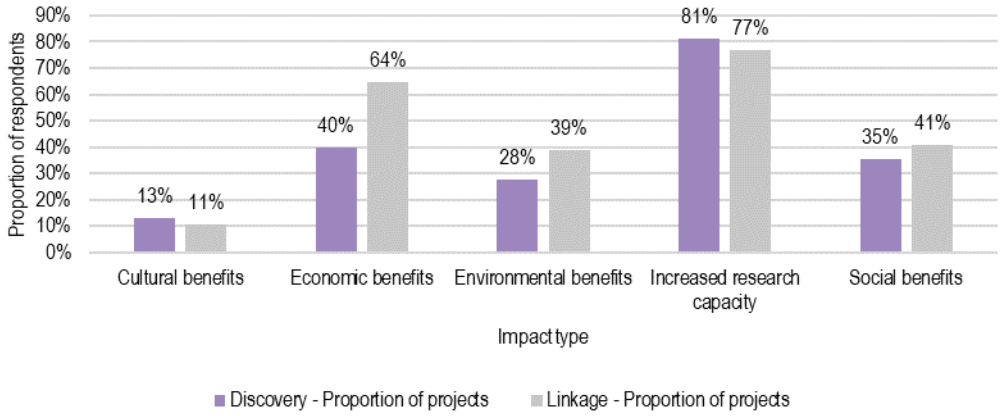
CE11 data is not available. For DE, FL (except FL10) and FT only cash contributions (no in-kind) can be entered into the application form for Administering Organisations, therefore, in-kind funding is not recorded for these schemes.

Source: ACIL Allen's analysis of ARC funding data for grants awarded between 2002 and 2021.

D.1.2 Impact analysis

Figure D.4 shows the broad economic benefits reported by Discovery and Linkage Programs. Increased research capacity was most likely to be delivered, followed by economic, and then social benefits.

Figure D.4 Final report data on broad benefits by Discovery and Linkage Programs

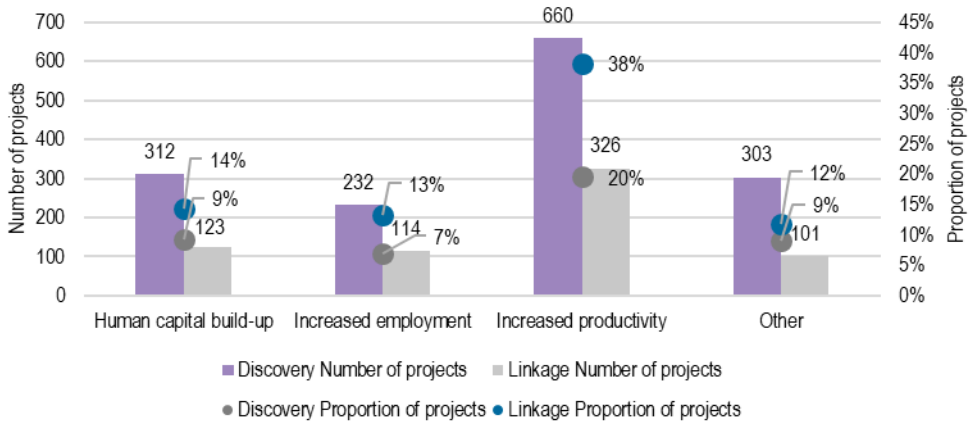


N=4,221 final reports

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

Researchers deliver economic impacts, such as increases in productivity, human capital build-up and employment (see Figure D.5).

Figure D.5 Final report data on economic impacts by Discovery and Linkage Programs

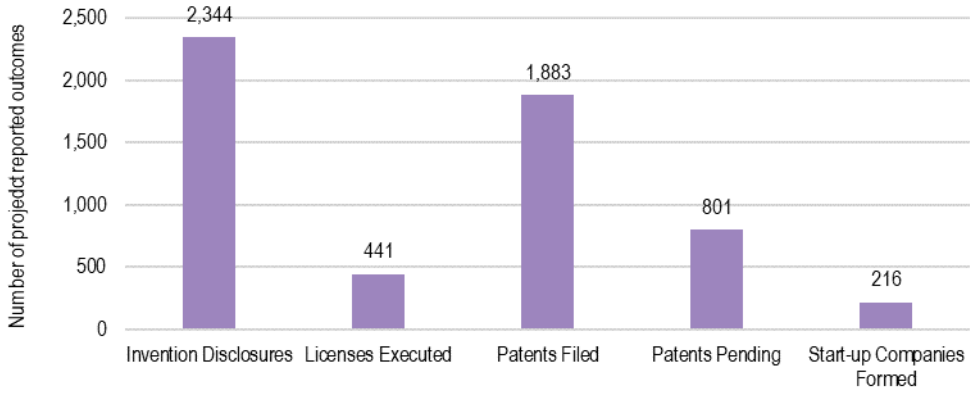


N=4,221 final reports

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

Final report data provides more detail on the numbers of different types of commercial outcomes delivered by projects (see Figure D.6).

Figure D.6 Final report data on commercial outcomes



N=22,352 (Discovery Program N=14,989 and Linkage Program N=7,363)

No data for CE prior to CE11, SR prior SR11 or LA prior LA14.

The total numbers of start-up/spin-out companies include unique company entries. The listed companies have not been checked to see if they were legitimate start-up/spin-out companies or if they are still in operation.

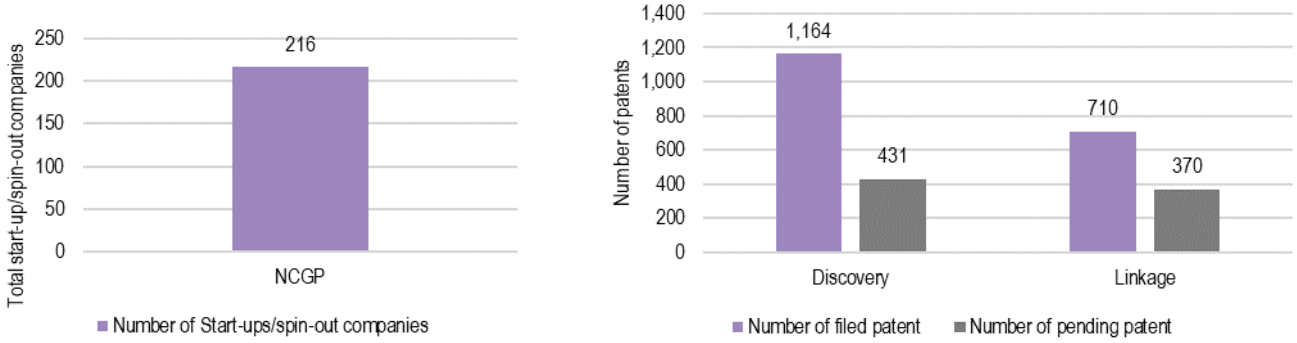
Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

The final report data in Figure D.7 shows the total number of start-up/spin-out companies (left chart) and patents (right chart) across the projects that reported start-up/spin-out companies and patents. 216 unique companies were formed from NCGP-funded projects.

Discovery Program projects reported more patents filed and pending overall compared to the Linkage Program, due to the large number of projects.

Figure D.7 Final report data on start-up/spin-out companies and status of patents by Discovery and Linkage Programs

Start-up/spin-out companies ***Patents***



N=240 final reports for start-up/spin-out companies and 1,274 final reports for patents. This includes only projects that reported these outcomes.

No data for CE prior to CE11, SR prior SR11 or LA prior LA14. Other missing rounds indicate no commercial outputs or outcomes were recorded.

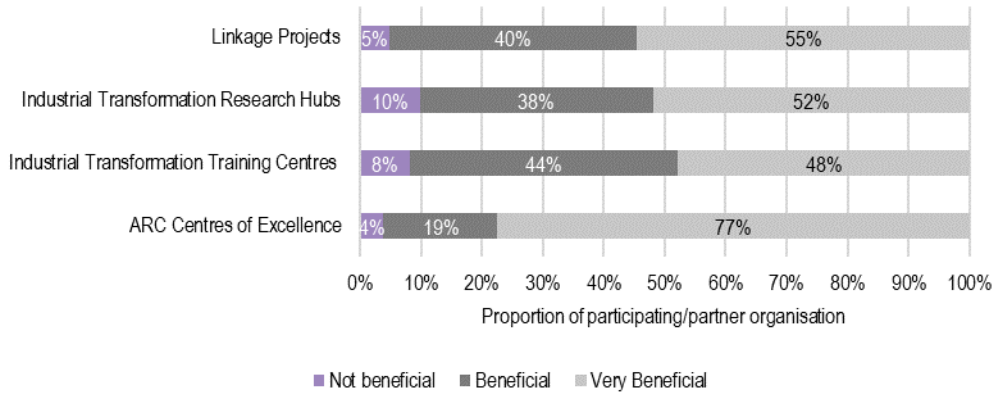
The total numbers of start-up/spin-out companies include unique company entries. The listed companies have not been checked to see if they were legitimate start-up/spin-out companies or if they are still in operation.

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

Collaboration analysis

For each scheme, Figure D.8 shows that most participating organisations considered the schemes to be very beneficial or beneficial.

Figure D.8 Final report data on the proportion of participating organisations finding the schemes beneficial



ARC Centres of Excellence n=235, Industrial Transformation Training Centres n=121, Industrial Transformation Research Hubs n=102, Linkage Projects n=1,434

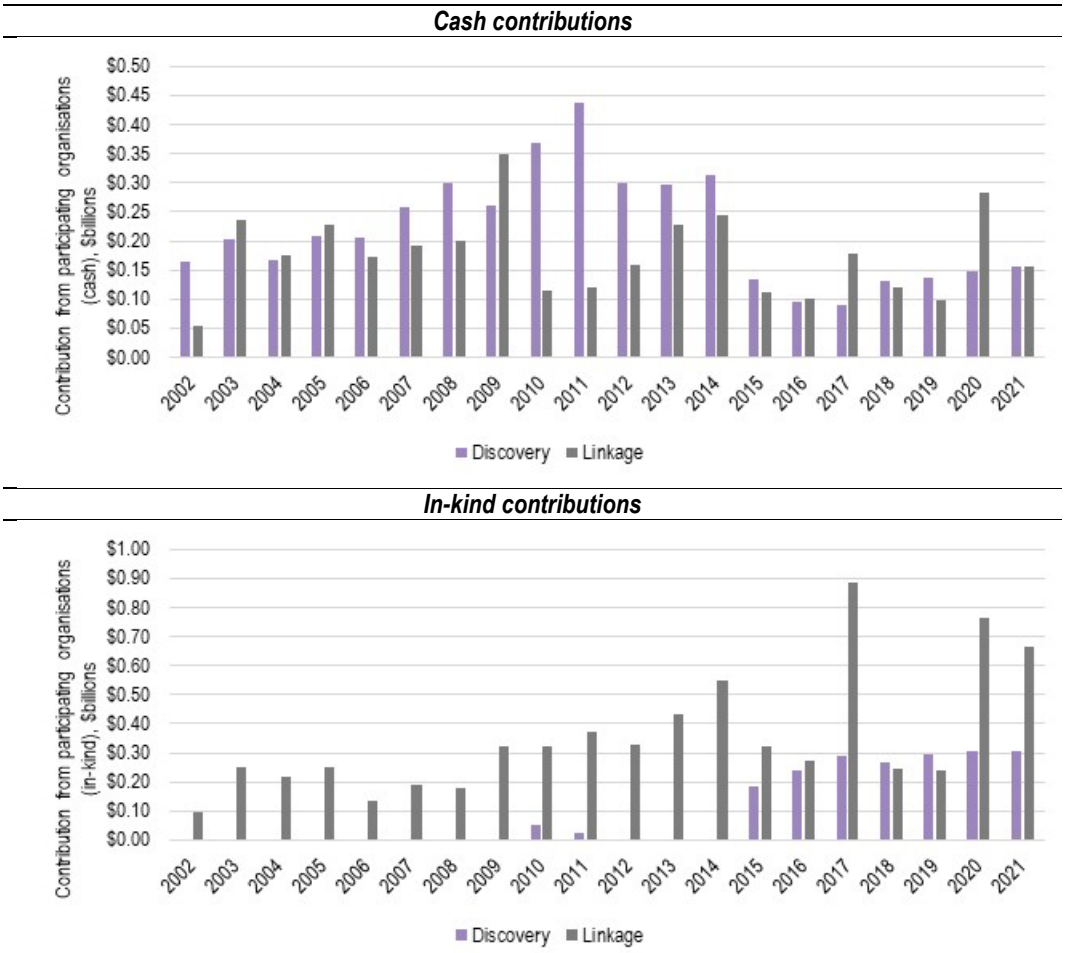
Data on whether the project was beneficial is asked in final reports for all participating organisations except Administering Organisations for CE (2011), IC and IH and just Partner Organisations for LP.

Source: ACIL Allen's analysis of ARC Final Reports for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

Figure D.9 provides application data on the cash (top chart) and in-kind (bottom chart) contributions made by participating organisations from 2002-2021. Cash contributions to Discovery Program projects total $4.37 billion. These peaked in 2011 at $0.44 billion and most recently was $0.15 billion in 2021. Cash contributions to Linkage Program projects total $3.52 billion. These reached $0.35 billion in 2009 and, most recently, was $0.15 billion in 2021.

In-kind contributions to Discovery Program grants were not listed for some schemes (DP and IN) until 2015 and continue to not be listed for other schemes (DE, FT and FL). From 2015, in-kind contributions ranged between $0.18 and $0.3 billion. Linkage Program received significantly higher in-kind contributions in 2017, 2020, and 2021 (see Figure D.9).

Figure D.9 Funding data on cash and in-kind contributions from participating organisations over time by Discovery and Linkage Programs



N=29,303 projects

CE11 data is not available. For DE, FL (except FL10) and FT only cash contributions (no in-kind) can be entered into the application form for Administering Organisations, therefore, in-kind funding is not recorded for these schemes.

Note: funding amounts are in current dollars (i.e. the value of the funding allocated in the award year).

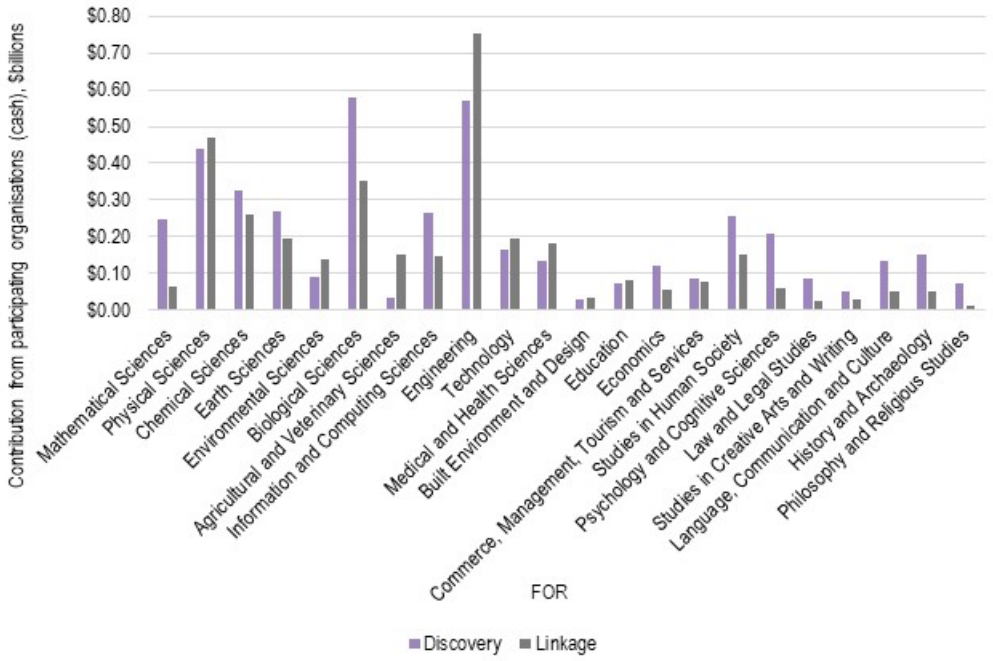
Source: ACIL Allen's analysis of ARC funding data for grants awarded between 2002 and 2021.

Figure D.10 shows the cash (top chart) and in-kind (bottom) contributions made by participating organisations, by Discovery and Linkage Programs and FoR. The largest cash contributions to Discovery Program projects were in the Biological Sciences ($0.58 billion), Engineering ($0.57 billion) and Physical Sciences ($0.44 billion) FoRs. Similarly, the largest contributions to Linkage Program projects were to the Engineering ($0.75 billion), Physical Sciences ($0.47 billion) and Biological Sciences ($0.35 billion) FoRs. This is likely a reflection of the higher cost of conducting research in these FoRs.

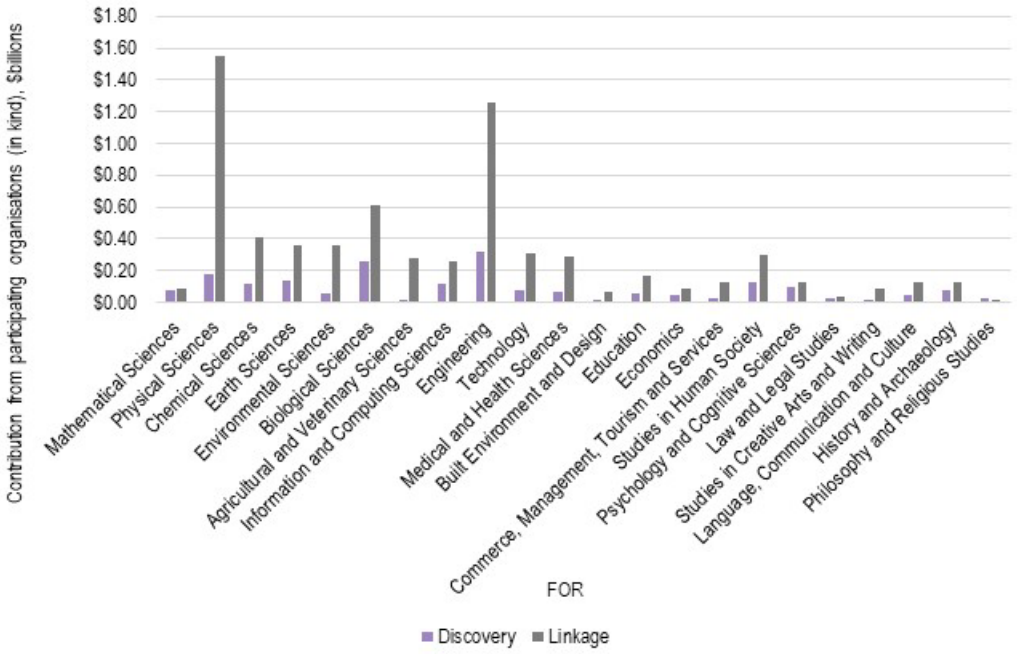
Similar to cash contributions, the largest in-kind contributions to the Discovery Program grants were made to projects in the Engineering ($0.32 billion), Biological Sciences ($0.25 billion) and Physical Sciences ($0.18 billion) FoRs. For Linkage Program projects, the largest in-kind contributions were to projects in the Physical Sciences ($1.53 billion), Engineering ($1.2 billion) and Biological Sciences ($0.61 billion) FoRs.

Figure D.10 Funding data on contributions from participating organisations (cash) by FoR, by Discovery and Linkage Programs

Cash contributions



In-kind contributions



N=29,303 projects

CE11 data is not available. For DE, FL (except FL10) and FT only cash contributions (no in-kind) can be entered into the application form for Administering Organisations, therefore, in-kind funding is not recorded for these schemes.

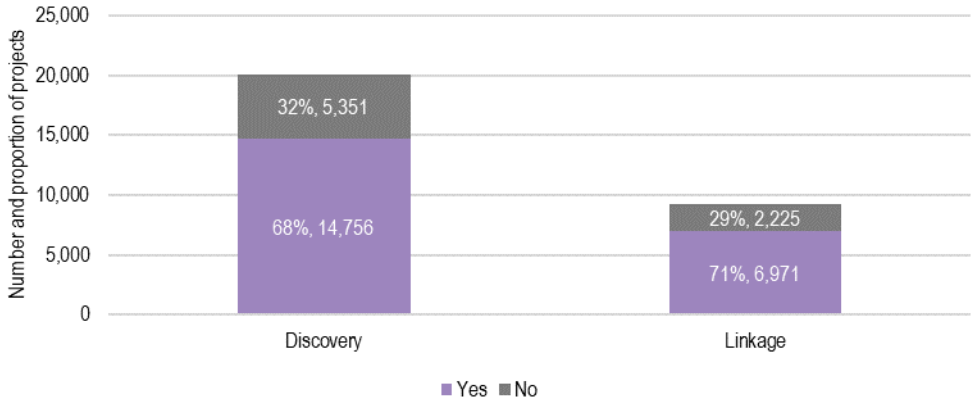
Note: funding amounts are in current dollars (i.e. the value of the funding allocated in the award year).

Source: ACIL Allen's analysis of ARC funding data for grants awarded between 2002 and 2021.

D.1.3 Alignment with Government priorities

Figure D.11 shows the number and proportion of projects aligning with government priorities by Discovery and Linkage Programs.

Figure D.11 Funding data on the number and proportion of projects aligning with government priorities by Discovery and Linkage Programs



N=29,303 projects

Source: ACIL Allen's analysis of ARC Application Data for grants awarded between 2002 and 2021 (with an ARC-approved Final Report by 30 June 2022).

D.2 NCGP scheme co-contribution requirements

The eligible Participating Organisations and their required contributions for NCGP schemes are overviewed in Table D.1.

Table D.1 Eligible Participating Organisations and their required contributions for NCGP schemes

Scheme(s)	Participating Organisations	Contributions
Australian Laureate Fellowships Future Fellowships Discovery Early Career Researcher Award	Administering Organisation	None, although contributions from the Administering Organisation is not an eligibility requirement for Discovery Program schemes, in most cases they provide significant contributions.
Discovery Projects Discovery Indigenous	Administering Organisation Other Eligible Organisation Other Organisation	
Linkage Projects	Administering Organisation Partner Organisation (at least one) Other Eligible Organisation Other Organisation	Partner Organisation(s) to provide total eligible cash and/or in-kind contributions that at least match the total funding requested, with total eligible cash contributions of at least 25% of the total funding requested. Eligible Organisation on an application must commit a significant contribution of cash and/or in-kind and/or other material resources to the application.
Industrial Transformation Research Hubs	Administering Organisation Partner Organisation (at least one Australian PO) Other Eligible Organisation Other Organisation	Each Other Eligible Organisation and Partner Organisation on an application must each commit a significant contribution of cash and/or in-kind and/or other material resources. Combined Partner Organisation(s) contributions must match or exceed the total funding requested. The combined Partner Organisation(s) cash contribution must be at least 75% of the total funding requested when any Partner Organisation has > 100 employees.

Scheme(s)	Participating Organisations	Contributions
Linkage Australian Postdoctoral Fellowships (CSIRO)	Administering Organisation Partner Organisation (at least one Australian Partner Organisation) Other Eligible Organisation Other Organisation	Each Other Eligible Organisation and Partner Organisation on an application must each commit a significant contribution of cash and/or in-kind and/or other material resources. Combined cash and in-kind contributions from all participating organisations, along with the ARC contribution, must be sufficient to support all the research projects described in the application.
Linkage Infrastructure, Equipment and Facilities	Administering Organisation Partner Organisation Other Eligible Organisation Other Organisation	All Eligible Organisation(s) on an application must make a cash contribution. Organisational cash contributions for direct costs must make up a minimum of 25% of the total direct cost of the research infrastructure. Each Partner Organisation must make a contribution of cash and/or in-kind and/or other material resources that is specific to the project.
ARC Centres of Excellence	Administering Organisation Partner Organisation (at least one) Other Eligible Organisation (at least one) Other Organisation	Eligible Organisations must commit a significant contribution of cash and/or in-kind and/or other material resources. Each Partner Organisation must make a contribution of cash and/or in-kind and/or other material resources that is specific to the Centre.
Special Research Initiatives	Administering Organisation Varies between rounds in terms of further organisation types	Varies between rounds
Supporting Responses to Commonwealth Science Council Priorities	Administering Organisation	None
Learned Academies Special Projects	Administering Organisation	None

Source: ARC from the most recent published grant guidelines for respective schemes as of July 2022.

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