

The economic and social impact of the Murchison Widefield Array

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Acronyms and abbreviations

| Abbreviations | Explanation |
|---------------|--|
| AAL | Astronomy Australia Limited |
| ALMA | Atacama Large Millimetre/submillimeter Array |
| APEX | Atacama Pathfinder Experiment |
| CGE | Computable General Equilibrium |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DISER | Department of Industry, Science, Energy and Resources |
| EHT | Event Horizon Telescope |
| EOS | Electro-Optic Systems |
| EY-GEM | EY-General Equilibrium Model |
| FTE | Full Time Equivalents |
| GDP | Gross Domestic Product |
| GNSS | Global Navigational Satellite Systems |
| GPS | Global Positioning System |
| GRP | Gross Regional Product |
| GSP | Gross State Product |
| ICRAR | International Centre for Radio Astronomy Research |
| LGA | Local Government Area |
| MMI | Modern Manufacturing Initiative |
| MMS | Modern Manufacturing Strategy |
| MRO | Murchison Radio-astronomy Observatory |
| MSF | MRO Support Facility |
| MWA | Murchison Widefield Array |
| NAOJ | National Astronomical Observatory of Japan |
| NCRIS | National Collaborative Research Infrastructure Strategy |
| NSF | National Science Foundation |
| NPV | Net Present Value |
| PSS | Professional and Scientific Services |
| SKA | Square Kilometre Array |
| STEM | Science, Technology, Engineering and Mathematics |
| TB | Terabyte |
| WA | Western Australia |

Executive Summary



1. Executive Summary

The Murchison Widefield Array (MWA) is a low frequency radio telescope operating in Western Australia. The MWA is an important component of Australia's strategic agenda for astronomical research. The impact of the MWA has been assessed through Computable General Equilibrium (CGE) modelling, combined with a comprehensive stakeholder engagement strategy.

The analysis demonstrates that the MWA has enhanced social, scientific, and economic outcomes, earning Australia a strong return on investment. The data collected by the MWA since it started operations in 2013 has supported research across the globe, enabled a plethora of discoveries, and helped Australia stay at the forefront of the broader space economy.

The construction and operations of the MWA have attracted funding from a variety of local and international sources. A portion of this funding is provided through the National Collaborative Research Infrastructure Strategy (NCRIS) with investment through the Department of Education, Skills and Employment (DESE) via Astronomy Australia Limited (AAL).

The MWA is moving into a critical period of its operations, focussing on the continued delivery of scientific outputs, and enabling the transition to the SKA. Reflecting on current contributions and future growth pathways can enable planning that maximises the benefit of the MWA.

A funding increase of 10% from NCRIS is required to ensure partner investment and provide essential upgrades for the MWA. Additional funding will enable improved telescope performance and unlock economic and scientific impacts across Western Australia (WA), Australia, and the MWA's international partners.

Scientific Impact

The MWA is a key part of Australia's scientific environment and the wider space economy. Access to the MWA has directly supported several breakthrough discoveries, including, but not limited to:

- ▶ Revealing new ionospheric structures in the Earth's upper atmosphere, critically important for understanding energy sources present on Earth's doorstep to Space;¹
- ▶ Discovering a mysterious object in our Galaxy that produces powerful bursts of radio waves every 18 minutes, possibly a dead star with an intense magnetic field;²
- ▶ Determining new limits on the Epoch of Reionisation, the period when the first stars and galaxies formed, more than 13 billion years ago;³
- ▶ Cataloguing over 300,000 galaxies, including an all-sky survey that resulted in the first radio-colour panorama of the Galaxy.⁴

Social Impact

The existence of the MWA and the scientific community that it supports enable positive social outcomes. The MWA team based at Curtin University contribute their time and expertise to champion astrophysics and STEM disciplines. Notable contributions include, but are not limited to:

- ▶ The annual Astrofest, coordinated by International Centre for Radio Astronomy Research (ICRAR) and held at Curtin University provides the community with an opportunity to learn about the Universe and engage with astronomers;

¹ Loi et al., May 2015

² Hurley-Walker et al., January 2022

³ Trott et al., February 2020

⁴ Hurley-Walker et al., September 2016

- ▶ The “Ilgarjiri - Things Belonging to the Sky” project, a collaboration between the Curtin University node of ICRAR and artists from Yamatji Art in Geraldton, was motivated by the MWA. The project resulted in sell-out art exhibitions around the world, raising significant funds for the Yamatji Art community;
- ▶ Building on Ilgarjiri, the creation of the ‘Star Dreaming’ film with direct contribution from the MWA Director, Professor Tingay, brought together storytelling between modern scientific astronomy and the oldest living culture of Australia’s First Nations people.

Economic Impact

The \$9.8 million Australian investment to build the MWA, combined with the \$13 million spent on operations, has resulted in a **\$58 million uplift in GDP** between 2010 and 2021. A further \$12 million was invested to de-risk the SKA, supporting an additional uplift in **GDP of \$4.6 million** between 2013 and 2021. This has assisted in the SKA’s progression to the procurement phase, while reducing construction risk, supporting future economic benefits equal to an uplift of **\$18.5 million in Australian GDP** between 2022 to 2028. These future benefits have been unlocked today by this investment.

Combined, the historical economic impact has resulted in a **\$62.6 million uplift in Australian GDP** between 2010 and 2021, driven primarily by a strong increase in scientific output. This excludes benefits still to be accrued through savings in the construction of the SKA, which raises the GDP impact to **\$81.1 million**, as summarised in the table below.

To date, every dollar invested in the MWA has resulted in a greater than **\$2 increase in Australian GDP**, delivering a benefit to cost ratio of 2.33. This is a strong return, especially when compared to other national infrastructure projects. Notably, maintaining and enhancing the output of the MWA offers an opportunity to increase this return over the next decade.

Table 1: Historical performance of the MWA⁵

| | | |
|--|---|---|
| \$34.8 million | \$81.1 million | \$83 million |
| Invested by Australian entities in building and operating the MWA including funding to improve the design and technical readiness of the SKA <i>Resulted in -></i> | Uplift in Australian GDP <i>Contributed by -></i> | In economic activity across the Professional Services & Scientific sector (PSS) |
| 100 | 30-40 | 21,170 |
| Number of FTEs integrated over the life of the MWA | Average papers published in peer reviewed journals each year since 2013 | Observing hours completed since 2013 |
| 35,800 | Terabytes (TB) of data captured since 2013 | |

Benchmarking the MWA

The scale of the MWA and its relationship to the SKA is relatively unique. However, the Atacama Pathfinder Experiment (APEX) is a highly revealing benchmark to consider against the current operational envelope of the MWA. The relationship between APEX and the MWA provides further insight into the potential of the MWA, as demonstrated in Table 2.

⁵ Various sources, EY analysis

APEX began operations in 2005 and is the precursor to the Atacama Large Millimetre/submillimeter Array (ALMA). APEX de-risked ALMA similarly to how the MWA has supported the de-risking of the SKA. The two telescopes complement each other, and APEX remains in use even though ALMA is operational.

Table 2: Benchmarking the MWA with APEX

| | MWA | APEX |
|---------------------------------|--|--|
| Commencement | Commenced operations in 2013 | Commenced operations in 2005 |
| Operating budget | Approximately \$2 million (AUD) per year | Approximately \$9.7 million (AUD) per year* |
| FTEs (regular operating period) | ~8 FTEs in a regular operating period | ~16 FTEs in a regular operating period |
| Publications | Between 30-40 publications a year. Over 250 publications since 2013 | Between 40-50 publications a year. Over 800 publications since 2006. |
| Observing hours | Around 2,500 hours of on-sky science time per year | Around 4,400 hours of on-sky science time per year |
| Data collection | On average 4,400 TB data per year | On average 130 TB data per year for the whole of the ESO |
| Science goals | Study of the Epoch of Reionisation, transient phenomena, galactic and extragalactic surveys, searches for extra-terrestrial intelligence, pulsars and Fast Radio Bursts, Solar and Heliospheric science. All at low radio frequencies. | Studying the formation of stars, planets, and galaxies, including the physical conditions of molecular clouds. |

Sources: MWA data, annual and quarterly reports, European Southern Observatory Annual Reports.

There are clear distinctions between APEX and the MWA. Notably:

- ▶ APEX has produced a much higher number of publications, likely due to its long operational life;
- ▶ The MWA currently operates on significantly less funding per year than the APEX telescope. Part of the difference may be attributed to infrastructure and operating requirements, though there is a significant difference in FTEs to run the telescope. This indicates that the MWA operates on a lean margin, accumulating project risk as a result; and
- ▶ APEX has improved its operations over time. APEX received major investment in 2017 after ten years of operations to overhaul the telescope and upgrade the site and infrastructure to remain competitive whilst ALMA was fully operational.

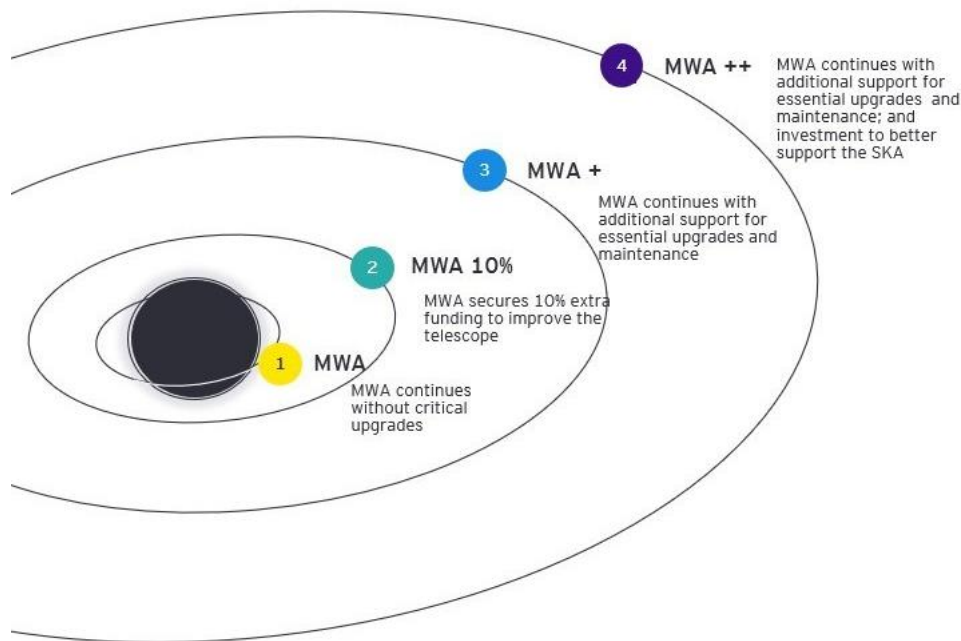
Overall, the MWA operates with half the FTEs and receives a fifth of the annual funding. However, it only slightly trails APEX in scientific outcomes.

Unlocking the future potential of the MWA

While the MWA has provided strong returns to the Australian economy, the existing funding envelope exposes the project to potential risks. An economic analysis of the MWA's potential has been conducted across four alternative funding scenarios. Each scenario was developed through consultation with the MWA team based at Curtin University.

Additional investment explored in this analysis could unlock scientific potential, as well as contributing to economic growth and creating jobs. These results are shown in Figure 1, below, with each description based on the average annual changes in the current funding provided by NCRIS.

Figure 1: Future MWA scenarios



The economic impacts under the various funding scenarios are shown below. Continuation of the current funding envelope (MWA +0%) sees a steadily falling contribution to GDP due to a degrading telescope and lower scientific output.

However, a 10% increase in funding from NCRIS, equal to \$150,000 per annum, unlocks \$3.5 million of funding from partner organisations and substantially improves the outlook of the MWA. The additional \$150,000 annually drives the largest change in outcomes (across the scenarios considered) and shows a strong increase in scientific output and continued support for the launch of the SKA. Over the seven years between 2022 - 2028, the MWA +10% scenario equates to a funding envelope of \$11.55 million from NCRIS (with funds to mid-2023 already committed) to deliver a potential \$222 million uplift in GDP, expanding the substantial ROI on this investment by the government.

Additional funding from NCRIS can be allocated towards various other activities, as explored in the MWA+147% and MWA +447% scenarios, each of which further raises the telescope’s contribution to the economy.

Table 3: Economic impact summary of future funding scenarios

| | Funding \$'M | Uplift in GDP \$'M | Uplift in GSP \$'M | Economic output (PSS) \$'M | Jobs (FTE) |
|------------------|--------------|--------------------|--------------------|----------------------------|------------|
| MWA +0% | 1.5 | 62 | 55 | 97 | 42 |
| MWA +10% | 1.65 | 222 | 182 | 354 | 151 |
| MWA +147% | 6.5 | 240 | 200 | 387 | 163 |
| MWA +447% | 28.2 | 286 | 242 | 446 | 192 |

Introduction



2. Introduction

The Murchison Widefield Array (MWA) is a low frequency radio telescope operating in Western Australia. The MWA is a critical component of Australia's strategic agenda for astronomical research, and acts as a key part of the global space economy. The MWA is providing significant benefits to Australia and Australia's partners around the world, as a precursor to the multi-billion dollar Square Kilometre Array.⁶

The MWA was established nearly a decade ago with support from the Commonwealth Government and builds upon initiatives by the Western Australian State Government and the ambitious efforts of various institutions, such as Curtin University. Major stakeholders include The Commonwealth Scientific and Industrial Research Organisation (CSIRO), the US National Science Foundation, and others in the MWA's partner countries.⁷

Since becoming fully operational, the MWA has made headlines worldwide. The unique national and international partnership of researchers and academics facilitated by the MWA has resulted in breakthrough discoveries on Earth and in space.

The MWA is a precursor facility for the much larger future Square Kilometre Array (SKA). In partnership with 20 countries, WA and South Africa are building the SKA over the next decade. The cost of the SKA is approximately €2 billion.⁸ The SKA is a major strategic priority for Australia's research community (endorsed by multiple Decadal Plans of the National Committee for Astronomy, via the Australian Academy of Science) and the Australian and Western Australian Governments.

The MWA has played a vital role in supporting the Government's strategic plan over the last decade and will continue to do so through to 2028 when the first phase of the SKA is expected to be near complete. The SKA will enable a greater understanding of the Universe and stretch capabilities in technology by being approximately 50 times more powerful than the MWA.⁹ As the SKA approaches the critical stages of construction following successful prototyping, maintaining operational and funding support for the MWA in this period remains paramount.

The MWA, SKA, and other astronomy facilities exist within the broader space-based economy. Space data and technologies are becoming increasingly important in the functioning of modern society, and we benefit from space-based technologies daily. This can only be expected to grow as there is high potential for expansion across many economic sectors; including sectors ranging from earth observation improving agricultural, water, and environmental management, to space situational awareness and exploration, and telecommunications satellite infrastructure and positioning (GPS) technologies.¹⁰ MWA technologies, and the skill sets generated, are relevant across these and many other sectors of the economy.

⁶ ICRAR, April 2021

⁷ Murchison Widefield Array, obtained January 2022

⁸ SKA Telescope, obtained December 2021

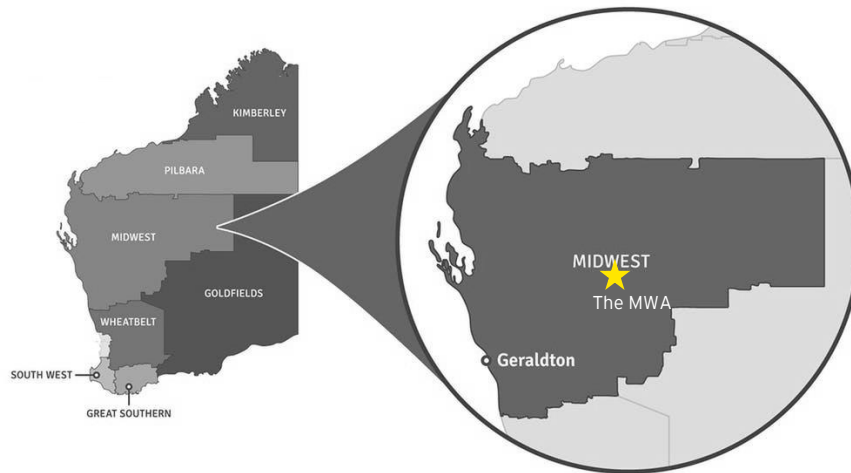
⁹ SKA Telescope, obtained December 2021

¹⁰ Australia Government, April 2019

2.1 About the MWA

The MWA operates at the CSIRO's Murchison Radio-astronomy Observatory (MRO) in a remote area located approximately 70km northeast of the settlement of Murchison and 300km northeast of the coastal regional hub of Geraldton. The MWA directly employs engineers and technicians and supports local communities and industries.

Figure 2: Location of the MWA¹¹



The MWA is a one-of-a-kind, world-class scientific facility and has been in operation since 2013. The telescope is in the remote outback Shire of Murchison. Shielded from radio frequency interference, the MWA is positioned to capture ultra-weak signals from space, including from the Galactic Centre, which is best observed from the Southern Hemisphere.¹² The telescope is made up of 4,096 dual-polarisation dipole antennas, distributed over more than ten square kilometres and arranged in 256 tiles. The project is driven by high-level computing power designed to capture a wide-field view of the sky and requires supercomputers at the Pawsey Supercomputer Centre, based in Perth.

This design and location give the MWA an unprecedented capability to measure astronomical phenomena. For example, scientists reported a “10-fold improvement” in the ability to undertake research based on data gathered by the MWA. Additionally, data processing techniques were developed by the MWA scientists, specifically in researching the Epoch of Reionisation.¹³

2.2 About the SKA

The Square Kilometre Array (SKA) is an international project to build a next-generation radio telescope, which will be 50 times more sensitive and able to survey 10,000 times faster than today's most advanced telescope. More than 20 countries worldwide have joined efforts in the development of the SKA.

South Africa and Australia are co-hosting the two telescopes in SKA phase 1. The 'SKA-Low' telescope, consisting of an array of low-frequency antennas, will be in WA, while the 'SKA-Mid' array of dish antennas will be in South Africa. The two telescopes will observe the sky at different radio frequencies and complement each other scientifically. The SKA will allow researchers to look back more than 13 billion years to watch the first stars and galaxies form, which will allow astronomers to answer some of the biggest questions in astrophysics.

¹¹ WA Primary Health Alliance, obtained December 2021

¹² [Murchison Widefield Array, obtained January 2022](#)

¹³ [Brown University, September 2019](#)

The Australian Government has committed approximately \$690 million to the SKA, which includes supporting the construction and early operations of the proposed telescope.¹⁴ This is in addition to tens of millions of dollars that have already been invested into Australia's participation in the SKA, which has focussed on a range of pre-construction design and planning activities required to advance the science needed to successfully develop the facility.

Construction of SKA Phase 1 started in 2021. Phase 1 will provide operational telescopes capable of carrying out the collection of data in low and mid frequencies. A future Phase 2 SKA embodies the ultimate ambition to grow the scale of the SKA by a further factor of ten.

The Commonwealth Government and the WA State Government have also established the MRO and supported the MWA, the CSIRO's Australian SKA Pathfinder Telescope (ASKAP), and the development of the International Centre for Radio Astronomy Research (ICRAR). These programs have seen the WA State Government, Curtin University, and UWA contribute over \$100 million of investment since 2009. In total, between 2010 and 2030, close to a billion dollars has, and will be, invested to develop, host, build, and operate the SKA and develop the research community surrounding this asset.¹⁵

The MWA acts as both a powerful telescope, and as a valuable prototype for SKA-Low. The building of the MWA in WA helped ensure that the SKA-Low will be developed in Australia and has enabled developments in telescope, provision of remote electrical power, and data-processing technology that combined, will make the SKA possible.

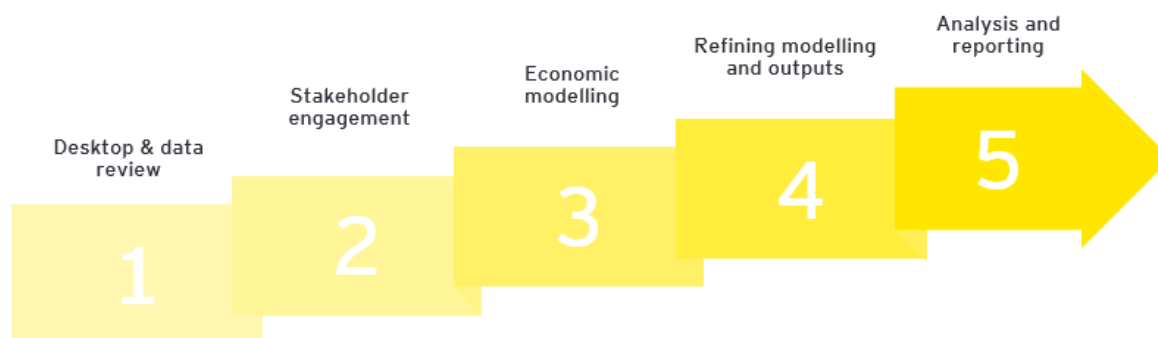
2.3 About the study

EY has been engaged by Curtin University (Curtin) to examine the economic and social impact of the MWA in Australia. That is, recognising that the MWA is an international facility, with partners from around the world, this study is focused solely on the impact the MWA has had on the Australian economy. Although the consideration of the impact in other MWA partner countries is out of scope for this study, it is expected that similar calculations would be possible to measure the local impacts in these countries.

The study considers how the MWA operates as a facility in Australia, receiving funding and in-kind contributions from various sources, and how this funding is translated into the tangible and non-tangible outputs of the MWA. A core focus of the study has been how the MWA has provided value in the past, the benefits accrued in support of the international SKA project, and the expected benefits to be derived in the future from the MWA's continued operations.

A summary of our approach to the project is shown in Figure 3 below.

Figure 3: Overview of our approach



¹⁴ Australian Government, December 2021

¹⁵ Various sources - MWA team stakeholder consultation, SKA Organisation, Australian Government & WA budgets

Desktop and data review

A desktop review was conducted to identify the areas in which the MWA has had the most significant impact from local, state, national, and global perspectives. Alignment with critical strategies across Government and the continued performance and opportunities presented by the MWA have been explored.

To support a robust analysis of the impact of the MWA, background research was undertaken to investigate the different ways that similar facilities have demonstrated value. The MWA is primarily a scientific and educational facility and, as such, the economic and social value of the facility is non-standard to model, relative to studies undertaken with more common methods, such as measuring the economic contribution of a manufacturing firm or mining company.

A unique methodology was developed to ensure the study captured the various ways in which the MWA provides value socially and economically, aligned to the value demonstrated by similar facilities.

Stakeholder engagement

Second, consultations with MWA stakeholders were undertaken to explore the role of the MWA and how it has provided value. Discussions focussed on how it has contributed to research, industrial development, and government policy objectives since its inception. Stakeholders included universities across Australia, project management teams supporting the development of the SKA, government, and manufacturers/suppliers.¹⁶

Consultations with a range of stakeholders were held in November 2021 to explore the role of the MWA both locally and internationally, including:

- ▶ How they fit in to the operations of the MWA, and how they have benefitted from the facility;
- ▶ How the MWA has contributed to:
 - ▶ The domestic and international radio astronomy, scientific, and academic communities;
 - ▶ The WA and local Murchison economies;
 - ▶ Surrounding industries, including construction, engineering, and manufacturing;
 - ▶ The development of supply chains and knowledge that would be crucial to the SKA project;
 - ▶ Both WA and Australia's national and international policy objectives.
- ▶ The importance of the continued operations of the MWA, areas where the MWA could provide additional value, and how this would be provided.

Economic modelling

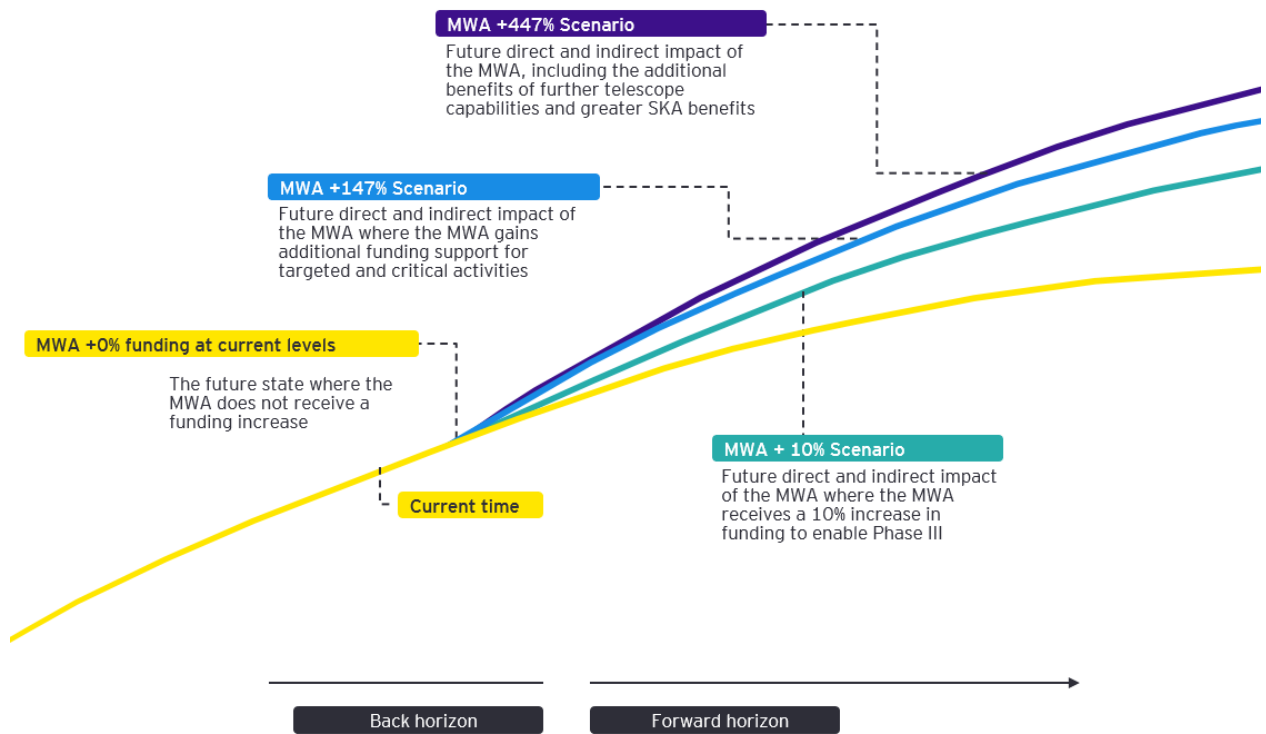
EY used an inhouse Computable General Equilibrium (CGE) model (EY-GEM) to quantify the direct and indirect economic impacts of the MWA. Four scenarios have been developed which outline the potential economic and scientific contributions of the MWA in the future, as well as reflecting on how it has provided value to date. These are shown in Figure 4, below.

Direct impacts consider key items including, though not limited to, funding expended (including from international contributors), persons employed, education and skills, and scientific and other works produced. Indirect impacts consider the potential flow-on impacts from direct impacts. Our outputs are presented in terms of GDP/GRP, value-add, employment for the local economy, and key statistics for relevant national impacts and spill overs.

¹⁶ The list of institutions consulted can be found in the appendix

Our scenarios test a range of possible future outcomes for the MWA, based primarily on various funding scenarios, and their impacts on the Australian economy.

Figure 4: MWA scenarios modelled



Note: The scenario names are derived from the change in NRIS funding from the current envelope

Report Structure

The report is structured in the following chapters:

- ▶ Chapter 3 provides an overview of the MWA and the role that it plays in the broader scientific, research, and policy landscape of Australia;
- ▶ Chapter 4 assess the historical impact of the MWA, since its inception, using the CGE model;
- ▶ Chapter 5 presents the impacts of a range of possible future scenarios for the MWA;
- ▶ Chapter 6 summarises the results of the study.

Investigating the impact of the MWA



3. Investigating the impact of the MWA

The MWA has provided scientific, economic, and social benefits to Australia and the wider scientific community. The project is an integral part of the space industry in Australia and has complex interdependencies with present and future developments and research.

As part of the stakeholder consultation, senior individuals in academia, government, the SKAO, Pawsey Centre, and key companies that have contributed to the MWA were interviewed. There was an overwhelmingly positive response from all parties on the benefits the MWA has provided and continues to provide. The following are a few of the positive takeaways provided by stakeholders.

The MWA has:

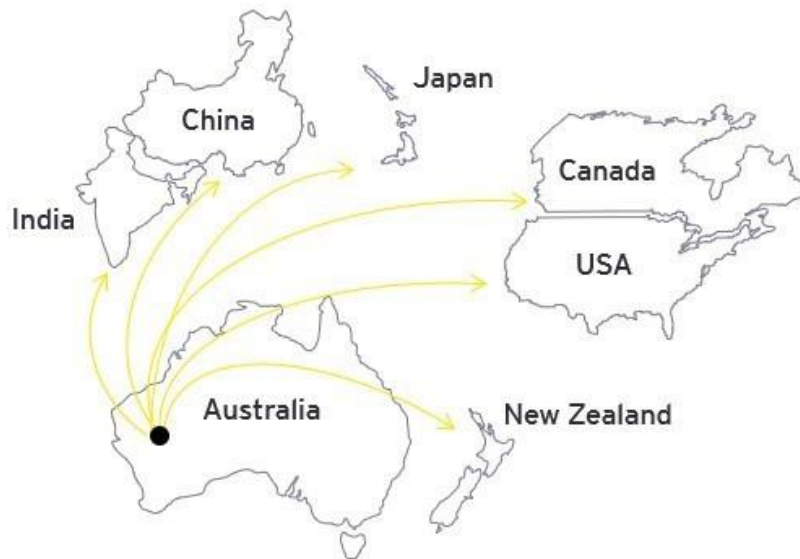
- ▶ Created sustainable jobs in WA and the Mid-West regions;
- ▶ Been a key input into the design and costing of the SKA and continues to support the project development team in a range of areas;
- ▶ Established a local manufacturing base and supply chain that will be crucial in delivering construction and maintenance to the SKA;
- ▶ Tested instruments and driven technological changes that have allowed design changes for the SKA, saving time and costs on that project;
- ▶ Driven the growth in WA's and Australia's scientific space capabilities;
- ▶ Resulted in the WA government and other universities funding specific courses that use the data from the MWA to train students, partially to help meet the demand that will stem from the SKA once operational;
- ▶ Strengthened the educational ecosystem across all phases of development, operation, and scientific interpretation;
- ▶ Provided construction and electrical capability building in regional workforce and more broadly Australia;
- ▶ Established state of the art modern equipment such as radio telescopes and the Pawsey Supercomputing Centre, exposing operators to manage enormous amounts of data through extensive data transformation and cleansing activities;
- ▶ Exposed astrophysicists, data scientists, and academics to astrophysical data for interpretation and investigation producing scientific discoveries;
- ▶ Provided long term program management, developing the relationships, supply chains, skillsets, and knowledge to execute the SKA;
- ▶ Through its partnership with Pawsey, the MWA has improved Australian supercomputing and big data management through identifying, learning, overcoming, and mitigating challenges realised during the development and operational lifecycle.

This chapter explores the MWA's impact by investigating the partnerships and performance of the MWA ecosystem, how it aligns with national objectives, its contribution to regional communities, the MWA's key partners, and its scientific and social footprints.

3.1 Local and international partnerships and MWA ecosystem

The MWA has been a product of research partnerships with eight domestic partners and more than 22 international institutions from seven countries. The MWA ecosystem includes Australia, China, India, Japan, Canada, New Zealand, and the USA. This is portrayed in the figure below.

Figure 5: The MWA's global network of contributors and partners



The MWA directly employs an average of 8 people, but over 250 individuals from more than 20 institutions have been members of the MWA. The MWA is supported by commercial vendors and suppliers, who contribute to and benefit from the MWA.

The MWA also collaborates with academic and scientific institutions across Australia. Working together, this ecosystem generates scientific and economic value for Australia and the global community. The MWA directly stimulates economic activity through this interdependent network of public and private actors. This ecosystem is portrayed in the figure below.

Figure 6: Academic and scientific players linked to the MWA



3.2 Support for industrial development and alignment with government

Strategic and economic alignment with the Australian space industry

The Commonwealth and State Governments have escalated the strategic and economic significance of the space industry over the past decade. The space industry represents a rapidly growing sector of the Australian economy. The industry represents over 380 companies, over 50 research institutions, and more than 20 government agencies.¹⁷ Australia's clear skies and low urban interference provide a strong strategic advantage in satellite communications, radio astronomy, and control operations. Australia has the workforce, natural resources, and competitive advantage to act as a key player in the global space economy.

The National Collaborative Research Infrastructure Strategy (NCRIS) was established to support the Government's broad innovation and research objectives.¹⁸ The NCRIS is a major contributor to the successful operation of the MWA, as the primary source of Australia's contribution to the performance and maintenance activities. The Commonwealth's NCRIS investments in the MWA are managed via contracts between Astronomy Australia Limited (AAL) and Curtin University, the operating entity of the MWA. Evidence that astronomy meets the strategic objectives of the Government is strengthened by the release of the Draft National Research Infrastructure Roadmap Exposure, which notes that optical and radio astronomy infrastructure and data storage are key to achieving national space objectives.¹⁹ Recognition of the Commonwealth Government's commitment to the SKA is demonstrated by the \$387.2 million allocation outlined in the 2021-22 Budget: Securing Australia's Recovery,²⁰ and the prior \$297.3 million dollar investment in 2015.

Table 4: Funding summary²¹

| \$9.8 million | \$13 million | \$12 million |
|---|---|---|
| Invested by Australian entities in building the MWA | Invested by entities in operating the MWA | Commonwealth funding directed to improving the design and technical readiness of the SKA, supported by the MWA. |

The Commonwealth Government's emphasis on Science, Technology, Engineering and Mathematics (STEM) skills and building them into the school curriculum is important for keeping up with the industries of the future.²² To deliver on the target of 20,000 new jobs in the space sector by 2030, 300 newly skilled scientists and 900 engineers need to be entering the workforce each year over the next ten years.²³ Projects such as the MWA provide great opportunities for graduates to work in the sector and encourage an interest in space. Recent reports suggest Australian universities, research bodies, and private organisations provide a strong foundation to meet the increase for workforce demand in the Australian space sector.²⁴

¹⁷ [Acil Alen, October 2017](#)

¹⁸ Department of Education, Skills and Employment, December 2021

¹⁹ Department of Education, Skills and Employment, December 2021

²⁰ Australian Government, December 2021

²¹ Various sources, EY analysis

²² Department of Education, Skills and Employment, obtained January 2022

²³ [Australian Government, April 2019](#)

²⁴ [Australian Government, July 2021](#)

3.3 Regional Overview

The MWA provides value and supports critical areas of the economy across various industries in Australia. Additionally, the MWA has gained traction through multiple programs and media strategies to inform and educate the public on the telescope's capabilities and discoveries in space more broadly.

The MWA and Western Australia

The MWA has been a significant part of WA's fast growth in becoming a centre of the Australian space industry, especially with regards to radio astronomy and space science. WA is endowed with the remote, isolated land areas necessary for sensitive telescope technologies. Because of this, internationally renowned infrastructure such as the MWA, ASKAP, CSIRO calibration Pinnacles Desert site, Jindalee Operational Radio Network, and the EOS Space Systems Satellite Laser Ranging Telescope have all been constructed in WA. Around these pieces of key infrastructure, over 70 international and Australian companies in space and space-related services now operate out of the region.

WA has the potential to become Australia's strategic space hub and a gateway to the international space economy. There have already been significant improvements in manufacturing capacity to support space activities, including ground stations for deep space communication, radio astronomy, and satellite laser ranging. Industrial capabilities from the mining and agricultural sector extend to operating space equipment in remote and harsh environments. WA is already leading the way in many areas of space research, including GNSS, optical communications, automation, and calibration.

The then Commonwealth Government Minister for Industry, Science and Technology, speaking with Business News on manufacturing objectives for Western Australia, specifically called out the benefits of the SKA in 2021. The Minister was quoted:

*"It's a great project, the ecosystem we're going to develop around it. The supercomputing centre gets us a foothold in expertise in quantum computing, the level of data to be processed by the Pawsey Centre is astounding."*²⁵

The comments support the current alignment and impact and emphasise the current and future potential of the MWA's operations and regional WA space industry opportunities.

Economic impacts

The Mid-West Region and Murchison LGA

The MWA has encouraged investment and growth into the Murchison and Mid-West Region. The Mid-West Region is one of WA's most diversified regional economies, hosting strong mining, construction, agriculture, tourism, and manufacturing sectors. In 2018-19 it added \$8.2 billion or 2.9% to Gross State Product and remains poised for future growth.²⁶ In 2015, the State Government published a 2050 Mid-West Regional Blueprint which looks to harness the Region's open spaces, abundant natural resources, and stunning landscapes to stimulate the growth of its output to \$47 billion by 2050.²⁷ The Regional Blueprint recognises the strategic geographical importance of the Mid-West region to observe the universe, including the financial investments required to align the MWA with associated projects and organisations such as the CSIRO and the SKA Observatory.

²⁵ Business News, July 2021

²⁶ WA Department of Jobs, Tourism, Science and Innovation, June 2020

²⁷ [Western Australian Planning Commission, February 2015](#)

The State's largest regional centre, Geraldton, is home to over 50% of the Mid-West's population and produces over half of its economic output.²⁸ Equipped with an airport and major seaport, Geraldton has served and will continue to serve as the most suitable and connected regional base for the MWA and SKA.

Murchison is one of the Mid-West's seventeen Local Government Areas (LGA's) and one of its most remote, with just 113 permanent residents. Historically, much of the Murchison LGA has been used for pastoral purposes but destocking of the land has increased since 2016. Mixed survey results on the economic state of the Murchison pastoral industry indicates low confidence in the future of this industry in the region.²⁹ This, however, creates opportunities for future growth in resource extraction and radio astronomy.

The Mid-West and the Murchison regions have been selected by the WA State Government as a region for infrastructure investment with over \$126 million injected since 2011, through the Mid-West Development Commission. Some of this investment has already been directed towards the MRO. A further \$94 million has been set aside for future infrastructure investment in the Region, positioning it optimally to support the future growth of the MWA.³⁰

The Federal Government's \$680 million commitments to the SKA provides Mid-West Region and Murchison communities with an opportunity to capitalise on services delivered from MWA operations.

3.4 Key institutions and partners

The MWA supports, and connects to, a variety of key institutions and partners. A more detailed list of these is included in Appendix B, with key entities outlined below.

Square Kilometre Array (SKA)

The MWA is an official precursor for the SKA. The lessons learned from the development of the MWA have proven that WA institutions and associated workforces can successfully construct, operate, and maintain advanced radio telescopes.³¹

The SKA has had the unique opportunity to leverage the MWA's existing infrastructure and knowledge to expedite the development of a functioning prototype. Combining the mature MWA infrastructure with specialised technical knowledge allowed the opportunity to test SKA prototypes in the operational environment, fast tracking the design and concept stages.³²

To date, the MWA has provided a physical platform for the development, prototyping, and testing of SKA sub-systems in the field. The SKA pre-construction and construction activities supported by the MWA have been executed under contracts worth more than \$12 million with the SKA Observatory and the Commonwealth Government. Much of these funds have been directed to firms that operate within WA.³³

Maintaining the MWA to ensure its continued operations provides the unique opportunity for the SKA to develop and build relationships with local contractors and technicians, strengthen local supply chains, and provide the workforce with significant experience before it becomes operational at a much larger scale on all fronts. The delivery and discoveries of the MWA, and ultimately the SKA, will influence decisions and impact the world for decades to come.

²⁸ [Remplan, obtained January 2022](#)

²⁹ Pastoral Land Board, December 2021

³⁰ Department of Primary Industries and Regional Development, obtained January 2022

³¹ Curtin University, January 2013

³² Curtin University, January 2013

³³ Obtained through stakeholder consultations held with the MWA team

Thus, the MWA and SKA projects have supported a flurry of industry activity in Australia, and specifically WA's space industry, connecting with the establishment of organisations such as the Pawsey supercomputing centre and ICRAR (as discussed below). To date, the operations of the MWA have met and exceeded expectations.³⁴

The MWA project team has provided unique value throughout the procurement and tender phases of the SKA development. As significant packages (in some cases with a value excess of €10 million) related to the SKA are released to the market, the MWA team is typically consulted to answer a range of technical queries, with an example shown in the MWAX Correlator case study, below. While the value of this knowledge transfer capability is difficult to quantify, the industry would struggle to respond to procurement requests without this service from the MWA team. Ultimately, this transfer of expertise supports Australian industries and vendors, building on workforce capabilities and aligning with the government's key strategic space objectives.

Case Study: MWAX Correlator

A new correlator, 'MWAX', has been designed with increased functionality to remove data processing limits, supporting more flexible observing modes, and allowing the future expansion of the telescope. MWAX replaces the ageing correlator of the telescope which has been used since the MWA began operating in 2013.

MWAX has involved in-house software development; procurement and benchmarking of state-of-the-art hardware systems; end-to-end testing; deployment, and installation on site; and, finally, commissioning. This highly anticipated upgrade enables a broader range of science cases and increases the quality and availability of MWA data.

MWAX was funded via an NCRIS Contingency Reserve grant provided to Curtin University and administered by Astronomy Australia Ltd (AAL). The Federal Government granted Curtin University \$1 million to enable the MWAX upgrade, providing the telescope even greater capability to process signals captured from the cosmos. Commissioning of the MWAX Correlator is a significant achievement for the MWA.

The correlator enables finer frequency and time resolution observations, which improves the ability to detect new transient sources such as pulsars and fast radio bursts; understanding of the physics of the sun and ionosphere; and the undertaking of simultaneous surveys for extra-terrestrial intelligence.¹ MWAX has been completed and has been in service generating data since the second half of 2021.

The MWAX correlator is a significant investment by the Australian Government that reflects the importance these technologies have for the future SKA project. Continued research and development in this area will directly aid the advancement and capabilities of these technologies in the future, enabling the SKA to draw on and apply these lessons during operations.

Pawsey Supercomputing Centre³⁵

The Pawsey Supercomputing Centre is a key element of the MWA's operational model. It is at the forefront of high-performance computing and provides important support for radio astronomy activities at the MRO. Pawsey hosts all the data generated by the MWA and the IT infrastructure required to serve it to MWA's global user community. Pawsey was originally commissioned in parallel with the MWA, and MWA's unique demands have continued to inform Pawsey's evolution toward SKA readiness.

This supporting infrastructure is a crucial component for the success of the SKA, which will require a further step change in computing power, and two of the world's largest super computers (in South

³⁴ Obtained through stakeholder consultations held with the MWA team

³⁵ The Centre for International Economics, April 2019

Africa and Australia) will be required to do so. In total, approximately 600 petabytes (PB) of data will be collected annually, which is enough to fill around 1 million average laptops.³⁶

The Pawsey Supercomputing Centre can place Australia and its workforce at the forefront of the fourth industrial revolution - the ability to manage, analyse, and interpret vast datasets. 95% of companies globally have expressed the view that managing large amounts of unstructured data is one of their greatest hurdles and will likely become more prevalent as data becomes more valuable.³⁷ Pawsey offers the chance for Australia to gain access to technical capabilities to support growth for emerging data scientists and new global commercial opportunities.

The MWA operations team at Curtin University has recognised the need for greater capacity for data storage retention and the ability to review existing data archives. The current Pawsey Supercomputing Centre capacity is limited to 40 PB for the MWA and currently stores 38.5 PB. For the MWA to continue improving performance, more data must be captured quicker for analysis and review. The team undertook an exercise to negotiate an increment cap increase of 10-20 PB and held discussions with the WA Government to review and destroy historical data, requiring an exemption from Government asset management regulations. The capacity increase and ability to continually refine the quality of archived data is one example of an obstacle amongst modern high-powered computer equipment and software in astronomy. Learnings from the MWA can be practically applied to future supercomputers in Australia and in executing the SKA.

International Centre for Radio Astronomy Research (ICRAR)³⁸

ICRAR was created with the direct purpose of supporting Australia's bid to host the SKA. Founded in 2009 by Curtin University and UWA, funded by the State Government of WA and the two universities, ICRAR now hosts over 200 staff and postgraduate students and is internationally renowned as a centre for science, engineering, and data processing. ICRAR works to attract world leading scientists and fosters collaboration for the MWA, SKA, ASKAP, and other facilities.

A spectacular example of ICRAR researchers making a fundamental discovery with the MWA is the discovery of a source of radio waves in our Galaxy that underwent bursts every 18 minutes over the course of three months in 2018. This discovery was only made due to the wide field of view of the MWA, and the fact that MWA data could be stored and reanalysed from the archive. This case study is expanded on in Chapter 3.5, below.

GCo Australia³⁹

GCo is a Geraldton based electrical contractor that has been part of the MWA journey since 2008. The relationship between the MWA and GCo is one of mutual development and demonstrates how business partners can successfully shape challenging projects in regional Australia, using a regionally based workforce. As GCo's understanding of the demands of the MWA and radio astronomy has evolved, so too has the scope of its contribution. Based on experience deploying and maintaining the MWA, GCo was commissioned by SKA (via Curtin) to develop and cost a deployment plan for the SKA antenna stations.

Recently, GCo worked on the CSIRO ASKAP facility. GCo has highlighted that employees enjoy working on exciting and unique projects where collaboration and problem-solving are paramount. Murray Hadley, CEO of GCo said that while working on specialised projects has challenges, problem solving in a collaborative and innovative environment whilst building client relationships comes with invaluable benefits. Mr Hadley specifically called out one instance where GCo and the Curtin University team collaborated to achieve radio silence through applying various earthing methodologies, a lesson that will be taken into the SKA. Over time, GCo has built out a collaborative

³⁶ Data Centre Dynamics, obtained January 2022

³⁷ Rohit Kulkarni, February 2019

³⁸ The International Centre for Radio Astronomy Research, obtained November 2021

³⁹ Obtained through stakeholder consultations held with the GCo Australia

relationship, bringing experience and practical expertise of the region, while the MWA team bring theoretical and scientific solutions, which is mutually beneficial, building a unique working culture of trust, loyalty, and transparency.

The nature, duration, and scoping requirements of MWA and potential SKA operations provide businesses like GCo with continuous, reliable, and certain work. Benefits of being able to plan long term provide commercial security and confidence to employers, encouraging an increased uptake of apprentices and employees. Long term workforce planning provides workers in the area opportunities to develop transferable skills, exposing them to various technologies and sectors such as renewable energy and mining.

Key learnings ascertained through working on the MWA directly impact CGo and other companies across the region. One such example includes recognising the design and component similarities between the MWA and large-scale solar farms, and the management of assets that include thousands of similar parts configured in various ways. The MWA and SKA have exposed GCo to innovative techniques to automatically track and trace components across the world, something which is being communicated to other contractors and will be particularly relevant for the global construction partnership and eventual asset maintenance of the SKA.

Building and developing business partnerships is vitally important for the local, state, and national economies. Training development programs, expansion of the workforce, and increased investment within Australia contribute to increased economic activity, as detailed further in Chapter 5.

3.5 Scientific impact

Table 5 provides a summary of the MWA’s performance outcomes to date. The MWA’s contribution is evident through many of the breakthrough discoveries and findings being published each year and the amount of quality data captured.

Table 5: Scientific Impact⁴⁰

| | | |
|---|--------------------------------------|--|
| 30-40 | 21,170 | 35,800 |
| Average papers published in peer reviewed journals each year since 2013 | Observing hours completed since 2013 | Terabytes (TB) of data captured since 2013 |

The MWA offers substantial value to scientific and academic communities around the world and has directly supported several breakthrough discoveries, including, but not limited to:

- ▶ Revealing new ionospheric structures in the Earth’s upper atmosphere, critically important for understanding energy sources present on Earth’s doorstep to Space;⁴¹
- ▶ Discovering a mysterious object in our Galaxy that produces powerful bursts of radio waves every 18 minutes, possibly a dead star with an intense magnetic field;⁴²
- ▶ New limits on the Epoch of Reionisation, the period when the first stars and galaxies formed, more than 13 billion years ago;⁴³

⁴⁰ Various sources, EY analysis

⁴¹ Loi et al., May 2015

⁴² Hurley-Walker et al., January 2022

⁴³ Trott et al., February 2020

- The cataloguing of 300,000 galaxies, including an all-sky survey that resulted in the first radio-colour panorama of the galaxy.⁴⁴

To date, the MWA has produced close to 40 PB of data, which has been archived, curated, and made available to users globally via a sophisticated access portal at the Pawsey Supercomputing Centre. The captured data have supported a formal project membership of over 250 individual researchers, 127 of which are attached to the Australian institutions. These researchers have produced 170 refereed publications based on MWA data. A further 106 refereed publications have been generated outside the MWA consortium, as MWA data have been released to the world's astronomers.⁴⁵

Collectively, the 276 publications have attracted 10,630 citations. Approximately 60% of MWA publications are led by Australian researchers and 99% of MWA publications have at least one Australian author. In 2015, the MWA project won the Space Science award at the Thompson Reuters' Australian Citation and Innovation Awards.⁴⁶

A significant fraction of MWA research has been conducted and led by graduate research students, with 25 PhDs completed since 2013 and with 18 currently in progress. In addition, a further nine MSc or Honours theses have been completed and at least eight MSc, PhD, and Honours projects have utilised publicly available MWA data.⁴⁷

Educational benefits through research and productivity

The existence of the MWA encourages and enables greater educational outcomes for STEM students. The MWA's advanced technical ability and accessibly inspires more students to obtain a PhD. A PhD level worker's average earnings are approximately \$29,000 more than those holding bachelor's level degrees.⁴⁸ These extra earnings are factored into the productivity term in the MWA modelling detailed in Chapters 4 & 5, described as PSS, but will continue to provide value to the economy long after the operational lifetime of the MWA.

3.6 Social impacts

The MWA is an asset for the nation and the world. The positive social impact of scientific discoveries and emerging technological capabilities should not be discounted. Scientific discoveries are important in fostering an interested and engaged community and empowering the future space sector workforce.

Programs and events support the industry and expose students and future scientists to the field of astronomy. MWA scientists participate in such events as the annual Astrofest, coordinated by ICRAR and held at Curtin University. Astrofest provides the community the opportunity to look through telescopes, engage with astronomers on recent discoveries, and discuss the latest space phenomena. Education programs and experiences supported by the Indigenous Australian Engineering School (IAES) offer STEM camps at Curtin University exposing engineering students to potential careers in astrophysics and provides the chance for MWA astronomers to communicate directly with students. Existing programs and events are broadly run as a part of STEM or astronomy led initiatives.

The existence of the MWA motivated a collaboration between the Curtin University node of ICRAR and artists from Yamatji Art in Geraldton. The "Ilgarijiri - Things Belonging to the Sky" project resulted in two sold out exhibitions of Indigenous art that travelled around the world and brought in

⁴⁴ Hurley-Walker et al., September 2016

⁴⁵ Various sources, EY analysis

⁴⁶ Various sources, EY analysis

⁴⁷ Curtin University, January 2022

⁴⁸ Australian Bureau of Statistics, August 2016

\$100,000 into the Yamaji Art community. The collaboration turned into Shared Sky, in collaboration with South African artists, resulting in further international exhibitions. Finally, between 2019 and 2021, a collaborative film called Star Dreaming was produced, winning national film awards (and is included in the case study, below). Due to the MWA, astronomers and Indigenous artists have meaningfully connected, shared knowledge, and brought the results to audiences of millions around the world.

MWA generates considerable media coverage, both nationally and internationally. A total of 2,112 media reports were published between January 2017 and October 2021 with internet publications making up 87% of the media output. The amount of media releases directly correlates with important discoveries. 1,021 of the publications over the period were released in 2020, which aligns with significant discoveries such as never before seen images of the Milky Way and the identification of the biggest explosions in the universe's history since the Big Bang. Media releases and the interest they attract, enhance the state and national space industry presence.⁴⁹

Case Study: 'Star Dreaming' documentary combining science with storytelling

Critically acclaimed and WA produced documentary film 'Star Dreaming' premiered in August 2021 at CinefestOZ film festival. The project was a collaboration involving modern scientific astronomy and the oldest living culture of Australia's First Nations people, who have been stargazing for 60,000 years. The 180 degree, immersive 45-minute film narrated by Ernie Dingo brings together the knowledge and visuals of the SKA and the Yamatji people who call the Murchison home. The documentary follows two school kids venturing on a mission to the Murchison to explain and inform viewers about the future SKA project and radio telescopes more generally.

Professor Tingay, from Curtin University and MWA Director, was integral in the development of the documentary and has been working closely with the Yamatji people for the past 13 years. "Over the course of that time, I've learnt an enormous amount, an indescribable amount to get that sort of insight into a completely different perspective on the night sky. But today, what's really important is that that's just the opening of the conversation; we've been able to connect around our mutual love of the sky and that's really led to a deeper discussion and understanding about a much broader set of considerations in indigenous culture, and their lived experience over the last 200-plus years, and what that's meant, and what country means to them," Professor Tingay describes.

The collaboration demonstrated between the scientists and First Nations Australians depicted in the documentary links science with the history of the land in which the telescope sits. The cultural contribution to the arts and engaging the worldwide community had resulted in several accolades and being showcased at the WA Maritime Museum in 2021, with plans for distribution across Australia and internationally in 2022 and beyond.

⁴⁹ Isentia, November 2021



How the MWA has delivered value

4. How the MWA has delivered value

The MWA generates substantial scientific and economic value for Australia and has been a game-changer for Australian radio astronomy engineering.

The construction and operation of the MWA have delivered economic value in many ways. First, through attracting a suite of funding to invest in supporting infrastructure, ongoing funding to support its operations, and through the increase in scientific output that it has enabled. As an international partnership, the MWA has also received significant investment from overseas. The below sections describe each part of the MWA value chain and how this has delivered value to the Australian economy.

The MWA has driven fundamental and applied scientific research and inspired technological innovation, in collaboration with multinationals and Australian SMEs. It has also demonstrated exemplary environmental awareness and cultural engagement. Importantly, the ongoing community outreach and promotion will lift the profile of STEM education. The economic modelling framework used here shows that the MWA also returns value to Australian GDP in addition to improving the skill base of Australians in the sector.

4.1 Back-casting the impact of the MWA

The impact of the MWA has been modelled by applying historical spend and outputs to the EY CGE model, EY-GEM.⁵⁰ The following economic variables have been used to analyse these results:

- ▶ Gross Domestic (or State and Regional) Product (GDP, GSP, GRP) - a measure of economic output calculated as the sum of consumer spending, investment, government spending, and net exports;
- ▶ Full Time Equivalent (FTE) employees;
- ▶ Industry output - total expenditure by industry;⁵¹
- ▶ Net Present Value (NPV) - A summation of what the value of future cashflows are worth in today's dollars at a 7% real discount rate.⁵²

All the results are displayed in comparison to the baseline, a scenario in which the construction and operations of the MWA do not occur. The analysis builds up the impacts by measuring both capital and operating expenditure, and changes to scientific output enabled by the MWA. These results therefore seek to demonstrate the broader societal impact of the MWA, considering its impact on the scientific ecosystem within which it sits.

There are, of course, a range of additional benefits associated with the MWA discussed and identified qualitatively, indicating that the realised economic impact results are conservative in nature.

⁵⁰ The EY-GEM model is EY's proprietary CGE model. A more detailed description of this model and its inputs can be found in the appendices

⁵¹ This number is larger than gross value added (GVA), the industry measurement of GDP, which is an indicator of the goods and services generated in Australia, including wages, profits and taxes, but excludes the spend on industry purchases - Industry output includes all components of GVA, plus all industry purchases

⁵² The 7% real discount rate is used as it is the average economy wide rate of return on investment

Assessing the capital and operating investments of the MWA

One of the most important economic outcomes of the MWA has been the initial and follow-on effects of the construction of the telescope. This investment has allowed for the scientific output and research to occur.

Construction of the MWA has occurred in two phases so far. The first phase of construction took place between 2007 and 2012 and cost \$51 million. The Australian funding component that realised the telescope was worth \$7.8 million. The main contributors to the Australian funding were NCRIS and the Education Investment Fund (EIF).

Across 2015 and 2016, a further \$2 million was invested in the MWA in Phase II, which resulted in a doubling of the number of antenna tiles installed in the array to 256, funded by the Australian Research Council (ARC). The new antenna tiles enhanced the MWA's capabilities by providing the MWA with a greater ability to produce high quality data and increasing its discovery space.

Operational funding has averaged \$1.9 million a year since 2013, which has also been used to cover certain capital upgrade programs. NCRIS has been the prime source of Australian funding, providing an average of \$1.2 million a year. MWA partner institutions have funded a significant percentage of the operational expenditure over the past 5 years, contributing on average \$700,000 per annum, with some of this investment coming from international partners. Together, this funding has supported up to eight fulltime Full Time Equivalent (FTE) employees.

A third capex phase (Phase III) is being considered, which will greatly enhance the output of the telescope, via the installation of 16 new receivers (doubling the current capacity) and improving performance. This will allow for a four-fold increase in the amount of data that can be collected by the MWA and will address the immediate and significant risk of failure due to equipment reaching end-of-life. The Phase III capital budget is estimated at \$3.5 million. Initial funding has been secured through local and international partner commitments.

Scientific output

The capture and storage of data enables an ecosystem of data scientists, engineers, and astronomers. The funding that supports the MWA's operations, from local and international donors, has a direct economic impact, which is measured through changes in output in the Professional and Scientific Services (PSS) sector.

First, the Pawsey data centre provides the critical computing infrastructure to support the MWA, with approximately 4 FTE high performance computing, IT and network professionals supporting the MWA footprint at Pawsey.

Second, most of the economic benefit that is derived from the MWA should be measured based on the change in scientific output. As an example, in Australia, Curtin University has significantly increased its astronomy research group over the last ten years. Approximately 26 Curtin scientists work using MWA data, producing output worth approximately \$6 million a year.⁵³ Further, the MWA supports programs at another six universities around Australia, with researchers regularly applying for funding to use the data from the MWA to undertake research.

Therefore, at any given time, there are several million dollars' worth of research ongoing across Australia, which has been made possible through the data that collected and stored by the MWA and Pawsey. Lastly, the on-going collection and storage of data will continue to support research, and thus, scientific output in the future.

⁵³ Any activity undertaken by a scientist that incurs a cost, wage, or profit. This includes including writing research papers and filing patents, as well as wages and costs of inputs

Outside the scope of this engagement are equivalent studies that are occurring internationally through the MWA partner organisations that serve to further increase the global value that the MWA has brought.

Back-casting results

The modelling confirms the positive impact the MWA has had on the Australian economy, delivering an uplift to Australian GDP of \$7 million in 2021 alone and a total GDP increase of \$58 million since 2010.⁵⁴ The MWA has also supported a significant increase in employment, with an average of 31 extra jobs (represented by FTEs) estimated across Australia since 2010 and 47 jobs in 2021. This compares favourably to the 8 FTEs directly employed by the MWA in 2021 and aligns with the stakeholder mapping and understanding of the number of Australian researchers that have been using the data. As shown in Figure 7, economic activity significantly increases after 2013 when the MWA became operational.

Most of the economic benefit of the MWA is seen in WA where the telescope is located and where the main institutions using MWA data are based. \$49 million of the total \$58 million GDP uplift occurred in WA and on average 24 extra FTE employees were based in WA.

Figure 7: The MWA's past impact on GDP

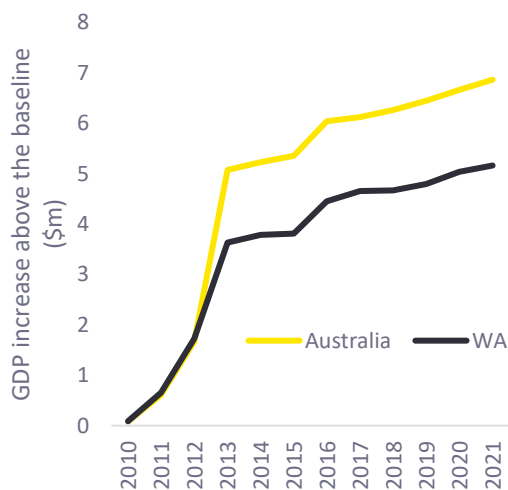
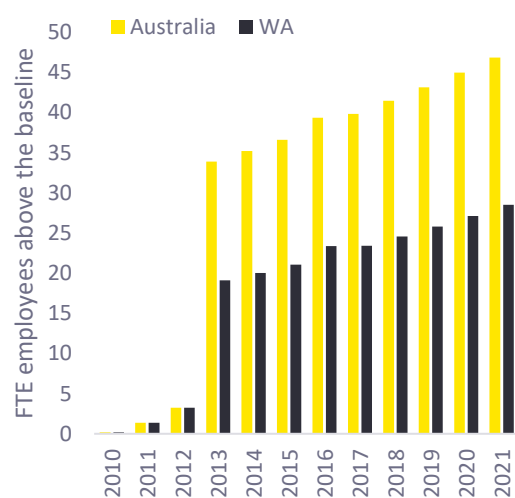


Figure 8: The MWA's past impact on employment



Scientific and professional services is the sector that the MWA has the largest impact on. This is the sector in which science, engineering, and data science sit; each of these are key services that are aligned to the MWA. Over this period of review, output from this sector increased by \$83 million, relative to the baseline, and was the main driver of changes in employment.

4.2 Back-casting the impact of de-risking the SKA, enabled by the MWA

The existence of the MWA has supported the development of the SKA by enabling research and prototyping of various components. This has expedited progress of the SKA and ensured a range of future benefits that flow into the next phase of the SKA's development.

Support of the SKA through existing MWA operations and resources

Technology Readiness Levels (TRL) provide a methodology that can be used to assess the maturity level of a specific technology, such as the scientific instruments that would be used at the MWA

⁵⁴ These impacts exclude the investment in de-risking the SKA, which are shown in the sections below

radio telescope. As shown in Figure 9, there are nine TRL steps, 1 being the lowest, and 9 being the highest.

Figure 9: Technology Readiness Levels⁵⁵

| Technology readiness level (TRL) | Description |
|--|---|
| 1 Basic principles observed and reported | Scientific research begins to be translated into applied research and development. Examples include paper studies of a technology's basic properties. |
| 2 Technology concept and/or application formulated | Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be proof or detailed analysis to support the assumptions. Examples are limited to analytic studies. |
| 3 Analytical and experimental critical function, characteristic proof of concept | Active research and development is initiated. This includes analytic studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative. |
| 4 Component and /or breadboard validation in laboratory environment | Basic technological components are integrated to establish that they will work together. This is relatively low fidelity compared with the eventual system. Examples include integration of ad hoc hardware in the laboratory. |
| 5 Component and/or breadboard validation in relevant environment | Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include high fidelity laboratory integration of components. |
| 6 System/subsystem model/prototype demonstration in a relevant environment | Representative model or prototype system, which is well beyond that of TRL 5, is tested in its relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment. |
| 7 System prototype demonstration in an operational environment | Prototype near or at planned operational system. Represents a major step up from TRL 6 by requirement demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, a vehicle, or space). |
| 8 Actual system completed and qualified through test and demonstration | Technology has been proved to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications. |
| 9 Actual system proven through successful mission operations | Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions. |

The MWA has played a key role in expediting the development of SKA prototypes, bridging the gap between TRL 1 and TRL 6 through testing that has been done on-site. Reaching SKA TRL 6 will continue to be enabled through MWA's support by:

- ▶ Applying technical expertise, knowledge, and experience obtained from MWA operations applied to troubleshooting and execution of the SKA;
- ▶ Utilising experienced local contractor relationships and supply chain networks which regularly supply, maintain, and repair various components of the MWA (e.g., GCo);
- ▶ Leveraging the Murchison site where the MWA resides by utilising existing power supply and tools to execute the SKA prototype.

Benefits associated with the development of the SKA prototypes with ongoing operation and improved performance upgrades of the MWA include:

- ▶ Testing the SKA prototypes in an operational environment past the design and concept stages, the MWA gives a much higher confidence to the TRL pathway;
- ▶ Removing obstacles relating to development and evolution of calibration and processing techniques that would not be realised until an operational SKA prototype was built.

The existence of the MWA has enabled a spend of \$12 million to test elements that will be used in the SKA, supporting an improvement in TRLs. The primary focus has been to trial the SKA prototype in the field, which would not be possible without the existing MWA infrastructure. This improvement in TRLs has helped to enable the SKA Organisation to move to the procurement phase of the project.

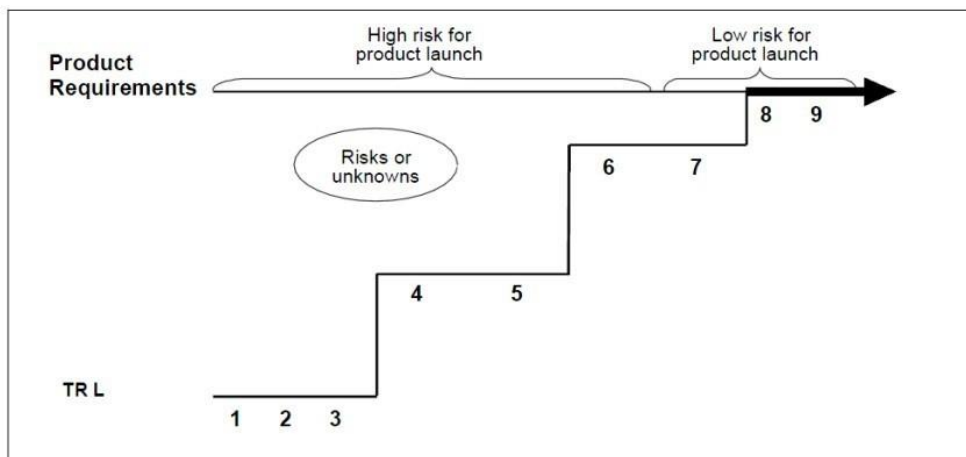
⁵⁵ US Government Accountability Office, January 2020

A high performing MWA will enable a range of further testing and improvements over the next few years, with up to an additional \$1.2 million per annum expected to be spent in critical areas of the array related to the SKA.

In terms of capturing these benefits, the analysis focuses on the impact that these programs have had in supporting the de-risking of the SKA and has been modelled separately from the back casting results that have been presented above. While the analysis performed cannot capture the total benefit of enabling the SKA to move to the procurement and construction phase, the impact on the potential for higher costs and the risk of scheduling delays in this phase of the SKA are considered.

Research into the link between TRLs and costs has demonstrated that construction and scheduling risk remains incredibly high at the early TRL stages of a technology, as depicted in Figure 11 below. Technology maturity and progress is a significant consideration due to the implications to program cost, scheduling, and the fundamental success of any project. Research from 68 defence and technology projects found a 46% cost growth (costs exceeding budgeted estimates) associated with programs from phase 2 (early TRLs), and 16% from phase 3 (more mature TRLs).⁵⁶

Figure 10: Programmatic risk as a function of TRL⁵⁷



Based on these studies, the capital expenditure that the existence of the MWA has enabled will translate into some significant savings for the SKA. To quantify these, a conservative saving of 20% on key components has been modelled. Current estimates for the construction of the SKA indicate that the array will cost in the region of €110 million for SKA Phase I, for which a €22 million saving has been applied, enabled by moving up the TRL curve. This economic impact has been modelled and presented below.

Lastly, schedule delays will have a big impact on costs for the SKA. Should a one-year delay occur for Phase I construction, the impact is estimated to be in the region of €14 million based on the annual and fixed construction support costs that are dedicated to the SKA.⁵⁸ Changes and adjustments in the budget envelope will likely have unintended consequences and further affect the overall scope of the SKA. For example, fewer antennas deployed due to cost overruns in the beginning phases of construction could lead to decreased performance and scientific output, substantially reducing the expected benefits of the SKA.

⁵⁶ Christopher R. Bissing, March 2021

⁵⁷ Bernard El- Khoury and C. Robert Kenley, May 2012

⁵⁸ SKA Organisation, November 2020

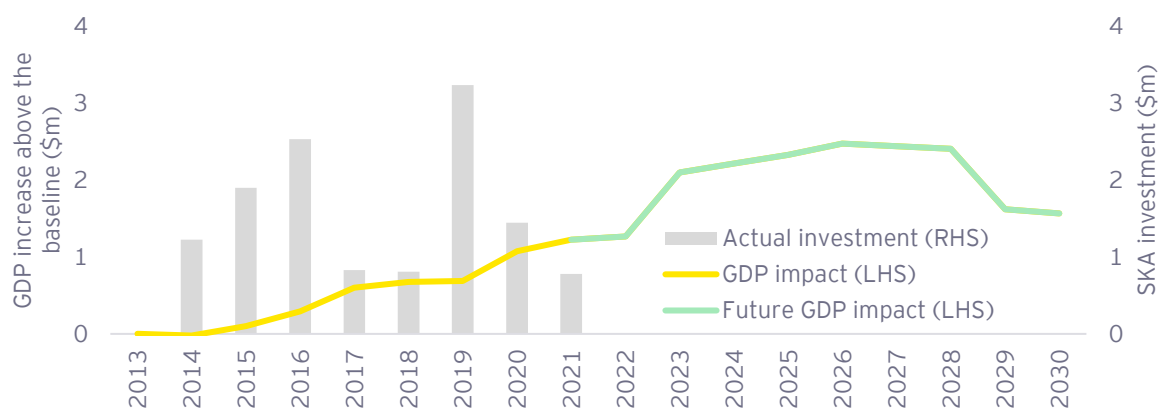
Back-casting results

The existence of the MWA has allowed the SKA program to move from TRL 1 to TRL 6 in many areas. This produces significant cost and time savings and leads to economic spill overs, contributing to Australia's GDP, as driven by two factors:

- ▶ The MWA has facilitated prototyping activity. This prototyping has involved construction planning and construction costs, both of which deliver a direct economic benefit. An investment of \$12 million from 2013 to 2021 through the MWA enabled SKA prototyping. This has led to an uplift in Australian GDP of \$4.6 million in this time and is shown as the GDP impact in the figure below. This figure is still relatively small as the benefits that flow through from savings on the SKA have yet to occur.
- ▶ Prototyping has enabled economic benefits in the cost saving that will occur for the SKA. This is predicted to result in average saving of \$0.8 million a year, based on the savings that accrue from the Australian investment in the SKA, and not the full cost of construction in the SKA. This is driven by the improvements in productivity in the construction and allows for an uplift of \$18.5 million in GDP above the baseline from 2022 to 2028 and is shown as the future GDP impact in the figure below.

Combined, it is forecast that this prototyping activity for the SKA will deliver economic benefits of approximately \$23 million from 2013 to 2030.

Figure 11: De-risking the SKA's impact on GDP



4.3 Total back-casting economic impact

The total economic contribution of the MWA (including de-risking the SKA) is a \$63 million uplift in GDP. This figure peaked in 2021 at \$8.2 million above baseline levels. Further, and not captured in the figures below, is the savings in construction of the SKA, which will accrue over its construction, due to the investment in prototyping enabled by the MWA. This delivers an additional \$18.5 million uplift in GDP, which can be recognised today.

The projects have also delivered significant employment benefits with an average extra 32 FTE employees in the Australian economy each year. The professional and scientific services sector drives both the increase in employment and GDP, with an \$82 million increase in output above baseline levels.

Figure 12: The MWA's past impact on GDP

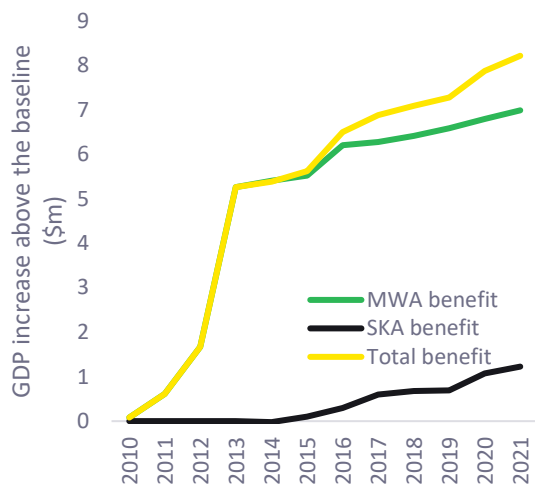
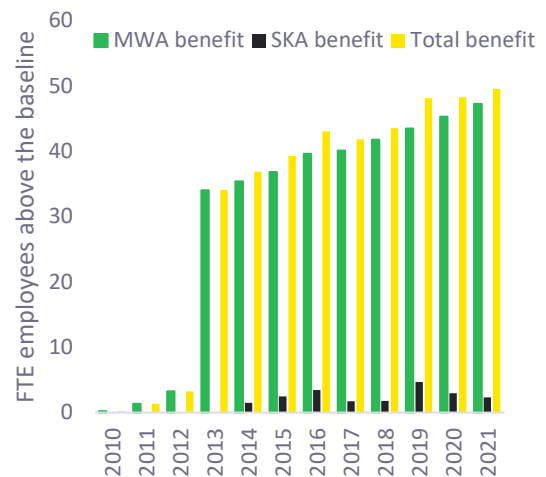


Figure 13: The MWA's past impact on employment



Combined, the GDP impact is \$81.1 million at the cost of \$34.8 million, meaning that every dollar invested in the MWA has resulted in a greater than \$2 increase in Australian GDP. A typical economic evaluation metric is a benefit-cost ratio (BCR). In this instance, the benefit-cost ratio of back-casting the MWA is 2.33. Table 6 below displays the recent results of infrastructure projects and the associated benefit-cost estimates, for which the MWA results compare favourably.

Table 6: National projects and benefit to cost⁵⁹

| Project | Benefit to Cost ratio |
|--|-----------------------|
| Brisbane metro | 2.40 |
| Murchison Widefield Array | 2.33 |
| University of Tasmania technology precinct | 1.95 |
| Eyre infrastructure project | 1.30 |
| Sydney metro city and southwest | 1.30 |
| Gold coast light rail | 1.10 |

4.4 Considering international astronomy infrastructure

As part of the desktop research exercise, similar projects have been identified and examined to gauge the different ways in which these types of facilities provide value to different communities. These entities were also benchmarked to the MWA at a high level.

In general, the scale of the MWA and its relationship to the SKA is relatively unique, influencing the ability to find projects of a similar scale or scope. While many projects were identified and compared, the following example discusses the Atacama Pathfinder Experiment (APEX) as a useful benchmark for the MWA.

⁵⁹ Infrastructure Australia, February 2020

The APEX Telescope

The APEX Telescope is a 12-metre diameter telescope, operating at millimetre and submillimetre wavelengths (between infrared light and radio waves), located in the Atacama Desert in Chile. APEX began operations in 2005 and is a single-dish telescope based on a prototype antenna constructed for the Atacama Large Millimetre/submillimeter Array (ALMA) project. APEX is a pathfinder for ALMA, and pioneered research into the physics of the cold universe that was critical for establishing ALMA around a decade later in 2014. The two telescopes now complement each other, and APEX remains competitive in an era of a fully operational ALMA.⁶⁰

APEX de-risked ALMA in a similar way to how the MWA has supported the de-risking of the SKA.

The APEX telescope has contributed to other major astronomy projects, including the Event Horizon Telescope (EHT) Consortium. Like the MWA, the APEX telescope contributes to monumental scientific discoveries, including ground-breaking imaging of the shadow of a black hole, as part of the EHT Consortium. APEX has also led to significant discoveries as a standalone telescope, including the first observations of hydrogen peroxide in space.

While utilising different receivers, infrastructure, missions, and operations, APEX is a useful comparator to the MWA due to its relationship with ALMA and the comparable scale of its operations. Critical aspects of the two projects are provided in Table 7 and discussed below.

Both telescopes exist in challenging physical environments.



⁶⁰ Rene A. Ong, July 2017

Table 7: Benchmarking the MWA with APEX

| | MWA | APEX |
|---------------------------------|--|---|
| Operational commencement | Commenced operations in 2013 | Commenced operations in 2005 |
| Operating budget | Approximately \$2 million (AUD) per year | Approximately \$9.7 million (AUD) per year* |
| FTEs (regular operating period) | ~8 FTEs in a regular operating period | ~16 FTEs in a regular operating period |
| Publications | Between 30-40 publications a year. Over 250 publications since 2013 | Between 40-50 publications a year. Over 800 publications since 2006. |
| Observing hours | Around 2,500 hours of on-sky science time per year | Around 4,400 hours of on-sky science time per year |
| Data collection | On average 4,400 TB data per year | On average 130 TB data per year for the whole of the ESO |
| Science goals | Study of the Epoch of Reionisation, transient phenomena, galactic and extragalactic surveys, searches for extra-terrestrial intelligence, pulsars and Fast Radio Bursts, Solar and Heliospheric science. All at low radio frequencies. | Studying the formation of stars, planets and galaxies, including the physical conditions of molecular clouds. |

Sources: MWA data, annual and quarterly reports, European Southern Observatory Annual Reports.

*Based on current investment agreement of €18.5 million over 2018 - 2022.

**Based on Astron Radio Observatory team managing the Netherlands facilities only.

While both entities produce a similar number of publications per year based on data collected, there are some crucial distinctions between APEX and the MWA. Notably:

- ▶ APEX has produced a much higher number of publications, due mostly to its longer operational life to date;
- ▶ The MWA currently operates on significantly less funding per year than the APEX telescope. Some of this may be attributed to differences in infrastructure and operating requirements, though the significant difference in FTEs for a regular operating period also indicates that the MWA is operating on a very lean margin and is accumulating project risk as a result; and
- ▶ APEX has improved its operations over time. APEX received major investment in 2017 after ten years of operations to overhaul the telescope and upgrade site and infrastructure and remains competitive in an era of a fully operational ALMA. Furthermore, APEX partners are currently exploring operational models to allow APEX to continue operating beyond 2022 under a new agreement that is cost neutral to the ESO.

It is interesting to note the similarities the MWA shares with APEX in scientific output, but the differences in funding received. The MWA has half the FTE employees and receives a fifth of the annual funding but only slightly trails APEX in scientific outcomes per year.



Opportunities to drive
future value

5. Opportunities to drive future value

The MWA is moving into a critical period of its operations, focussing on continued delivery of advanced scientific outputs and implementation of the SKA. Reflecting on current contributions, and potential future economic growth pathways can enable strategic planning that maximises the benefit of the MWA in the pre-SKA era (2022 - 2028).

The MWA's current funding envelope exposes the project to potential risks. Comparison with international projects (such as the APEX telescope) reveal that the MWA is operating with modest resources.

This chapter examines both the implications of maintaining the current budget envelope, potential growth opportunities for the MWA, and the potential benefits that could be realised under various scenarios.

5.1 Future development pathways for the MWA

The MWA has already delivered significant value for its investment, with the value of scientific discoveries far exceeding initial expectations. Unique discoveries have influenced other activities and spurred research by others, often using data from other telescopes. This is notable, considering that the MWA has operated with a highly conservative and minimal operations budget since its initial commissioning in 2013. Moving forward, enhanced funding and investment in the MWA will allow it to maintain, upgrade, and expand upon its existing infrastructure and employment profile to bring about significant additional value for its key partners, Australia, and the global astronomical community.

To explore these opportunities, four forward development pathways have been constructed to illustrate where the MWA could expand its impact. The purpose of this exercise is exploratory: to demonstrate how the operations of the MWA have the potential to build on the value delivered to date, by reinvigorating the mission of the MWA.

Exploring this impact demonstrates that the MWA has the capacity to deliver significant economic benefits for the space, scientific research, and higher education industries in the Mid-West region, throughout WA, and Australia.

Four key development pathways are shown in Figure 14 and discussed below.

Figure 14: Future MWA scenarios

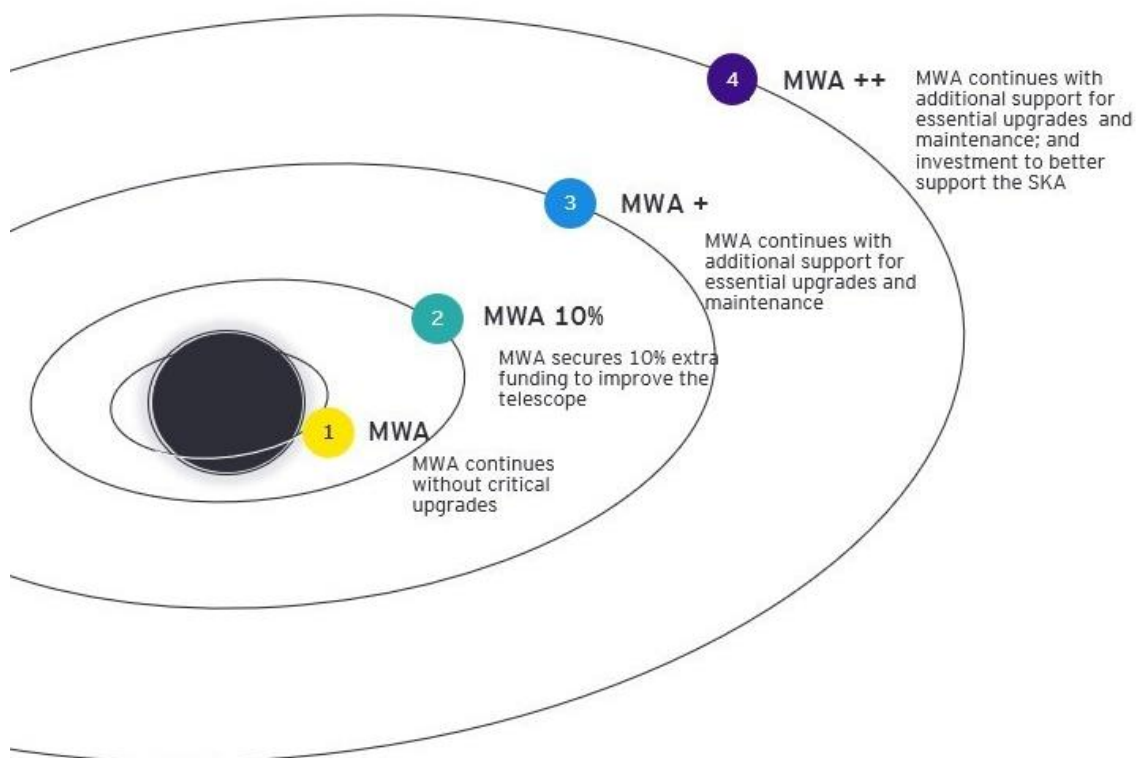


Table 8 summarises the funding scenarios and outlines the total NCRIS funding required to deliver each scenario.

Table 8: MWA scenario expenditure

| | Past* | Current | MWA +10% | MWA +147% | MWA +447% |
|---|-------|---------|----------|-----------|-----------|
| MWA Direct | | | | | |
| FTEs - Total | 7.9 | 7.9 | 8.5 | 12 | 17 |
| Average income (p.a.) (\$'M) | 1.9 | 2.2 | 2.4 | 3.7 | 5.5 |
| <i>Cash (NCRIS)</i> | 1.2 | 1.5 | 1.7 | 3.0 | 3.2 |
| <i>In-kind</i> | 0.7 | 0.7 | 0.7 | 0.7 | 2.3 |
| Average cash expense (p.a.) (\$'M) | - | 1.8 | 2.2 | 3.7 | 5.5 |
| Additional Investment (\$'M) | 9.8** | - | 3.5 | 7 | 28.5*** |
| <i>Additional cash to upgrade (NCRIS)</i> | - | - | - | 3.5 | 25 |
| <i>Partner contributions (upgrades)</i> | - | - | 3.5 | >3.5**** | >3.5**** |

Note: *This represents the inputs that have been used for the back-casting results explored in Chapter 4

** The domestic construction funding of the MWA was \$7.8 million, while the total cost for Phase I was \$51 million. \$2 million of funding was allocated to Phase II

*** This represents \$25 million for doubling the MWA size plus \$3.5 million for data connection upgrades

**** These two scenarios will likely attract greater partner contributions due to the scale of upgrades

1 MWA - continued current funding (MWA +0%)

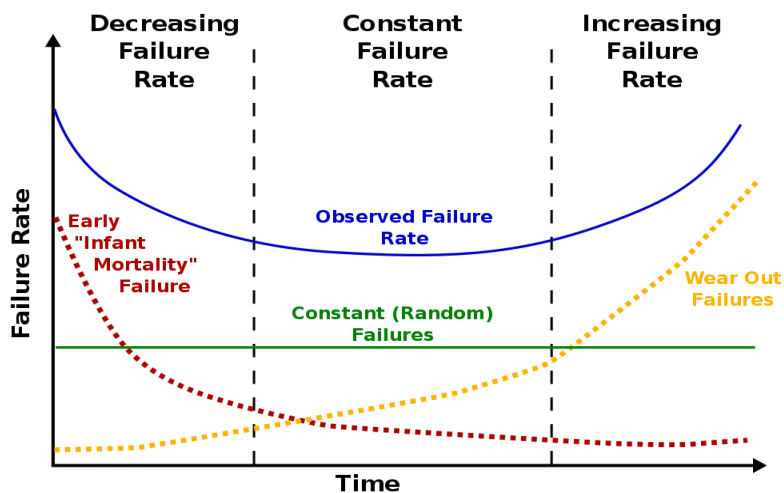
The baseline scenario reflects the continuation of current funding trends. The current level of funding allows the MWA to maintain most of its current hardware. However, as the MWA's original infrastructure continues to age, current levels of funding will prove insufficient to guarantee continued performance and provides no capacity to upgrade or expand upon this foundation. In this scenario, 7.9 FTEs will continue to be directly funded by the MWA for core operational activities.

This scenario will see the continuation of the approximately \$2.2 million of funding per year that the MWA receives, meaning that funding is expected to fall in real currency terms. 68% of the funding envelope is expected to be derived from NCRIS, representing just 1% of the NCRIS budget in a standard year.

Consequences of maintaining the current funding envelope

Funding dedicated to the MWA has already been falling in today's money and has already resulted in delays for crucial maintenance and upgrades needed on the site. As the telescope ages, its maintenance demands will be expected to increase. The resulting cash shortfall is likely to lead to increased unplanned downtime, which is reflected by the Reliability Bathtub Curve below (Figure 15). This trend has already been apparent at the MWA, with unplanned downtime increasing from a reasonable average of 7.8% from 2013- 2018, to an average of 24.1% from 2019.⁶¹

Figure 15: Reliability Bathtub Curve⁶²



As a result, maintaining current funding levels poses a risk to the quality of the data produced by the MWA, endangers funding commitments from other local and international partners, and has potential ramifications for the execution of the SKA. These include:

- ▶ Reduced operating expenditure (due to limited funding) would continue the trend in performance degradation:
 - ▶ The most likely scenario (and one that has been modelled here) would result in the failure of 2 of the 16 currently installed receivers over the next five years, reducing output from the MWA by approximately 12.5%;

⁶¹ NCRIS - AAL Quarterly Project Reports, various dates

⁶² Edward Wyrwas, January 2011

- ▶ Further, the failure of these receivers means that there may be a lower level of flexibility in maintaining and reconfiguring the system of antennas and receivers collecting data, likely resulting in further productivity losses (akin to 8%);
- ▶ Overall, this approximate 20% loss of data output from the MWA is a conservative scenario based on field experience from similar technologies. The applied assumption is well below other electrical hardware degradation rates benchmarked in Table 9.

Table 9: Degradation benchmarking

| Benchmarked components | Degradation exceeding design life (%) |
|-------------------------------------|---------------------------------------|
| Solar panels (PV) ⁶³ | 80% |
| Electronic capacitors ⁶⁴ | 60% |

It is critical that this unplanned downtime is minimised. The consequences of increased downtime due to unscheduled repairs on data integrity include:

- ▶ Reduced capture and production of reliable, high-quality data from the array leading to a reduction in discoveries by scientists in Australia and internationally;
- ▶ Greater scepticism of data quality being produced;
- ▶ Increasing lack of data confidence in the most extreme case could lead to withdrawal of funding for research projects relying on the MWA data.

Estimates of the implications of this scenario are set out below.

Funding the MWA at current levels sees economic outcomes above the baseline until 2030. On the conservative assumption that the reduction in output from the MWA results in a similar reduction in scientific discoveries from the array, GDP is still \$5.3 million above the baseline in 2030 (albeit lower than today's \$7.0 million uplift to GDP estimated in 2021) and delivers total returns of \$62 million over the next nine years. Most of this economic activity occurs in WA, delivering an uplift to GSP of \$5.0 million in 2030; equivalent to 94% of the total economic benefit.

The continued operations of the MWA still support employment opportunities across the MWA ecosystem, delivering on average 42 extra FTE employees across the economy over the next nine years. Of these 42 extra employees, 32 are located in WA.

⁶³ Sara Wolf, obtained February 2022

⁶⁴ Mark Harris, April 2021

Figure 16: The MWA's future impact on GDP at current levels

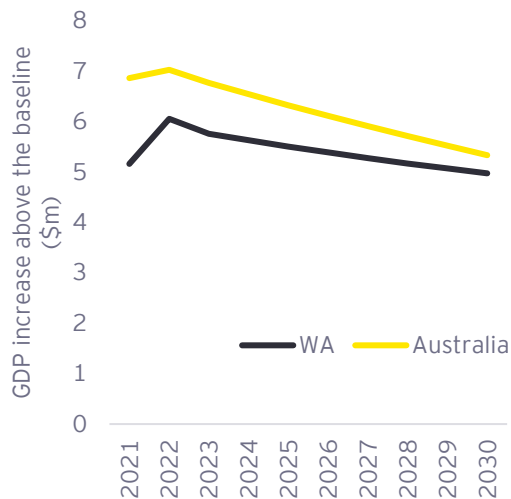
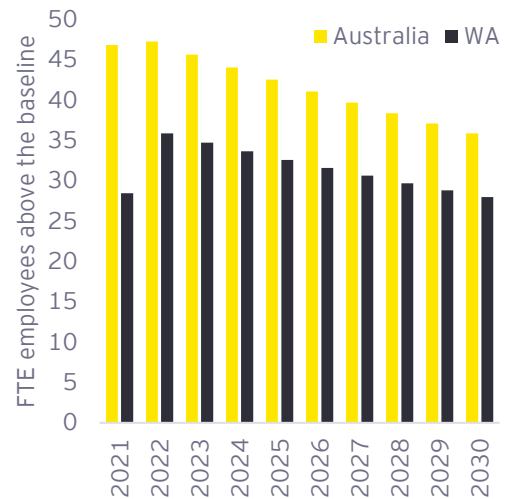


Figure 17: The MWA's future impact on employment at current levels



Overall, the ageing instruments and the risk of catastrophic failure of the array will lead to a reduction in scientific and professional services output in this scenario. Practically, this means that existing astronomers in Australia will have access to progressively less funding to do research over the next few years. The compounding effect of this would be passed on to the SKA through an increased probability of the “valley of death” scenario becoming a reality. By far, the largest risk associated with this scenario is a lack of infrastructure, people, and institutions to support the successful implementation of the SKA over the next decade.

2 MWA +10% - MWA operates with additional 10% NCRIS funding

Under this scenario, a 10% incremental increase in funding from the Australian Government has been modelled to determine the effects on MWA operations, productivity, and viability over the forecast horizon.

This 10% uplift is seen as **the minimum practical case for the continued high impact operations with an upgraded MWA**. Under the current funding arrangement, the Commonwealth provides \$1.5 million in direct support through the NCRIS program. An additional 10% funding means that ongoing contributions would equal \$1.65 million per annum, a difference of \$150,000 a year. This supports the continued operations of the facility, helping to maintain the current assets, and, more importantly, releases an additional **\$3.5 million of committed investments** from partner organisations to enable critical upgrades to parts of the array.

The \$3.5 million investment will substantially upgrade the array, doubling the receivers installed from 16 to 32 and enabling the full operation of the currently installed 256 tiles. Currently, the 16 receivers installed on site can only receive information from 128 of the 256 tiles at any time. The improved capability will result in a four-fold increase in output, affording the opportunity to increase research and discoveries by all individuals using the data (locally and internationally) in the lead up to the SKA.⁶⁵

This scenario means that the MWA’s operational budget going forward increases to \$2.35 million per year, with 70% of this funding coming from NCRIS. This represents just 1% of the NCRIS budget in a standard year and is still well within the change in funding allocated to NCRIS as part of the

⁶⁵ \$2.5 million in the form of digital systems (hardware) contributed by an MWA partner organisation/country - the remaining ~1 million cost will be met from cash contributions from other MWA member countries

Australian Government's efforts to stimulate investment in science. Importantly, this notional increase in funding and commitment unlocks substantial value. Scientific and professional services output is expected to improve in this scenario in two ways:

- ▶ Firstly, through the change in funding allocated to the sector;
- ▶ Secondly, a strong increase in productivity of the scientists using the data from the MWA to undertake research. The same community using more (and better data) will result in more discoveries, in turn attracting more funding from other institutions/partners.

Further de-risking of the SKA

The successful execution of MWA Phase III, enabled by scenario MWA +10% will see a further 16 receivers built and connected to the existing array increasing the quality of data captured.

This upgrade of the array allows the MWA to enhance its supporting role in the de-risking of the SKA, testing new array configurations (a mix between older and newer equipment), and higher levels of storage at Pawsey. The lessons gained through procurement, installation, system integration, and testing aid in developing transferable skillsets that local teams could apply during the construction of the SKA. The increased data collection, computing power and capability will provide data analysts valuable technical troubleshooting experiences before an operational SKA comes online in 2028/29.

The MWA will continue to be available to support SKA prototyping activities and to assist in advancing other SKA sub-systems toward higher TRLs.

MWA +10% leads to increased economic outcomes

A 10% funding increase allows for increased scientific output which would drive economic returns over the next decade. This leads to an increase to Australian GDP of \$25 million in 2030, relative to the baseline, and an overall increase to Australian GDP of \$222 million over the next decade, \$160 million above the current funding scenario. Therefore, a notional 10% increase in funding from NCRIS results in a quadrupling of the economic impact from the MWA, notwithstanding the flow on benefits to the SKA.

Figure 18 : MWA +10% future impact on GDP

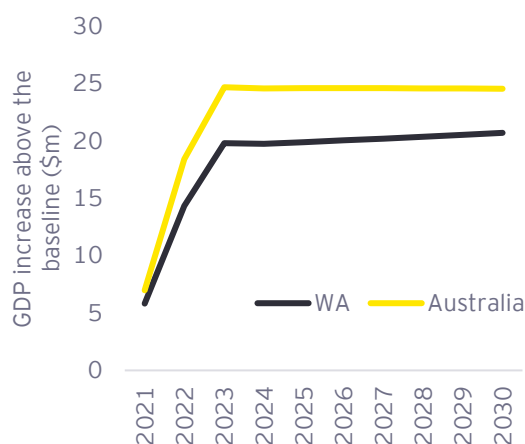
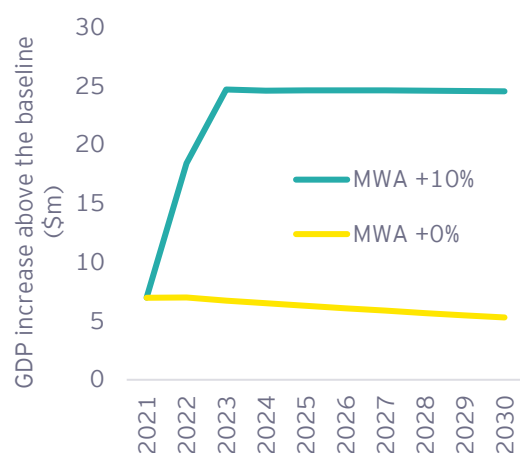


Figure 19: MWA +10% GDP compared to MWA



Equally, the MWA+10% scenario delivers a significant impact to employment, creating an average of 85 FTE employees above the baseline in Australia. Most of these jobs are in WA, which sees an increase of 61 FTEs. There are on average 40 more FTEs supported across the Australian economy in this scenario compared to the scenario in which there is no increase in MWA funding. This increase in employment is driven by the increased productivity of the MWA instrument. This enables greater scientific output, which in turn encourages more universities and institutions to

allocate staff to work on MWA data. This results in a \$354 million change in output in the professional and scientific services sector over the decade.

Figure 20: MWA +10% future impact on employment

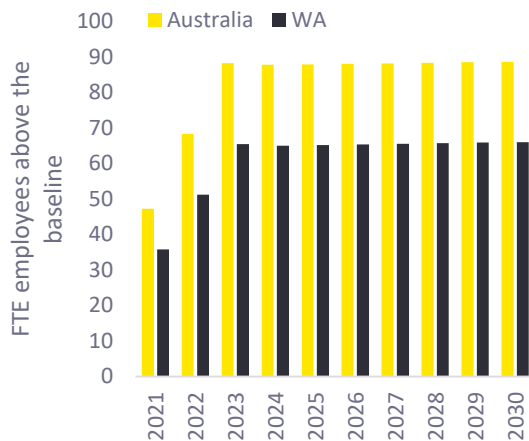
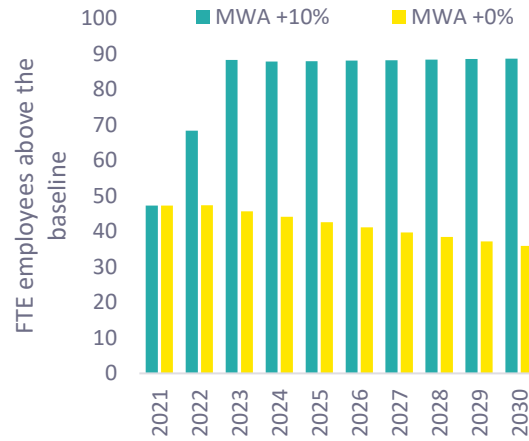


Figure 21: MWA +10% employment compared to MWA



3 MWA +147% - MWA operates with additional 147% increase in NCRIS funding

Under the MWA +147% scenario, the MWA benefits from all the funding arrangements highlighted in the MWA +10% scenario above, as well as additional funding to undertake targeted activities. This funding will support four additional FTEs to be directly employed by the MWA. These employees will assist with critical infrastructure and scientific engagement, and in doing so will raise the impact that the MWA has on Australian scientific output.

Under the MWA +147% scenario, the Commonwealth is assumed to increase funding to \$3 million per annum via the NCRIS program. A key part of this scenario is the implementation of a system software upgrade that will allow for additional preventative and end-of-life maintenance.⁶⁶ This will minimise downtime, improve safety, and reduce risk of failure.

These upgrades will reduce the downtime leading to an increase in capital productivity, as more data will be collected. This improvement is estimated to be around 5% relative to the output seen from the MWA +10% scenario above.

While the MWA +10% scenario has included the expansion of the array, in this case (and above), older equipment is still utilised on part of the facility (i.e., continue to utilise the 16 old receivers even though these have reached their end-of-life ranges). The MWA +147% scenario will replace the 16 end-of-life receivers, to achieve a full fleet of 32 new receivers to continuously support 256 tiles.

De-risking the SKA

The increased FTEs for operational support, additional funding to pre-empt maintenance issues, and software upgrade and deployment, will continue to de-risk the SKA. Key benefits to manage interface risk include:

⁶⁶ Obtained through stakeholder consultations held with the MWA team
Curtin University
The economic and social impact of the Murchison Widefield Array in Australia
A member firm of Ernst & Young Global Limited
Liability limited by a scheme approved under Professional Standards Legislation

- ▶ The enablement of further research on computing and software to support the operations of the SKA;
- ▶ The enablement of a system upgrade to improve resilience of MWA operations and reduced instance of downtime and risk of ceasing operations before the SKA is ready;
- ▶ An allowance for alternative data connection options to be explored at scale to reduce electrical consumption on site, lower utility costs, and hasten remediation should downtime occur, providing a trial for the SKA.

MWA +147% drives further economic outcomes

The additional funding that the MWA receives in the MWA +147% scenario delivers a further increase in economic benefits. The key maintenance program improves the productivity of the MWA, allowing for greater scientific output in the sector. This scenario sees a \$27 million increase in GDP above the baseline in 2030, which is \$22 million more than in the MWA +0% scenario and approximately \$1million greater than the MWA +10% scenario. This delivers a total economic benefit of \$240 million to GDP over the next nine years, a \$178 million uplift compared to the MWA +0% scenario and \$18 million more than MWA +10% scenario. The direct funding of the MWA increases by \$1.35 million annually when compared to the MWA +10% scenario. These improvements are driven by the reduction in MWA downtime, increased spending on preventative maintenance and increased scientific output.

Figure 22: MWA +147% future impact on GDP

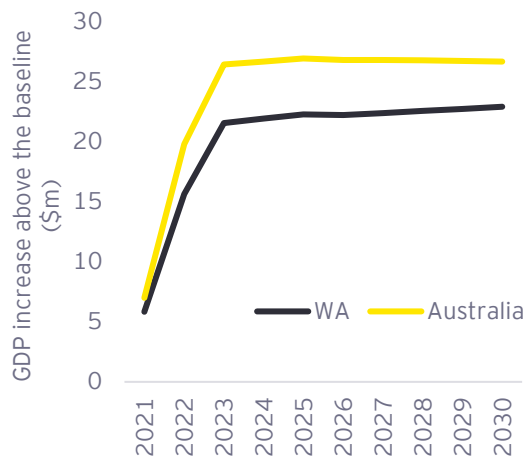
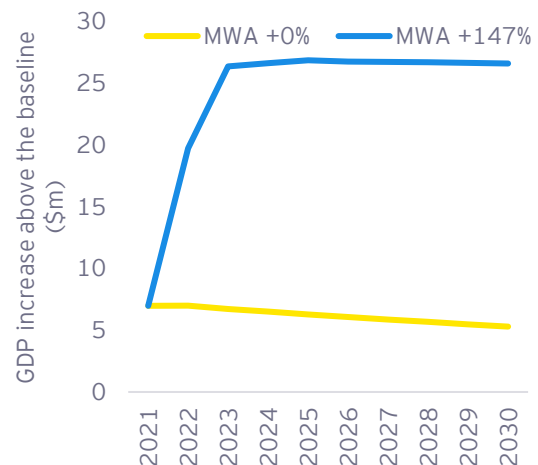


Figure 23: MWA +147% GDP compared to MWA



There is a significant increase in employment outcomes, with an average of 85 extra FTE employees per year compared to the baseline, an increase of 43 FTEs compared to the MWA +0% scenario. Of these 85 FTE employees, 64 would be based in WA.

Figure 24: MWA +147% future impact on employment

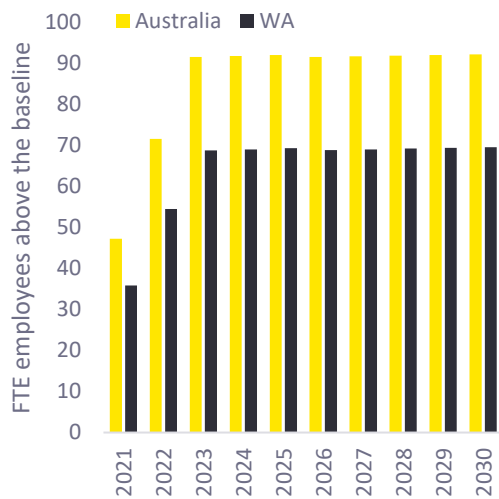
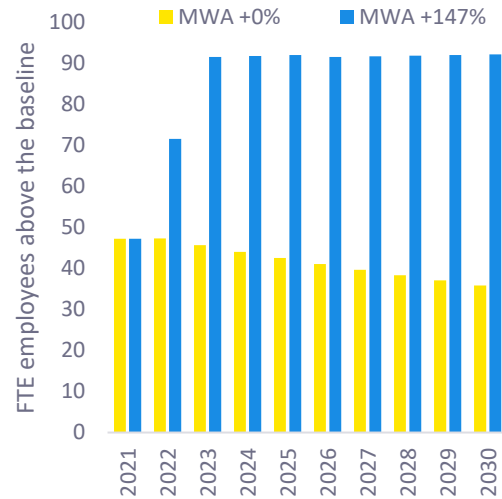


Figure 25: MWA +147% employment compared to MWA +0%



Professional and scientific services is again the biggest driver in the uplift of economic activity, increasing output by \$387 million in total above the baseline (this results in a \$146 million contribution towards GVA). However, in this scenario we start to see spill-over benefits of the increased activity in the rest of the economy.

4 MWA +447% - MWA operates with additional 477% increase in NCRIS funding

The MWA +447% scenario shows what the MWA can achieve when increasing its operational capacity. This funding will support nine additional FTE employees directly employed by the MWA and includes a \$25 million upgrade to double the array by building an additional 256 tiles, rivalling the scale of the SKA in some dimensions. This level of funding would bring the MWA funding to levels comparable with APEX.

Under this scenario, several projects and programs are undertaken to improve the functionality of the MWA. These will further de-risk the SKA and support deeper community and scientific engagement. This scenario includes all additional inputs included in MWA +147% as well as additional investment in both education and training programs, combined with further infrastructure upgrades, as outlined below.

Increasing community and scientific engagement

In a best-case funding scenario, the MWA would be able to support the following programs:

- ▶ Industry and stakeholder engagement role - A specific role helping the MWA to engage with industry, market, and surrounding communities;
- ▶ Workforce planning role - Supporting workforce planning between the MWA and SKA transition, and responsibility for administering internship and apprenticeship programs;
- ▶ PR and communications - Specific role helping to publish and promote the outputs of the MWA including publications in journals and key discoveries, website, and social media platform management;
- ▶ Fieldwork coordination and construction activities - Management, coordination and construction planning roles to help coordinate the upgrade, operation and maintenance of the MWA's equipment;

- ▶ Internship program - A \$500,000 per year program supporting internship programs and supported places;
- ▶ Apprenticeship program - A program to increase and maintain the maintenance and construction workforce, with specific knowledge on the MWA and working in the Mid-West region.

Infrastructure upgrades and improvements

With sufficient funding, the MWA could complete infrastructure upgrades to enhance the quality and productivity of the scientific output from the array. The following are potential improvements for the MWA have been modelled:

- ▶ System upgrades - Implementation of an asset management plan and budget to undertake critical preventative and end-of-life maintenance. This maintenance will minimise downtime, improve safety, and reduce risk of failure;
- ▶ Doubling the array size through the increase to 512 tiles and replacement of 16 legacy receivers enabling all 64 new receivers - This will allow better data collection and will be able to be utilised past 2028, as a risk mitigation if the SKA is significantly delayed.

De-risking the SKA

With some targeted programs, the MWA can further de-risk the development and implementation of the SKA and ease the transition out of the MWA. The following are the programs input through the model:

- ▶ Operational support and capability - building a pool of expertise to reduce resource risk and better transition between the MWA and SKA;
- ▶ MWA / SKA integrators, "leveraging roles" - Discipline focused roles (high performance computing, engineering) to connect with providers, leverage content, and promote knowledge transfer;
- ▶ SKA transition program - Additional staff focused solely on SKA work, that will transition directly to SKA in the mobilisation period.

The combined uptake in economic activity outlined above is what proves as the basis for this scenario.

MWA +447% leads economic outcomes with important spill overs

The substantial changes outlined in the MWA +447% scenario combine to see a large uplift in economic outcomes across Australia. GDP increases by \$286 million above the baseline, which is \$224 million above the MWA +0% scenario and \$49 million above the MWA +147% scenario. This benefit peaks in 2030, with GDP \$34 million above the baseline in that year. This scenario sustains GDP growth above baseline levels.

Figure 26: MWA +447% future impact on GDP

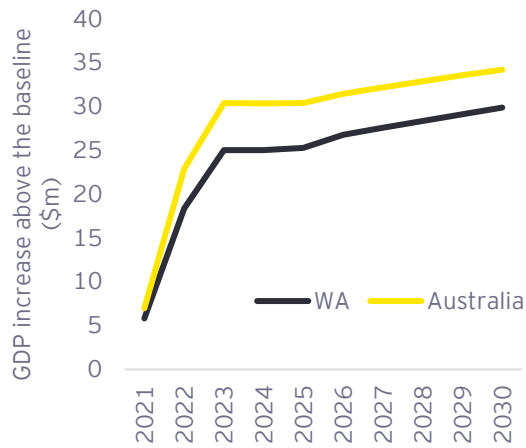
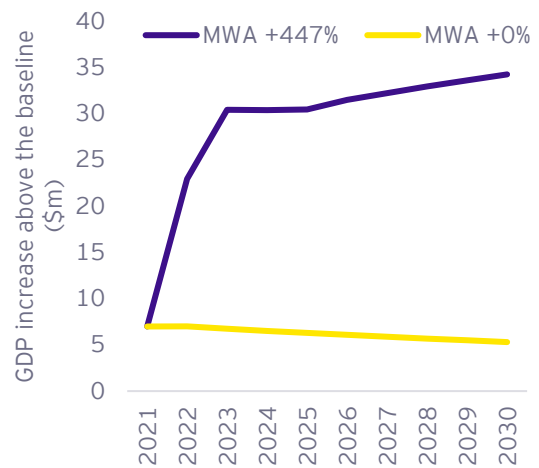


Figure 27: MWA +447% GDP compared to MWA



Employment again sees a substantial uplift, with an annual average of an extra 100 FTE jobs throughout Australia. This is an increase 58 jobs when compared to the MWA +0% scenario. Of these 100 jobs, 76 would be based in WA.

Figure 28: MWA +447% future impact on employment

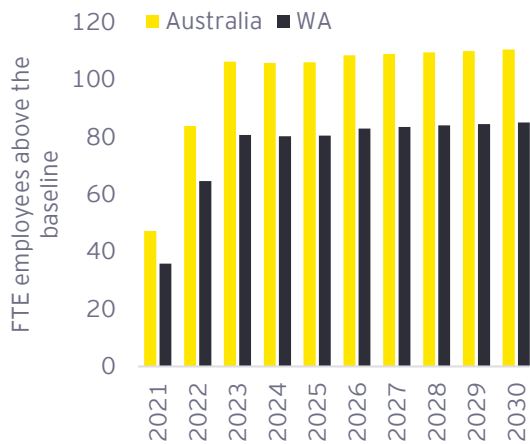
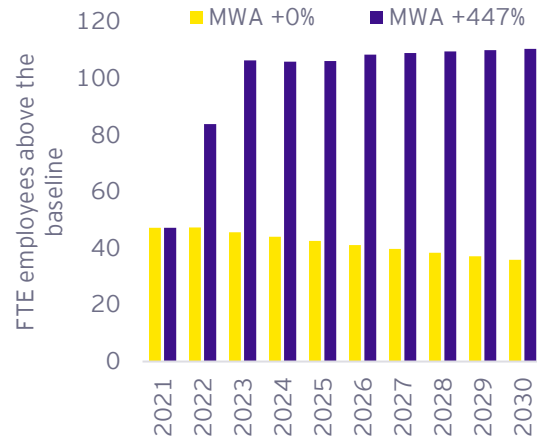


Figure 29: MWA +447% employment compared to MWA +0%



The economic growth is driven by the uplift in scientific and professional service activities, with a \$446 million increase in output above baseline levels (\$171 towards GVA). This scenario drives important spill-over effects into other parts of the economy as, MWA related activity stimulates other sectors.

These returns are significant given that a doubling of the funding agreement leads to quadrupling of return on GDP, compared to the MWA +0% scenario. This shows the potential of the MWA if allowed to operate at full capacity.

Life after launch

Importantly, the circumstances for the MWA following the launch of the SKA have not yet been confirmed. It is undetermined if the MWA will cease operations entirely. Referring to the example of APEX and ALMA, there are potential benefits to maintaining the MWA to support the SKA and continue the important work of the facility. The collaboration between APEX and ALMA and other telescopes has facilitated some great achievements. The calibration between ALMA and APEX was

essential to driving the final image quality and fidelity of the first image of black hole shadow in 2019. A similar approach could be considered for the MWA.

5.2 How pathways deliver long-term benefits

The modelling shows that all future MWA funding pathways will continue to deliver results to both the Australian and WA economies. The MWA +447% scenario delivers the most benefit to the Australian and WA economies. Not only does it deliver the most economic benefit, but the programs implemented in this scenario will see key social benefits and significantly de-risk the SKA. So, while the impacts are only modelled to 2030, MWA +447% will continue to deliver significant economic impacts into the future. However, this scenario is by far the most expensive.

MWA +10% represents the best value for money as the least expensive increment that will realise a significant increase in productivity and economic impact. MWA +10% is also likely to attract new partners to the MWA consortium, which could then potentially fund additional improvements identified in the MWA +147% and MWA +447% scenarios. A summary of the expected economic impacts across the four scenarios is shown in the table and figures below.

Table 10: MWA table of results

| | Region | GDP total (\$m) | GDP NPV (\$m) | Average annual | |
|-----------|-----------|-----------------|---------------|----------------|------------------|
| | | | | FTE | PSS output (\$m) |
| Past | Australia | \$58 | | 31 | 83 |
| | WA | \$49 | | 24 | |
| MWA +0% | Australia | \$62 | \$44 | 42 | 97 |
| | WA | \$55 | \$39 | 32 | |
| MWA +10% | Australia | \$222 | \$151 | 82 | 354 |
| | WA | \$182 | \$123 | 61 | |
| MWA +147% | Australia | \$240 | \$163 | 85 | 387 |
| | WA | \$200 | \$135 | 64 | |
| MWA +447% | Australia | \$286 | \$192 | 100 | 446 |
| | WA | \$242 | \$162 | 76 | |

Figure 30: Comparison of Scenarios GDP impact

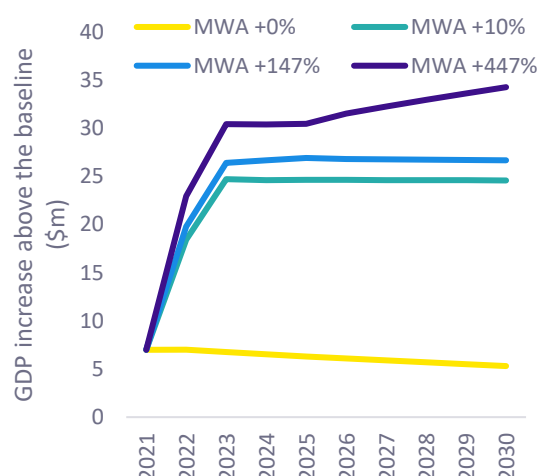
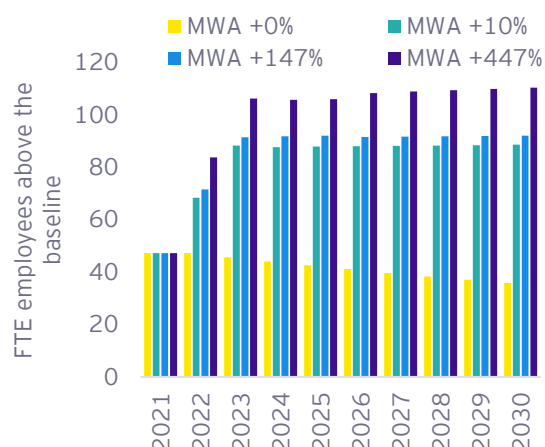


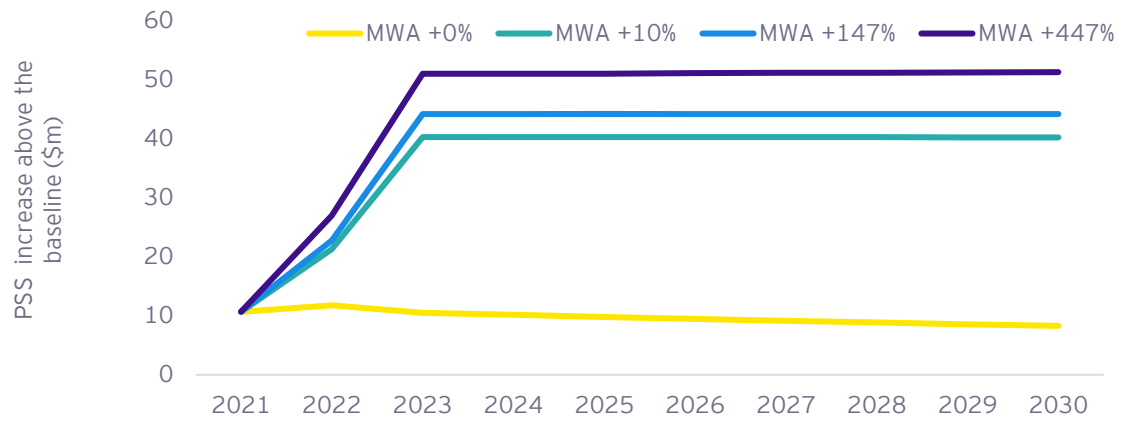
Figure 31: Comparison of Scenarios employment impact



The professional and scientific services sector drives the economic outcomes in MWA +10%, +147% and +447%, as the completion of MWA Phase III allows for increased output in the sector. However, in the MWA +0% scenario the lack of investment in the telescope results in decaying infrastructure,

which translates into a decline in output from the professional and scientific services sector. This is contrasted with the other scenarios modelled, and practically is an outcome of lower quality data being delivered from the MWA, which results in a reduction in funding dedicated to research.






Figure 32: Increase in professional and scientific services output



6. Summary of results

The MWA is a critical component of Australia's strategic agenda for astronomical research and is providing significant benefit to Australia's partners around the world. The MWA, ASKAP, and the SKA, have put WA and Australia on the map for being able and willing to develop, execute, and manage significant technical, strategic and scientific instruments, harnessing WA's geographic advantage, and supported by multilateral and bilateral relationships and academic excellence.

There are far-reaching opportunities for the MWA to continue developing and evolving through ongoing operational investment and support from Government. They are challenging to quantify in aggregate and are grouped into the critical areas of scientific, social, industry, international relations, economic and notable, the link to the SKA. Unlocking future value is measured across a range of funding scenarios.

| | |
|--|---|
|  <p>Scientific</p> | <p>The primary outputs of the MWA fulfil its science mission and are closely related to the scientists and academics that use its data. There have been a significant number of scientific publications, 30 - 40 each year, that would not have been possible without the MWA. Additionally, the MWA has led to important scientific discoveries including the detection of the largest known eruption in the universe since the Big Bang, the discovery of a bursting radio source with 18-minute period (possibly a magnetar), and the cataloguing of 300,000 galaxies across the Universe.</p> |
|  <p>Social</p> | <p>The MWA provides social value through their local activity and engagement programs. The MWA team based at Curtin University contribute time and expertise to champion astrophysics and STEM disciplines to local schools. The MWA was also recently involved in a collaboration with First Nations Australians to produce the film 'Star Dreaming' which won multiple accolades and continues to tour nationally and abroad.</p> |
|  <p>Industry</p> | <p>There has been the development of activity in industries that support the MWA. For instance, the MWA collects a significant amount of data that would be unable to be processed without the Pawsey Supercomputing Centre, meaning that substantial investment in the centre was spurred by the MWA. Additionally, there have been remarkable achievements in engineering driven by the MWA including sourcing power from surrounding solar plants without disturbing the observing environment.</p> |
|  <p>International Relations</p> | <p>The MWA has many international partners that have contributed to Australia's diplomatic activities across the science and education sector. International partners include institutions from the USA, India, UK, Canada, China, Japan, and New Zealand.</p> |
|  <p>Economic</p> | <p>The MWA has delivered significant economic value to Australia, increasing GDP by an estimated \$62.6 million since 2010 (including the historical SKA re-risking investment) and leading to an average annual increase of 31 FTE employees.</p> |



The SKA



Unlocking Future Value

As a precursor to the Square Kilometre Array (SKA), the MWA has provided the ideal platform to support early-stage prototyping, reducing development risk. De-risking the SKA enabled by the MWA has positively contributed to the economy by an estimated GDP increase of \$23 million from 2013. \$4.6 million was contributed through direct investment, and \$18.5 million has been estimated to future productivity and construction savings related to the SKA.

Four development pathways were identified that offer varying levels of value. MWA +0% will maintain current funding, while MWA +10%, MWA +147% and MWA +447% will increase NCRIS funding by 10%, 147% and 447%.

Significant increases in economic output (GDP) are tied to the MWA +10%, MWA +147%, and MWA +447%, scenarios. In addition, all scenarios beyond the current funding trajectory provide additional benefits by reducing risks relating to the continued development and construction of the SKA.

Based on the analysis performed and contained in this report, the future funding scenario of MWA +10% is the minimum practical scenario. The scenario outlines an NCRIS funding increase of 10% for a five-year period (2023 - 2028), which is equal to \$150,000 per annum and unlocks \$3.5 million of funding from partner organisations. This drives the largest relative change in outcomes from the MWA, supports a strong increase in scientific output, and continues to build the scientific community to support the launch of the SKA.

Notably, however, the analysis indicates that additional value can be extracted from the asset should additional funding be made available (as portrayed in the MWA+147% and MWA447% scenarios).

Appendices



Appendix A Modelling methodology

A Computable General Equilibrium (CGE) model was selected as appropriate given the objectives of the study and the requirement to examine value delivered in the past, and forecasted for the future across multiple scenarios.

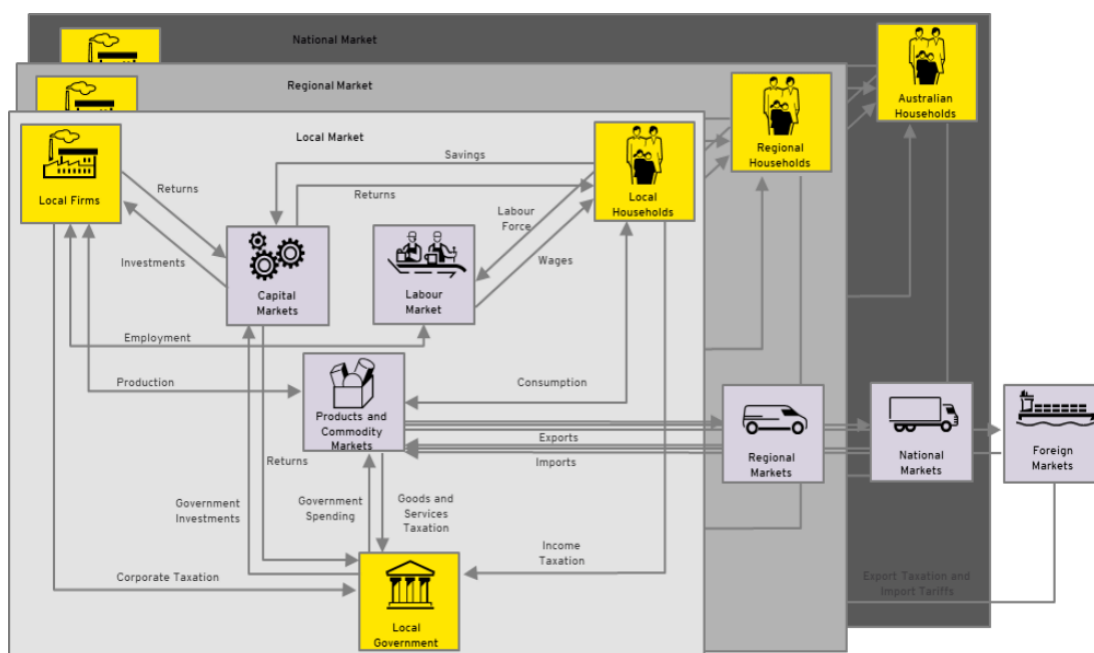
The EY General Equilibrium Model (EY-GEM) is a large scale, dynamic, multi-region, multi-sector model of the global economy, with an explicit representation of the national and NSW and sub-state economies. This detail allows us to consider varying economic impacts across the construction and operational phases of the Project. EY-GEM is based on a substantial body of accepted microeconomic theory.

EY-GEM is dynamic and is solved on a year-by-year basis over a prescribed period of time. This will allow us to consider the forward-looking nature of investments in the Project as well as test a range of different scenarios related to the project. In practical terms, the modelling is based on defining a counterfactual, or baseline scenario, which is then compared with a scenario under which the Project goes ahead. The difference between the two scenarios provides us with a measure of the economic net benefits of the Project.

The modelling will capture the direct effects (demand effects due to the proposed investment, such as construction activity), indirect effects (flow on effects into other industries during and post construction), labour market dynamics (relocation and displacement of labour, wage changes) and implications for government funding.

The model projects changes in macroeconomic aggregates such real gross state product (real GSP) which is an output measure of the state economy, real gross state income (real GSI) which is a welfare measure for state's residents, employment, export volumes, investment and private consumption. At the sectoral level—agriculture, tourism, retail trade, and real estate—detailed results such as output, exports, imports, employment, value-added; and taxes are also produced.

The below diagram is a visual representation of the CGE model.



Appendix B Key institutions and partners

| Entity | How they are Involved in MWA |
|--|---|
| Astronomy Australia Ltd. (AAL) | AAL's contribution of operations funding to the MWA ensures support is provided to the globally distributed network of researchers, engineers, planners and managers dedicated, on behalf of the astronomical community, to the realisation of the SKA. |
| Pawsey Supercomputing Research Centre | The Pawsey Supercomputing Centre is a key element of MWA's operational model. They are at the forefront of data processing and analytics and provides important support for radio astronomy activities at the Murchison Radio Astronomy Observatory. They host all the data generated by the MWA and the IT infrastructure required to serve it to MWA's global user community. Pawsey was originally commissioned in parallel with the MWA, and MWA's unique demands have continued to inform Pawsey's evolution toward SKA readiness. |
| GCo Australia | GCo are a Geraldton based electrical contractor that has been part of the MWA journey since 2006. As their understanding of the unique demands of the MWA and radio astronomy has evolved, so too has the scope of their contribution. Based on experience gleaned deploying and maintain the MWA, GCo were commissioned by SKA (via Curtin) to develop and cost a deployment plan for the SKA antenna stations. |
| Balance Service Group | Balance engineer James Buchan has been working on the SKA project through his PhD with ICRAR. The project he is working on involves designing and prototyping a solar hybrid stand-alone power system that will supply energy to the antenna. |
| SKA Project | The Office for the SKA Organisation (SKAO) is responsible for coordinating the global activities of the SKA project. This includes engineering, science, site evaluation, operations and public outreach. |
| Department of Industry, Science, Energy and Resources | The SKA is a global big-science project to build the world's largest and most capable radio telescope. Australia will host an SKA telescope in Western Australia. By hosting the SKA project means new opportunities for Australian businesses across many sectors, including construction, science and communications. The WA Government's investment in radio astronomy and related activities has led to significant benefits for WA including; employment opportunities, science education outcomes, international collaborations, significant science infrastructure and high calibre radio astronomy and engineering expertise. |
| International Centre for Radio Astronomy Research (ICRAR) | University of Western Australia and Curtin University are both Universities involved in ICRAR and are institutional members of the MWA. Over time, a significant fraction of ICRAR's science, engineering and data research programs leverage the MWA. |
| University of Melbourne | Professor Stuart Wyithe is Associate Dean, Research in the Faculty of Science at the University of Melbourne. He is the current Chair of the MWA Board. |
| Yamaji Art | The Wajarri Yamaji have played an important role in enabling Australia to co-host the SKA. The Australian SKA Office and CSIRO are working with the Wajarri Yamaji to negotiate a land agreement to access the site and realise the SKA project on the Wajarri Yamaji country. Yamaji Art have been a primary partner and contribute for several the key cultural initiatives that have grown out of the MWA. |

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52. The 7% real discount rate is used as it is the average economy wide rate of return on investment
53. Any activity undertaken by a scientist that incurs a cost, wage, or profit. This includes including writing research papers and filing patents, as well as wages and costs of inputs
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Appendix D Release notice

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