FINAL REPORT

Understanding the impact of the Australian e-Health Research Centre

A research impact assessment for the Health & Biosecurity Business Unit of the CSIRO

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Abstract

- The Australian E-Health Research Centre's (AEHRC) portfolio of research works delivers valuable gains to the Australian community and economy on multiple fronts: improving the efficient running of hospitals, supporting the shift of care out of hospitals into community settings, and improving clinical outcomes.
  - Access to health services is improved using broadband and mobile communications to deliver innovative technologies in the community to support Australians living with chronic disease, and the various needs of an ageing population in urban, rural and remote settings.
  - Health and medical data, such as genomics, imaging, clinical and sensor data, are being used to best effect to inform clinicians on evidence-based targeted treatments, tailored to patient needs and individual characteristics – and to improve research outcomes.
  - Health systems are being transformed by connecting data with decisions that improve hospital performance and productivity.
- In recognition of the value and quality of research, programs within the AEHRC are already returning generating significant revenue, despite programs being spread across the Technology Readiness Level (TRL) spectrum. A third of all programs have a TRL of 4 out of 9, and are still being validated in a laboratory environment. Only 11 per cent have successful operational experience with sustained engineering support (rated 8 or 9 out of 9), and 26 per cent have a rating of 3 or below, as they are still in the proof of concept stage or below.
- Close to half of the total investment costs of the Centre have been returned through revenue, with $38 million out of $80 million leveraged from various state government and industry sources over the past 5 years to further support and extend AEHRC's work into the Australian community.
- A large variety of AEHRC platform technologies and associated products are already in use or being trialled in research centres, Australian hospitals, residential aged care facilities, and individual homes as adoption continues to expand.
- New insights into diseases have been made using AEHRC technologies through large clinical studies where AEHRC staff have leadership roles, resulting in clinical trials of novel therapy and treatment.
- Patients are benefiting from more targeted treatments, preventative strategies, and improved rehabilitation, improving patient quality of life and workforce productivity.

- **Academic citations, publications in peer reviewed journals, and numerous awards and appearances in the international media are testament to the innovation and value of e-Health to researchers, clinicians, and health system managers, in Australia and internationally.**
- **Economic analysis of just one technology — the Care Assessment Platform / MoTER cardiac rehabilitation program — substantiated a benefit cost ratio of 3.8 to 4.2 depending on existing access to services.**

1 Addressing the problem of access to well targeted, quality healthcare

Addressing Australia's key health priorities through the development of technologies that improve the efficiency and effectiveness of the health system and improve patient health outcomes and equality.

Cost pressures on Australia's health system

Three of the central pillars of the financing of the Australian healthcare system include:

- achieving universal access
- achieving equity in service provision, and
- containing the cost of all health services, including services funded by Government.

When it comes to healthcare, *access*, *quality*, and *cost* are all major priorities for the Australian Government.

On the cost side, Australian Government health expenditure is forecast to rise from 4.2 per cent of GDP in 2014-15 to 5.7 per cent of GDP by 2054-55 (or $260 billion in today's dollar terms).[1] Health cost growth has many dimensions:

- the **Australian population is getting older**, and health costs per capita are linked to older age. The Australian Institute of Health and Welfare reports the population aged 65 and over has more than tripled in the past 50 years, with Australians aged 85 and over increasing ninefold — trends that are predicted to continue, particularly as the baby boomer generation ages.[2] Health spending on the average person aged 85 years and older is over four times the spending on the average person across all ages[3]
- on average, **Australians are earning more**, and tend to consume and expect greater or higher quality health care services
- **changes in disease rates**, partly due to changes in lifestyle factors, are increasing the prevalence of chronic health conditions, which increases demand for treatment, and
- **technology change opens up new treatment options**, which are often expensive (although effective), increasing the price of, and demand for, health services.

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[1] Australian Treasury Projections, Intergenerational Report 2015. http://www.treasury.gov.au/~/media/Treasury/Publications%20and%20Media/Publications/2015/2015%20Intergenerational%20Report/Downloads/PDF/05_Chapter_2.ashx.

[2] See http://www.aihw.gov.au/ageing/about/

[3] Department of Health, in Australian Treasury Intergenerational Report 2015, p. 63.

The Australian e-Health Research Centre solution

The Australian e-Health Research Centre (AEHRC), CSIRO Digital Health Research program and an unincorporated joint venture between CSIRO and the Queensland Government, represents a national research response to Australia's health system priorities in several important respects.

- **Improving access to health services**. Through the use of broadband and mobile communications, the Health Services group delivers innovative technology to overcome the burden on health services, including those caused by chronic disease, and the needs of an ageing population. A wide range of technologies are being developed and tested to improve health services to urban, rural and remote Australians.
- **Personalising diagnosis and treatment**. The AEHRC has harnessed the use of genomic and biomedical data by using advanced mathematical methods to transform large volumes of data into clinical information. This means that treatments and interventions can target precisely the patients benefiting the most, while sparing those unlikely to benefit to avoid unnecessary cost and side effects. This research is made possible through strong partnerships and networks of researchers, clinicians, and industrial partners that enhance technology uptake and leverage much broader investment in targeted diagnosis and treatment in Australia.
- **Transforming health systems**. Various elements of the AEHRC research program connect the availability of data with decisions that improve patient outcomes and health system performance and productivity. The unleashed value of health data in electronic health records and administrative data sets is being used to improve the understanding of demand for hospital services, and the efficiency of ED presentations, triage, and hospital admissions processes. Patients benefit from improved data quality, data interoperability between clinical systems and clinical decision support through the clinical terminology tools of the AEHRC.

Inputs

The AEHRC represents a substantial investment into Australia's national research on the application of information and communication technologies (ICT) to improve health services and clinical treatment.

The AEHRC has invested approximately $80.3 million in e-Health research over the past 5 years, relatively evenly spread across the Health Informatics, Biomedical Informatics, and Health Services research areas (table 1.1). Queensland Health, as the Queensland Government joint venture partner, has invested $7.5m of this $80.3m, with additional project funding of approximately $3m through various Queensland Health divisions and Hospital and Health Services. Approximately $42m of the funding has come from CSIRO.

CSIRO has invested another $981 000 has been invested in corporate overheads, including capacity development, patent costs, payments to students, and workshops.

1.1 CSIRO's investment in the AEHRC – July 2012-June 2017

Program	Costs ($)	Revenue ($)
Health Informatics		
Clinical Terminology	8 075 199	-6 460 080
Clinical Information Systems	4 982 414	-2 473 473
Natural Language Processing	4 257 569	-1 745 842
Health Data Analytics	7 573 073	-3 098 165
Health Data and Genomics	**822 801**	**-311 220**
Health Informatics - Total	**25 711 056**	**-14 088 780**
Biomedical Informatics		
Medical Image Analysis	12 363 574	-5 227 425
Clinical Imaging	5 698 344	--1 624 580
Surgical Simulation	353 169	-212 242
Transformational Bioinformatics	3 104 727	-181 741
Biomedical Informatics - Total	**24 648 864**	**-8 558 072**
Health Systems		
Mobile Health	5 123 187	-2,084,632
Engagement and Effectiveness	2 085 032	-1,282,924
Health Internet of Things	5 102 300	-819,126
National Tele-health Evaluation	3 968 893	-2,747,975
Tele-health and logistics — WA	13 668 057	-8,158,704
Health Services - Total	**29 947 469**	**-15 093 360**
Total e-Health	**80 307 389**	**-37 740 213**

Source: CSIRO, unpublished.

Program costs have been offset by external funding and revenue raisings of close to $38 million over the period. Key non-CSIRO sources of funding include:

- **strategic government funding** from Queensland (Qld) Health's investment as a Joint Venture partner and WA Health's investment in the Perth based Tele-Health Research and Development group
- **grant funding directly** from the National Health and Medical Research Council, National Institute for Dementia Research, CRC for Mental Health, Advance Queensland, Heart Foundation, Diabetes Australia, WA Translational Research, Prostate Cancer Foundation and NSW Cancer Council
- **grant funding indirectly through collaborations** with the University of Queensland, the Florey Research Institute, Queensland University of Technology, Queensland Institute Medical Research Berghofer, and Curtin University
- **corporate project funding**, including from Siemens, GE, JJ, Telstra Health, RDNS, Integrated Living, Bromillow, Medtech, HCF, Neurovision Imaging
- **other government funding**, including from Queensland Health, Western Australian (WA) Department of Health, Victoria (Vic) Department of Human Services, New South Wales (NSW) Health, Australian Government Department of Health, National

e-Health Transition Authority and the Australian Digital Health Agency and funding from many Health and Hospital Services

- **licencing/option agreement revenue (to date and expected)**, including from Surgical Science, Telstra Health, China Telecom, QIMR-Berghofer, ZOC China, TeleMedC USA, WA Department of Health, NVI USA, Amazon Web Services, Samsung, and TrakGene, and the Australian Digital Health Agency
- **income from consultancy work**, including from Gallipoli Medical Research Foundation, Royal Australasian College of Surgeons (RACS), NPS MedicineWise, Resonance Health, PwC, and MOH Holdings (MOHH) Singapore.

The AEHRC is involved in many large research collaborations that have attracted government and commercial funding over many years. These include:

- **The Australian Imaging Biomarker Lifestyle (AIBL) Study of Aging** – with the Florey Institute, Austin Health, Edith Cowan University and other partners.
- **CRC for Mental Health** – a $40m CRC program in mental health.
- **The Queensland Genomics Health Alliance** – a $25m Queensland Health initiative.
- **The Melbourne Genomics Health Alliance** – a $35m alliance of 10 Victorian health and research organisations.
- **The Australian Genomics Health Alliance** – a $25m NHMRC grant with over 30 partners around Australia.

The projects within the AEHRC are at various stages of development. Some are focused on the development of platform and early stage technologies, some have produced outputs that are only just started to be adopted or trialled, and others are already producing market ready products and services that are becoming part of everyday healthcare in hospitals and community settings.

Examples of some of the technologies produced as a result of e-Health research is showcased in boxes 1.2, 1.3, 1.4, 1.5, and 1.6 below.

1.2 Clinical terminology tools improving health data interoperability

Clinical Terminology Tools enable the use of standards-based clinical terminology in digital health records to improve data interoperability, and the consistency and precision of recorded data, leading to reduced medication errors and optimised use of health data. Key **platform technologies** include **Snorocket**, which for the first time enabled semi-real-time authoring of very-large-scale clinical ontologies such as SNOMED CT, and **Ontoserver**, which is a world-leading clinical terminology service implementing HL7's FHIR Terminology Services and supporting syndication–based content distribution. Ontosever has been licensed by over 20 organisations in Australia and is used in a number of products in use in Australia. Ontoserver has also been licensed internationally and supports products in the UK and New Zealand.

This has led to the creation of three **products**, including:

- **Snapper.** Snapper:Map is a web browser-based app that enables authoring maps from legacy terminology to standards-based terminologies, and Snapper:Author is a browser-based app for authoring the HL7 FHIR terminology resources and publishing them to a FHIR terminology server. Snapper is available free for use in Australia as part of the National Clinical Terminology Service from the Australian Digital Health Agency.
- **SnoMAP**, which enables diagnoses recorded using SNOMED CT-AU in Emergency Departments to be converted to ICD10-AM codes for non-admitted patient reporting purposes. SnoMAP is currently being used by the Queensland Digital Hospitals program.
- **Shrimp**, which is a web browser-based app that provides an interface for searching for codes, and a dynamic and interactive hierarchy viewer.

1.3 Mobile Health-based models of care

The AEHRC has developed an international reputation in the research and development of mobile health enabled models of health care.

The Cardiac Rehabilitation Program scientifically validated a Digital Cardiac Rehabilitation solution using smartphone apps and web portals to give clinicians the ability to deliver more convenient, flexible and engaging cardiac rehabilitation services to patients. Cardihab™ has been created as a spin–off company to help patients reach optimal health when at risk of, or living with, heart disease.

The use of the MoTER platform for cardiac rehabilitation has been proven to improve rehabilitation uptake, adherence and completion. **Economic analysis of the technology calculated a benefit cost ratio (BCR) of 3.8 when switching a proportion of coronary heart disease patients from traditional centre-based rehabilitation to mobile-enabled cardiac rehabilitation. For those taking up cardiac rehabilitation that would otherwise not receive services, the BCR is 4.2.** It is also estimated that the Care Assessment Platform / MoTER cardiac rehabilitation technology could reduce Disability Adjusted Life Years by 15 918, over 10 years.[4]

Recently the AEHRC has commenced 4 clinical trials with Metro North and Metro South Health and Hospital Services of mobile health enabled models of care

- The PD BUDDy feasibility study uses the AEHRC mobile health MoTER platform adapted to support peritoneal dialysis patients. The trial is in collaboration with Logan Hospital and 19 patients have been recruited.
- The MoTHER feasibility study for women with their first diagnosis of Gestational Diabetes started recruitment in mid–August. This program uses the AEHRC mobile health MoTER platform adapted for Gestational Diabetes. The trial is in collaboration with Redland Hospital.
- Twenty participants in the 40 patient REMODEL project - using mobile health for outpatient diabetes management - were recruited in July. This project is a joint project between the AEHRC, University of Queensland and Queensland Health. 40 people will be recruited for the Randomised Controlled Trial, with the intervention group managed using MoTER Diabetes platform for six months at Princess Alexandra Hospital.

The AEHRC international reputation in mobile health research has attracted many national and international organisations to approach the AERHC above mobile health trials.

- J&J Medical Australia contracted the AEHRC to develop and trial a mobile health platform to support patients having a total knee replacement. With the design and development now complete, the Total Knee Replacement (TKR) program is now undertaking a clinical trial with five hospitals across 3 states participating.

4 The Centre for International Economics 2017, Understanding the value of the Care Assessment Platform / MoTER cardiac rehabilitation program.

1.4 Medical Image Analysis — converting images into quantitative information and biostatistics

Medical Image Analysis using advanced analysis algorithms can turn individual and populations of images into clinical useful quantitative information. These are used to support the analysis for research and clinical studies into neurodegenerative diseases, osteoarthritis, post-traumatic stress disorder and cerebral palsy to better screen, diagnose, and treat disease.

Four **platform technologies** have been developed. The **MilxView** platform supports internal research efforts and provides a dedicated 3D medical imaging visualisation platform to deliver project-specific clinical applications. **MilxXplore** simplifies the representation of data and aggregate results for faster, user friendly exploration of imaging data. **MilxCloud** is a web interface that quantifies imaging biomarkers and produces email-able web reports. **MilxInformatics** provides a scalable best practice integrated data management and cloud system for imaging and non-imaging data.

Two **products** are quite mature while others are under development.

- **CapAIBL** is patented technology that performs quantitative PET measurements without the need of an MRI, and reduces subjectivity and brings quantified measurements of FDG, Amyloid, and Tau direct to the user. Currently CapAIBL supports five major Alzheimer's disease trials in Australia, while the clinical market will likely develop in the near future.
- **ChondralHealth** is MRI software that provides automated quantitative measures of cartilage tissue in joints. This allows identification and monitoring of cartilage changes for early intervention before structural and functional deficits are irreversible. ChondralHealth is currently licensed to Siemens for their next generation MRI machines.

Clinical Imaging focuses on extracting quantitative information from medical image data to improve individual treatment decisions. Platform technologies are focused on improving treatment decisions for clinical applications including prostate cancer, brain cancer, cerebral palsy, and brain aneurysms.

Three **products** are under development and currently being used to support clinical trials. These include *iAccessCP*: helping radiologists remotely report on MR images of the brains of children with cerebral palsy, *CONSULT*: informing neurosurgeons about critical white-matter pathways to reduce risks associated with surgical procedures, and *Resonance Health Liver Fibrosis Prototyping Platform*: a python based software package that tests multiple machine learning approaches to care. Further clinical imaging products are described in Box 2.5.

1.5 Medical text analytic technologies to improve data quality and useability

Medical Text Analysis has applied advanced natural language processing information retrieval and machine learning techniques, to easily and consistently extract clinical information from patient medical records and make it accessible to clinical staff. This has transformed unstructured free-text health data in radiology and pathology reports, progress notes, discharge summaries, and death certificates to improve decision-making, and health system efficiency.

- **Platform technologies** include **Medtex** -- supporting fast text processing and analytics of large-scale clinical narrative reports -- and **HealthSearch --** providing capability for large-scale medical record searching and analytics.

Products based on these platform technologies include:

- **Medtex—Automating Cancer Registry tasks**, processing and analysing live pathology feeds for cancer notifications from across Queensland. This tool is currently used to provide up-to-date information on a nightly basis for Queensland Health's internal cancer statistics, the Queensland Cancer Control and Analysis Team.
- **Medtex — ED Test Result Reconciliation**, a system for reliably identifying abnormal or positive results from radiology and pathology reports and linking these with patient records from ED information systems to provide decision support to the manual checking process.
- **Medtex — Autocoding**, an automatic coding process for diagnoses and causes of death from text information in EMR progress notes and death certificates.
- **RadSearch** —a fast, interactive search technology to enable access to, and understanding of, patient information contained in free-text medical records. RadSearch is currently used in the PA Hospital to search, retrieve and analyse free-text radiology reports for case study reports and data exploration.

1.6 Transformational bioinformatics — future ready with Big Data

Transformational bioinformatics uses machine learning technology, cloud-computing, and other novel BigData infrastructure to handle high-dimensional life-science data. Genomic data analysis will especially benefit from the technology as it processes large population-scale cohorts to provide prospective insights and mechanisms for disease prevention, such as risk prediction, treatment, stratification, and genome editing.

Platform technologies include **VariantSpark**, a Hadoop/Spark-based machine learning framework for obtaining insights from population scale 'onomics' datasets, and **GT-Scan**, a cloud-based recommender engine for computational guided genome engineering application.

Recent products include **VariantSpark::CursedForest**, which allows random forest analysis to perform variable important analysis or classification on genomic profiles, **GT-Scan::TUSCAN**, which enables GT-Scan to evaluate the on-target sensitivity of CRISPR-Cas9 binding sites, **GT-Scan::Version2** and **Version3**, adding SNP-awareness and covering other endonucleases. **LifeDNA**, a tool accessed via the web predicts obesity risk from genomic data and is currently being trialled internally within CSIRO.

The AEHRC bioinformatics and health informatics research teams are working together to find novel ways of combining clinical phenotype information encoded with clinical terminologies such as SNOMED CT with the genotype information - a perfect application for Big Data tools such as VariantSpark.

2 Impact pathway for the Australian e-Health Research Centre

AEHRC has delivered an impressive portfolio of research, building strong links with users to ensure adoption of technologies, techniques, and decision supports that deliver benefits to patients, the health system, medical research and the wider community.

Outputs: what AEHRC delivers

All the programs within the AEHRC portfolio have delivered new platform technologies and associated products that are actively being trialled and adopted by researchers, clinicians, hospital administrators, and other health system stakeholders.

The relationships and networks that have been built have changed the nature of research and its translation and adoption into homes, hospitals, industries, and communities.

Key output domains across the e-Health portfolio include the following.

- **New partnerships and collaborations** developed, relating to the research itself as well as its translation into clinical and community settings.
- **New technologies and techniques** have been substantiated to improve decision making for patients and for the health system. Selected examples include:
  - diagnosis and risk assessment tools to enable earlier identification of Alzheimer's disease through, for example, blood, MRI and Amyloid PET biomarkers
  - predictive analytics algorithms use health system and clinical data to provide information to, for example, predict the likelihood of patient readmitting when they are discharged, or to provide information for planning staffing levels for an Emergency Department
  - the Remote-I "store and forward" tele-health system is enabling screening of patients for eye disease without the need to travel to major centres.
- **New and better data sets** are being established, along with new systems to extract more value from data, to improve the evidence base for cost effective and clinically effective healthcare.
- **New employment and study opportunities** have been created to develop Australia's skills base around ICT and health.
- **CSIRO's and Australia's international reputation** is being enhanced by a large number of high quality publications in Australian and international peer reviewed journals, and various appointments of CSIRO staff on international

association/society boards and international journal editorial boards, and associated memberships.

- **Spin out companies and commercial agreements** have also been enacted or are currently being pursued, leading to various licensing and option agreements, purchases of research, and international patents.

Examples of some of the deliverables from the AEHRC were mentioned in the technology boxes 1.2-1.6. above. Further examples showcasing the deliverables of AEHRC are provided in boxes 2.1, 2.2, and 2.3 below.

Impact pathways for each of the respective subprograms across Health Informatics, Biomedical Informatics, and Health Systems are detailed in Appendix A.

2.1 Smarter Safer Homes: supporting older Australians to live at home for longer

The analytics developed from data derived from the wireless sensor and monitoring technology employed on the **Smarter Safer Homes** platform provides up-to-date and trending information of individuals' progress, independence and health status as an objective measure of Activity of Daily Living. The platform includes a sensor-based in-home monitoring system for data collection, a cloud computer server for data analytics, and various interfaces for data presentation to assist families and carers and clinicians to observe health status.

By enabling timely prevention and intervention, older Australians that would otherwise require 'low care' residential aged care are able to continue to live safely at home for longer.

As well as supporting an individual capacity to remain at home, there are also financial savings to the Australian Government by delaying or preventing earlier entry into a residential aged care facility (RACF).

There is potential for application in RACF to more efficiently and effectiveness attend to residents' abnormal vital sign measurements and/or early intervention towards any mobility problems.

There is also scope to extend the technology to provide clinical and assistive care support, which could also enable individual with more complex needs to remain at home should they so choose.

Some RACFs are also using the technology to conduct research into early dementia symptoms by examining correlations between daily activities such as mobility and sleep quality with neurodegenerative disorders.

The Smarter Safer Homes platform is currently being trialled in two large trials. A CSIRO funded "100 homes" test bed in Brisbane is currently getting underway. While a $1m grant from the Commonwealth Department of Health is funding a 200-home trial in Qld and NSW.

2.2 Patient flow modelling projects: meeting hospital performance targets and better patient outcomes

Patient flow modelling and simulation based on up to 10 years of ambulance, hospital inpatient and Emergency Department (ED) data produced linked datasets of clinical and administrative data that supports:

- early identification of disease outbreaks
- prediction of ED presentations and hospital admissions and discharges
- identifying reduced patient flow system performance related to hospital occupancy
- assessment of risk factors for reported adverse events
- identification of patient characteristics for hospital 'frequent flyers' with a high risk of readmission
- identification of patient characteristics/experiences that results in hospital costs being 'more' or 'less' than expected.

The value of this evidence based dataset to hospital performance is considerable and has been used to improve bed management practices, reduce overcrowding, decrease complaints following elective surgery cancellations, and improve health outcomes and mortality rates. Identification of patient characteristics that signal a high risk for hospital readmissions is now used in national programs to manage patients outside the hospital system to lower long-term health care costs. Various bed prediction models also form a regular component of daily bed management across major public hospitals in Queensland and are available nationally by licencing to Telstra Health.

The **Patient Admission Prediction Tool** (PAPT) has been used in many Queensland Hospitals for over five years and is used on a daily basis for planning at a number of these hospitals. PAPT has recently been licensed to Health IQ and is being implemented commercially in at least three hospitals elsewhere in Australia.

Analysis by CSIRO (not validated by the CIE) estimated savings for a Queensland Health reference hospital at between $1.67 and $2.23 million in 2016 dollars due to improved bed utilisation and reduced elective surgery cancellations because of the PAPT.[5]

[5] CSIRO 2017, Research Impact Evaluation of the Patient Admission Prediction Tool, CSIRO July 2017.

2.3 Blood based biomarker technologies: targeting better health outcomes

Personalised, or targeted medicine has revolutionised healthcare particularly cancer care, using advanced diagnostic tools to screen for disease, identify problems early, align patients with treatments that will work for them, and spare patients from unnecessary or ineffective exposure to toxicity. Several biomarkers are being developed for various diseases to improve targeted and precision medicine.

- Biomarkers of Alzheimer's disease pathology have been developed with greater than 80 per cent accuracy in predicting disease pathology, with current work underway to improve accuracy to 90 per cent. This will allow for new pharmaceutical developments and clinical trials.
- Biomarkers for inflammatory bowel disease have been developed to assist in predicting the need for early surgery. Biomarkers are also being used for research purposes to define the biological ramifications of treatments directed towards changing biomarkers to alter the disease pathway.

These biomarkers have been identified as part of large ongoing trials in Alzheimer's diseases (AIBL) and inflammatory bowel disease (QIMR-Berghofer) in which the AEHRC is a key partner. These results are key in attracting on going funding for these large ongoing trials, often from multi-national pharmaceutical companies.

The underlying platform technologies have been showcased in a large number of journal publications, conference abstracts and industry collaborations.

Outcomes

While the outcomes of the AEHRC are multifaceted across the portfolio, they typically fall under the following areas:

- improved health system performance
- improved patient health outcomes
- spill-overs from collaborations and reputation effects
- improved research quality, and
- improved societal outcomes.

Improved health system performance

Many outputs of the AEHRC program enable earlier, more preventative treatments as well as enable care to be delivered in lower cost care settings. Both these aspects improve health system performance and deliver more cost-effective health care. For instance:

- **performance enhancing systems are being adopted**, and becoming part of everyday hospital administration and care, improving reporting systems, workflow systems, compliance systems, and standardising care
- **improved flow of patients and healthcare resources within hospitals is being achieved** through improved bed management planning and patient admission prediction, reducing costly bed block
- **new coordinated care models and mobile health technologies enable ageing in (lower cost) place**, rather than in hospital, when it is clinically appropriate to support the aged in their home
- **adverse events, medication errors, and preventable hospitalisations are reduced**, freeing up resources for improved healthcare quality, and
- **clinicians can make evidence based decisions to avoid clinically unnecessary care**, through improved screening and diagnostic tools that target health care resources to where they are clinically necessary.

Selected examples of the efficiencies achieved to date include the following:

- Tele-Health's **automated screening tools for diabetic retinopathy** can reduce specialist referrals by 45 per cent, by only referring patients that actually require further examination and treatment to specialists. This is supporting the adoption of tele-ophthalmology in Queensland and Western Australia and has recently been trialled in GP clinics.
- Medical Image Analysis has developed an **MRI based test** to assess **knee cartilage** health using biochemical measures to support preventative strategies and monitoring. This is currently undergoing clinical trials around the world as part of new Siemens MRI technology. The clinical imaging team is evaluating an **MRI based test** that could predict response to cholinesterase inhibitor drugs that is often used in prodromal **Alzheimer's disease** treatment. Currently, only 30 per cent of patients respond and the remainder incur side effects and costs without improved outcomes.

- The Australian National Clinical Terminology Service from January 2017, provides **Ontoserver** as a free sub-licence from the Australian Digital Health Agency for use in Australia. Over 20 organisations have licensed Ontoserver and it is now being used in commercial products around Australia. The Royal Australasian College of Surgeons' logbook tool is using Ontoserver to migrate from an in-house terminology to using SNOMED CT for recording surgeons' activities. SnoMAP is in regular use by the Princess Alexandra Hospital, Mackay and Townsville hospitals and Queensland Health for generating ICD10-AM-based reports for ED funding purposes as well as improving accuracy of clinical documentation in ED. Shrimp is now provided as a free service, with a growing audience of 2000 users per month around the world.

Improved patient health outcomes

All aspects of AEHRC are ultimately about proving population health, and patient health outcomes. Across the e-Health portfolio, this is achieved by the following.

- **Providing better treatments**. While they are at various stages of adoption into standard clinical care, a wide range of outputs are about translating research findings into clinical practice, resulting in improved patient outcomes as patients benefit from the availability of better diagnostic, monitoring, and treatment technologies. Selected examples include:
  - enabling patients at higher risk of Alzheimer's disease to be identified and treated earlier with new drugs new drugs undergoing trials based on the AEHRC findings and technologies
  - giving access to the latest technologies for managing Cerebral Palsy to young Australians suffering from the disease
  - enabling men suffering from prostate cancer to be treated without additional harmful radiation from CT scans, with their tumour better targeted using MRI
  - improving patient involvement in rehabilitation
  - providing access to the MoTER platform (which uses mobile technologies such as smartphones, wearables, and sometimes passive sensors to test the effectiveness of new care models) to a wider range of patients with chronic conditions (diabetes, COPD)
  - providing patients virtual access to specialists via junior doctors and nurses using MICE Imaging App for burns, plastics, dermatology, ENT and dentistry, and
  - providing tools for early detection of systemic diseases (Alzheimer's diseases, stroke, heart diseases) and eye diseases non-invasively using clinical decision support systems (DR Grader for diabetic related eye diseases).
- **Enhancing access to better health care decisions**. Many elements of the AEHRC program bring together otherwise disparate or incompatible data sets to provide evidence based decision support that selects treatment pathways that are most likely to work best, such as the Remove-1 telemedicine system, and the greater range of treatment options provided for Crohn's disease based on clinical research.

Evidence of adoption and use of research in patient care is provided in boxes 2.4 and 2.5.

2.4 Adoption of Medtex in assessment and treatment pathways for cancer care

Medtex — Automating Cancer Registry tasks has been used within Queensland Health to analyse pathology feeds from 2008 to the present (live feed) for cancer notifications. The Peter MacCallum Cancer Centre has completed the first trial of Medtex to automate the detection of clinical stage and risk stratification data from patients with genitourinary cancers, which showed equivalent or superior outcomes to human annotators. The Royal College of Pathologists of Australasia has also used been involved in a Medtex proof-of-concept for cancer structured reporting from speech software. **Medtex — ED Radiology reconciliation** has been trialled by the Royal Brisbane and Women's Hospital and Gold Coast University Hospital to reconcile radiology reports and ED discharge diagnosis data for limb fractures for decision support. Similarly, The Prince Charles Hospital has been involved in a proof-of-concept for **Medtex — ED Pathology reconciliation** to show the system can reliably identify positive test results, helping minimise the need for reports to be reviewed. **Medtex Auto-coding** has been through the prototyping/demonstrator phase with Cancer Institute NSW and NSW Ministry of Health.

2.5 Adoption of imaging technologies to improve radiotherapy treatment

MR alone external beam radiation therapy planning software tools aimed at improving treatment accuracy have been developed and clinically validated with localised prostate cancer patients through two retrospective clinical trials at the Calvary Mater Newcastle Hospital, NSW (each published in IJROBP, the highest impact factor radiation oncology journal).

The development of these software tools received research support from the Prostate Cancer Foundation Australia, Cancer Council NSW and the NHRMC. A current prospective multi-centre clinical study (ANZCTR trial ID ACTRN12616001653459) is underway (25 patients will be treated over 12 months). In addition to the MR conversion software, open source tools have been developed for robust image registration and to enable communication between radiation therapy treatment planning machines (ITK DICOM-RT utilities) with over 10,000 downloads from around the world.

The aim is to eliminate the need for CT scans in treatment planning, reduce the amount of normal tissue impacted (reducing side effects) and potentially increase the dose of radiation delivered to the tumour.

Additional clinical studies are currently investigating extending the method for head and neck, anal and cervical cancer treatment.

2.6 Remote-I: Tele-ophthalmology for remote Australia

Remote-I is a web-based telemedicine platform that provides specialist eye care to the rural and remote Australia. Full high-resolution images of a patient's retina with a special low-cost camera. The encrypted images are then securely forwarded to a city-based ophthalmologist via a broadband connection where they are examined, overcoming the need for patients to travel for a live consultation. Remote-I includes built-in comparisons for various eye diseases can also help local care providers identify people in need of urgent treatment.

A trial of tele-ophthalmology to Torres Strait in Queensland and the Goldfields in Western Australia was funded through the National Tele-health Pilots scheme by the Commonwealth Department of Health using the NBN interim satellite. Of the over 1500 people to receive screening, there were 80 new diagnosis of diabetic retinopathy and 8 patients received expedited sight saving surgery. The trail also demonstrated the economic value of the approach – potentially saving each state department of health over $30,000 a month in patient travel.

Spill overs from collaborations and reputation effects

The AEHRC projects are often **multi-disciplinary** and encourage **collaborative behaviours** within, and outside of the CSIRO, with a strong emphasis on integration across the 'discover-translate' continuum, including collaborations with hospitals.

As research quality improves, research outputs are adopted and results are communicated worldwide, having a beneficial reinforcing reputation effect that helps CSIRO **attract and retain the best and brightest people** to add to its research base.

Collaborations with partners also often results in adoption of outputs by research partners, such as in the case of cloud based delivery of advanced medical image analysis. For instance, from the Biomedical Imaging team, **CapAIBL and CurAIBL** cloud platform is provided for non-commercial research purposes to various medical research institutes. Over the past 4 years, it has been used by 35 researchers from 22 institutions across 6 countries, with 2 547 PET scans analysed through CapAIBL. ChondralHealth software is being evaluated by Siemens for release as a product on their MRI scanners.

Strong reputation effects resulting from the AEHRC is evidenced by multiple awards that have been awarded to research teams such as for:

- Many 'best paper' awards at conferences, including:
  - Multiple Branko Cesnik Award for Best Paper at the HIC conference, and a gold award in the 'Improving health equality and closing the gap' category in the 2015 Victorian Public Healthcare Awards.
  - Health Data Analytics' **project analysing the relationship between flow targets and patient outcomes** was 'best paper' at the 2016 Australasian College for

Emergency Medicine Conference in New Zealand, the Don Walker Award for Efficiency presented by the Health Informatics Society of Australia

- Many AIIA iAwards including recognising innovation in ICT;
  - **National Clinical Terminology Service** (NCTS) won two Qld iAwards in 2017 — the Infrastructure and Platforms Innovation of the Year and the Public Sector and Governments Market category.
  - **The bioinformatics research** GT-Scan2 won two iAwards in NSW - the Big Data / Machine Learning Innovation of the Year and Industrial and the Primary Industries category.
  - The SnoMAP tool, a collaboration with Metro South Brisbane HHS, won second place in the 2016 iAwards for Research and Development.
  - **Telehealth** received the iAwards for Remote-I under Health category and Overall Winner in 2011, WA ICT Awards for Remote-I, the ASIA Pacific ICT awards for Remote-I, iAwards for Dr Grader, WA ICT Awards for Dr Grader, iAwards for AMD grading system, and WA ICT awards for AMD grading system.
  - **Mobile Health** received the iAwards 2011 e-Health, iAwards 2011 e-Inclusion and e-Community, and iAwards 2014 Health Category.

Improved research quality

To varying degrees, all programs within the AEHRC portfolio improve the quality of research, and therefore the outcomes from research. The key ways in which this is achieved are set out below.

- **Creating new or expanded world-class medical research infrastructure.** Be it through expanded ICT infrastructure for health research, the creation of new or better health information, software or hardware that assists in the communication of medical insights, or the creation of other decision support tools, the research itself is more efficient, more insightful because of AEHRC, and delivers better research outcomes.
- **Creating opportunities for clinicians to re-engage with research**, emphasising the clinical and translational aspects research, and partnering these with scientific and technological research goals.
- **Opening up additional funding sources for research.** To a certain extent, *more* funding research can be aligned with *better* research, and the AEHRC has had considerable success in obtaining matched funding for research from outside the CSIRO. It has also had success in diversifying funding sources. Some projects in particular have attracted substantial leveraged capital relative to CSIROs contribution. Over the past 5 years, **the program has attracted close to $38 million in revenue**, most of which is from competitively tendered grant funding from entities such as the National Health and Medical Research Council (NHMRC), the Australian Digital Health Agency, and State Government Health Departments and the like.
- **Prioritisation of research.** The AEHRC has helped point CSIROs research effort toward Australia's key health issues, with specific focus on chronic diseases (diabetes,

cancer, and mental health) and health states that absorb a high proportion of health costs in high cost settings (like cardiac patients in hospitals).

Improved societal outcomes

As population health improves, so too does workforce participation and labour productivity, generating gains to Australia more broadly.

The reverse is also true — poor population health results in productivity losses associated with workforce absences and in some cases premature death.

'Productivity losses' associated with poor health and premature death of disablement can be avoided or mitigated with the assistance of AEHRC technologies.

Better health helps patients and carers that can continue to work and earn, and with improved productivity. Avoided productivity (and financial) losses can be considerable, depending on how long individuals are unable to work productively, and whether substitute labour is available.

Aside from avoided reduced wages and income, better health also brings better **quality of life**. Depending on the health condition, quality of life is measured by considering Years Lived with Disability (YLD), multiplied by a 'discount factor' that captures the harshness of a persons' disability or suffering, multiplied by a factor that captures the duration of the suffering. Burden of disease analysis quantifies the impact of health problems and premature deaths on a society,[6] and is available for all of the diseases being addressed by the AEHRC.[7]

Improvements in **health equality** add to the value of improved health further still, by reducing the societal cost of social disengagement and productivity costs associated with underutilised labour. Health equality is directly impacted by the AEHRC, which enables:

- standardised reporting
- consistency in clinical management,
- delivery of health services via technology to rural and remote Australia,
- delivery of health services to patient in the community and
- increased seniors' compliance with best practice home care and supports.

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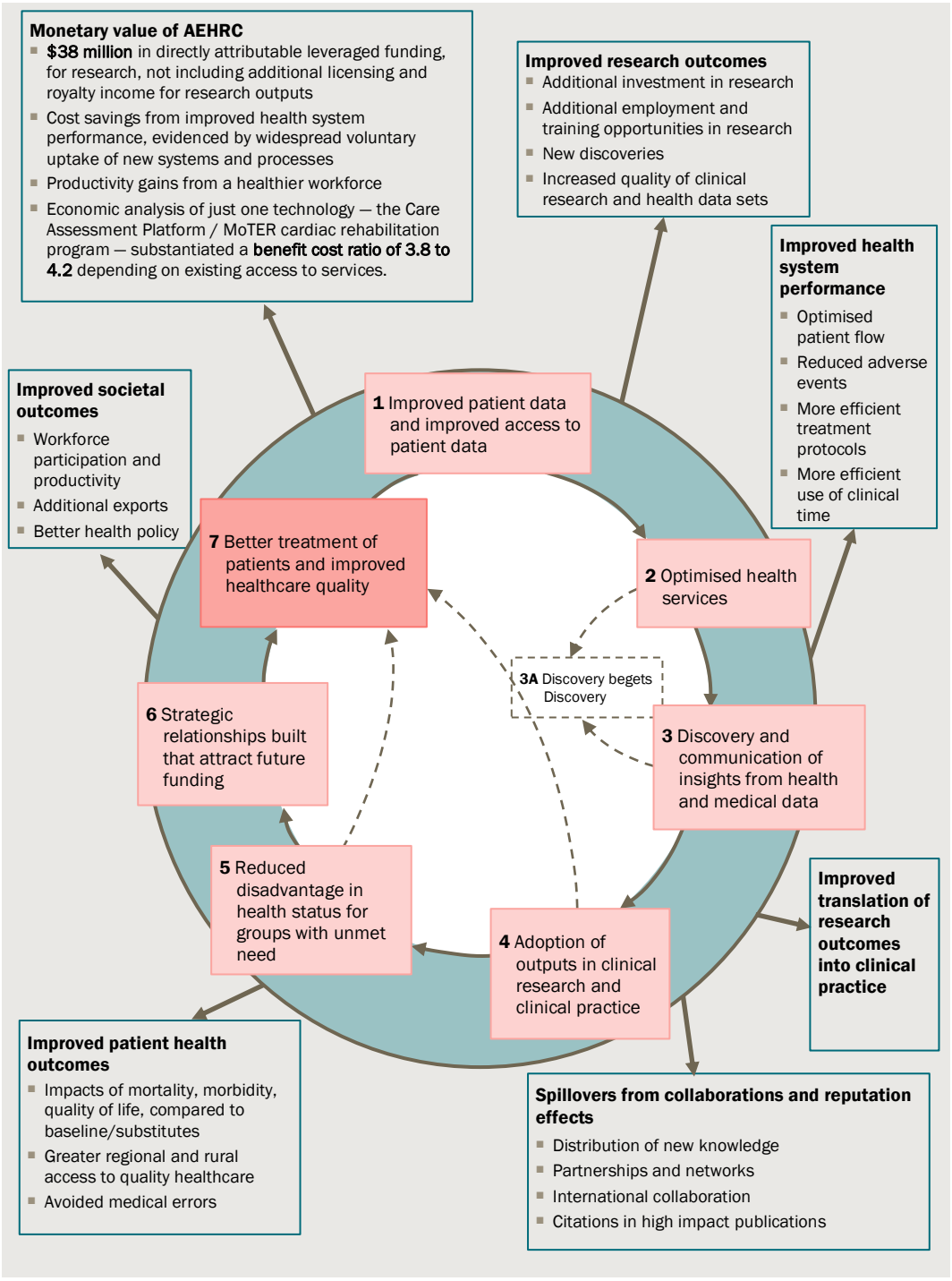
6 This burden is measured with loss of DALYs (loss of Disability Adjusted Life Years), which equals Years of Life Lost (YLL) plus (discounted) Years of Life lost due to Disability (YLD).

7 Available at https://vizhub.healthdata.org/gbd-compare/

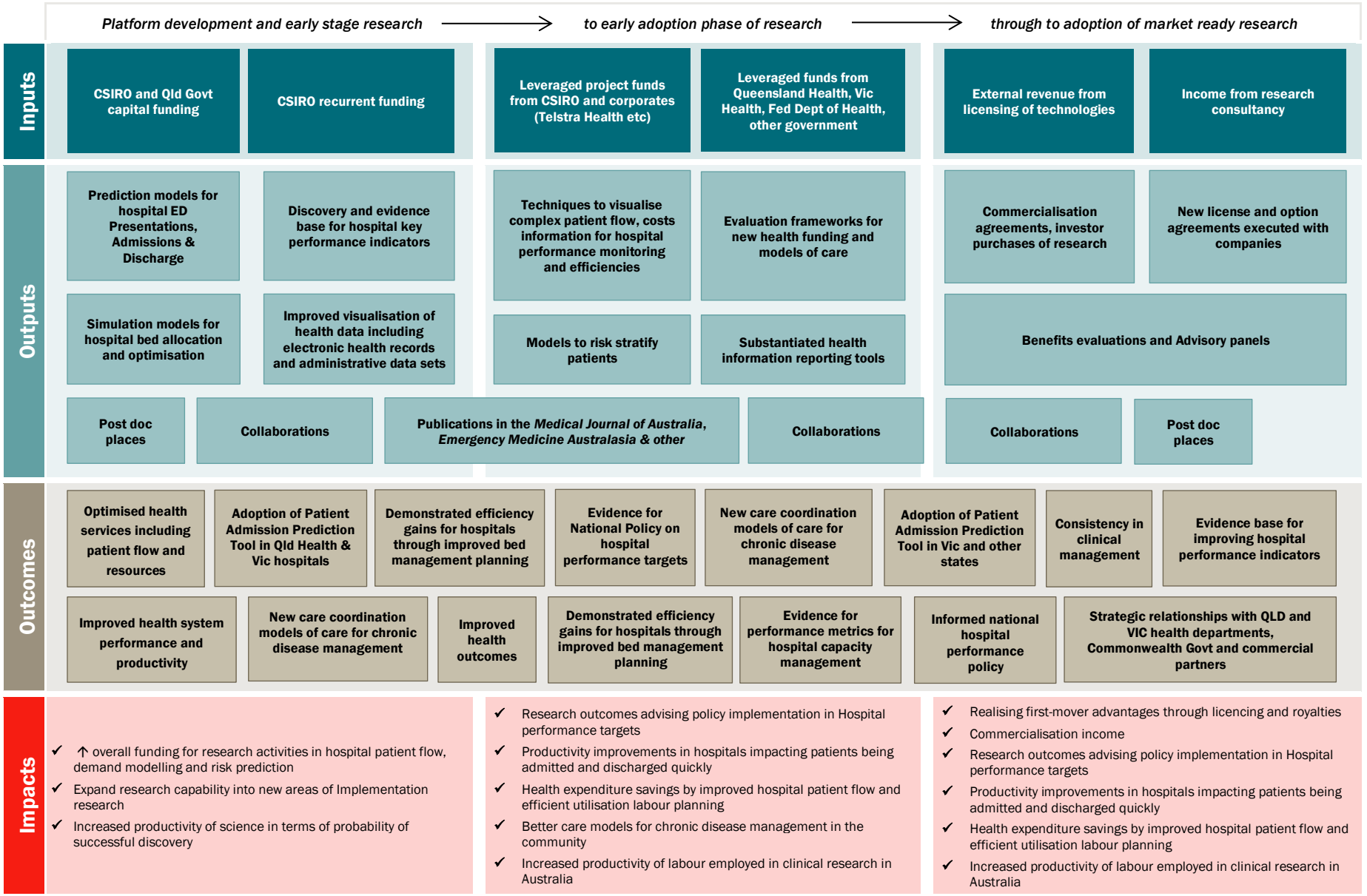
2.7 Key outcomes and impacts of AEHRC



Data source: CIE.

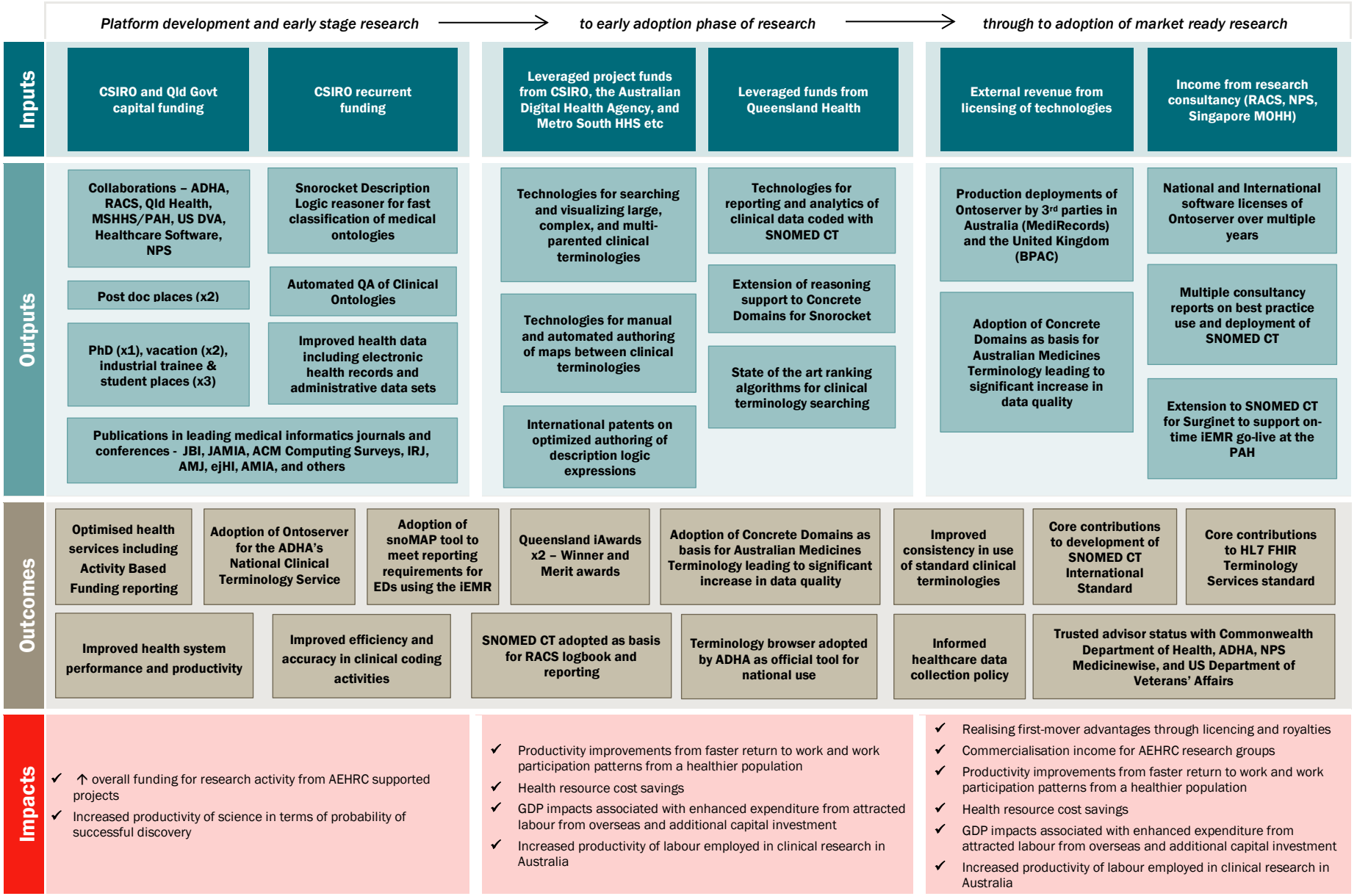
A Impact pathways for programs within the AEHRC portfolio

A.1 Impact map for Impact map for the Australian e-Health Research Centre (Health Data Analytics Team)



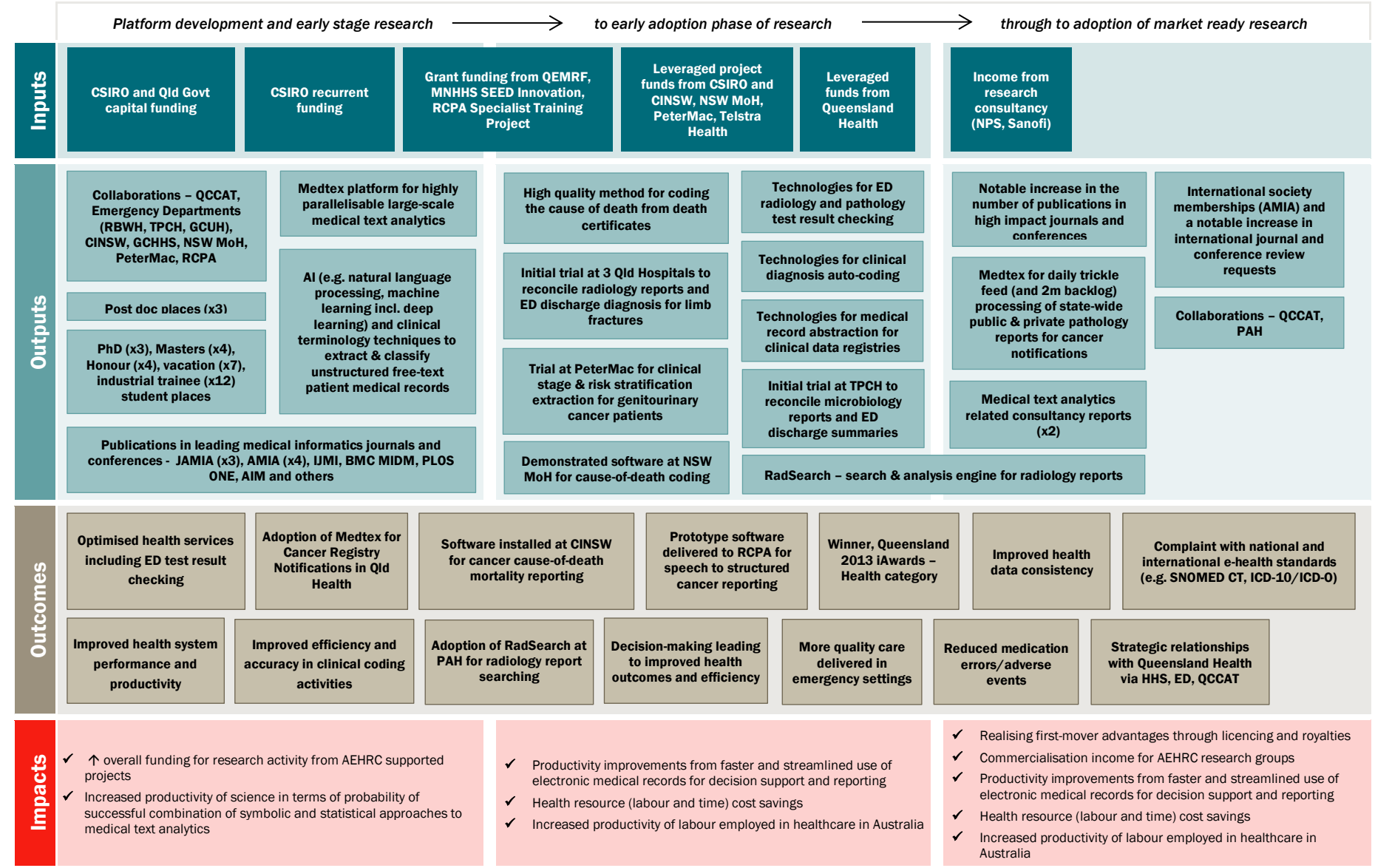
Source: CIE.

A.2 Impact map for the Australian e-Health Research Centre (Clinical Terminology Tools)



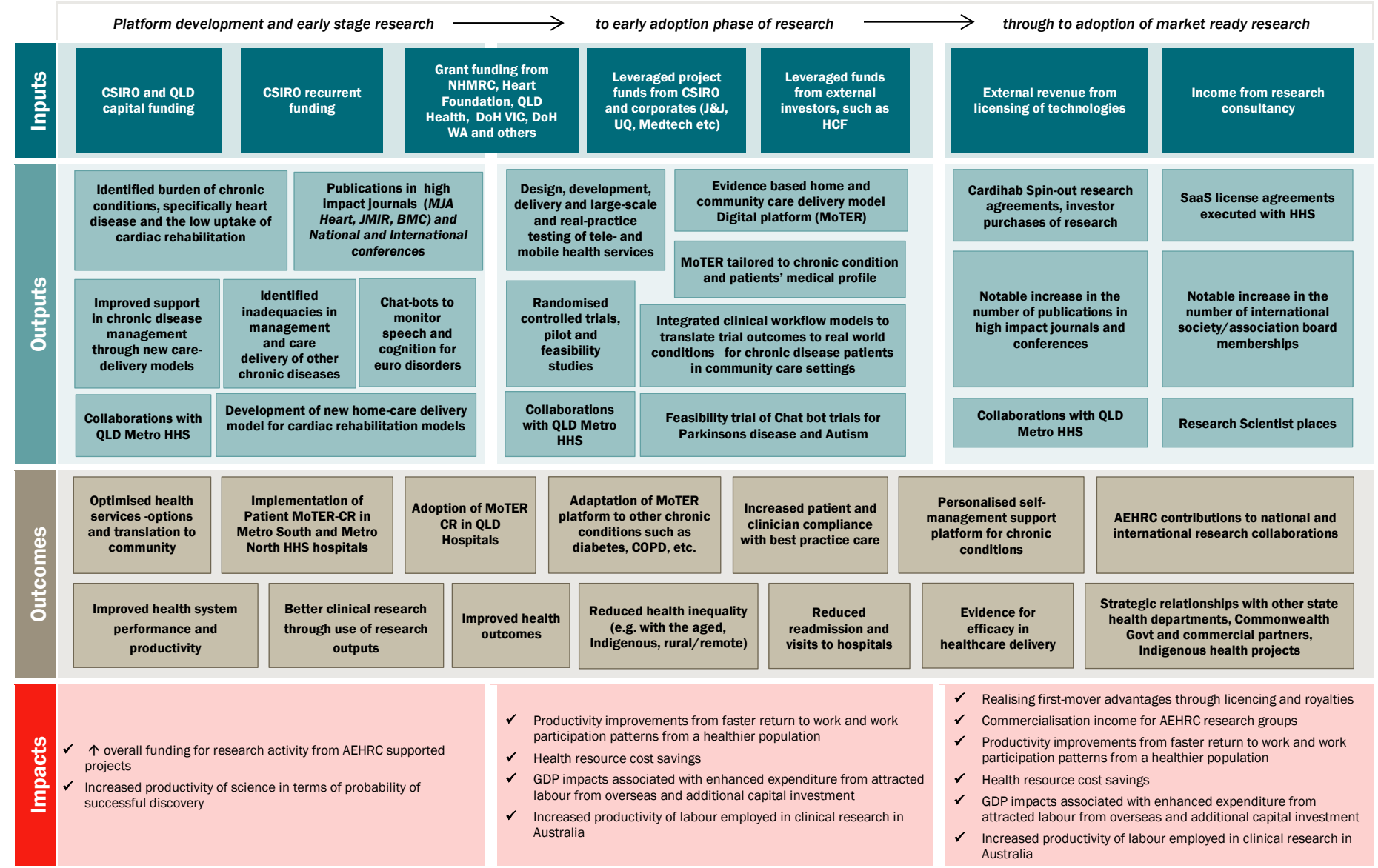
Source: CIE.

A.3 Impact map for the Australian e-Health Research Centre (Medical Text Analytics Team)



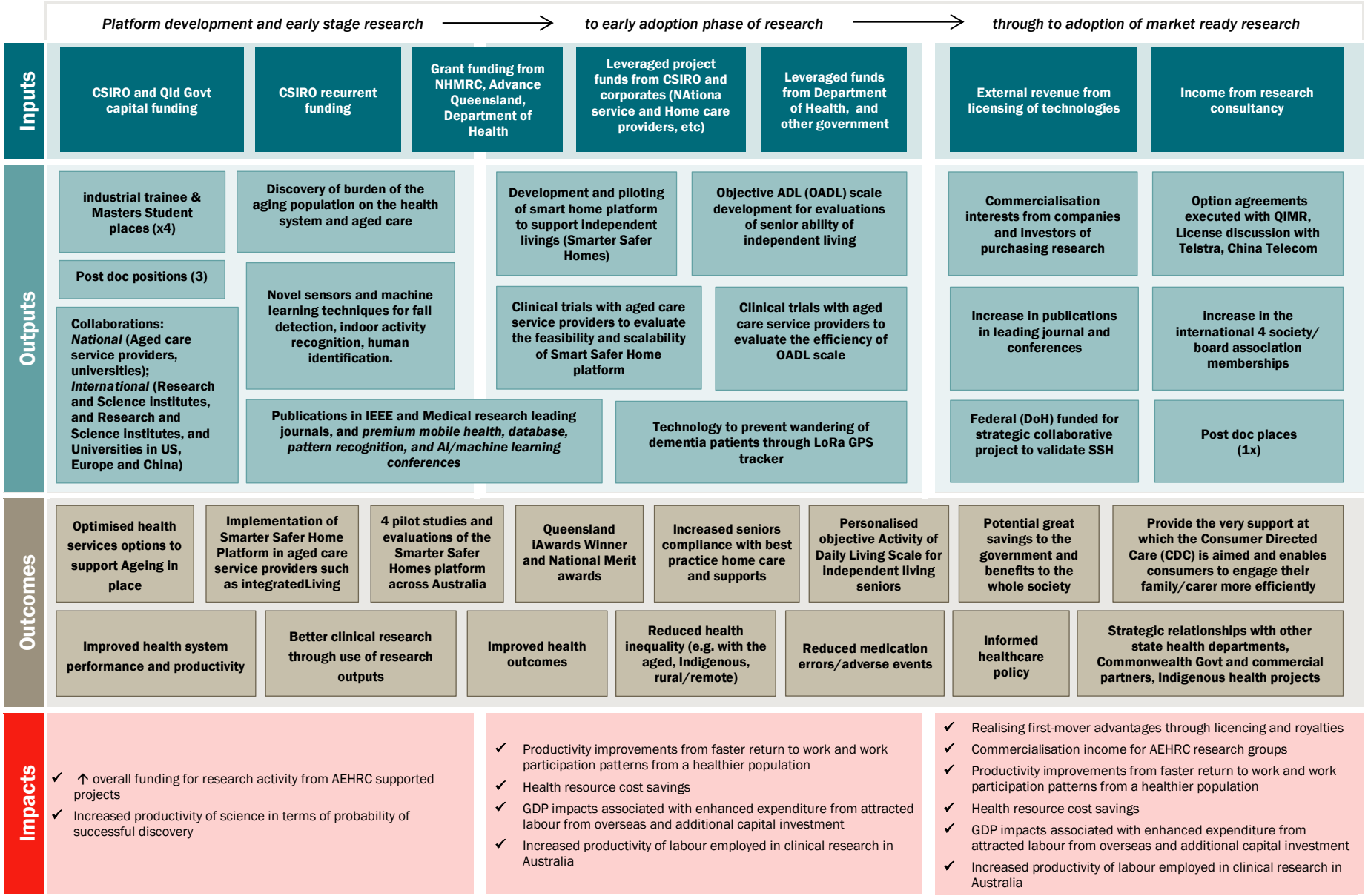
Source: CIE.

A.4 Impact map for the Australian e-Health Research Centre (Mobile Health Systems Team)



Source: CIE.

A.5 Impact map for the Australian e-Health Research Centre (Health Internet of Things Team)



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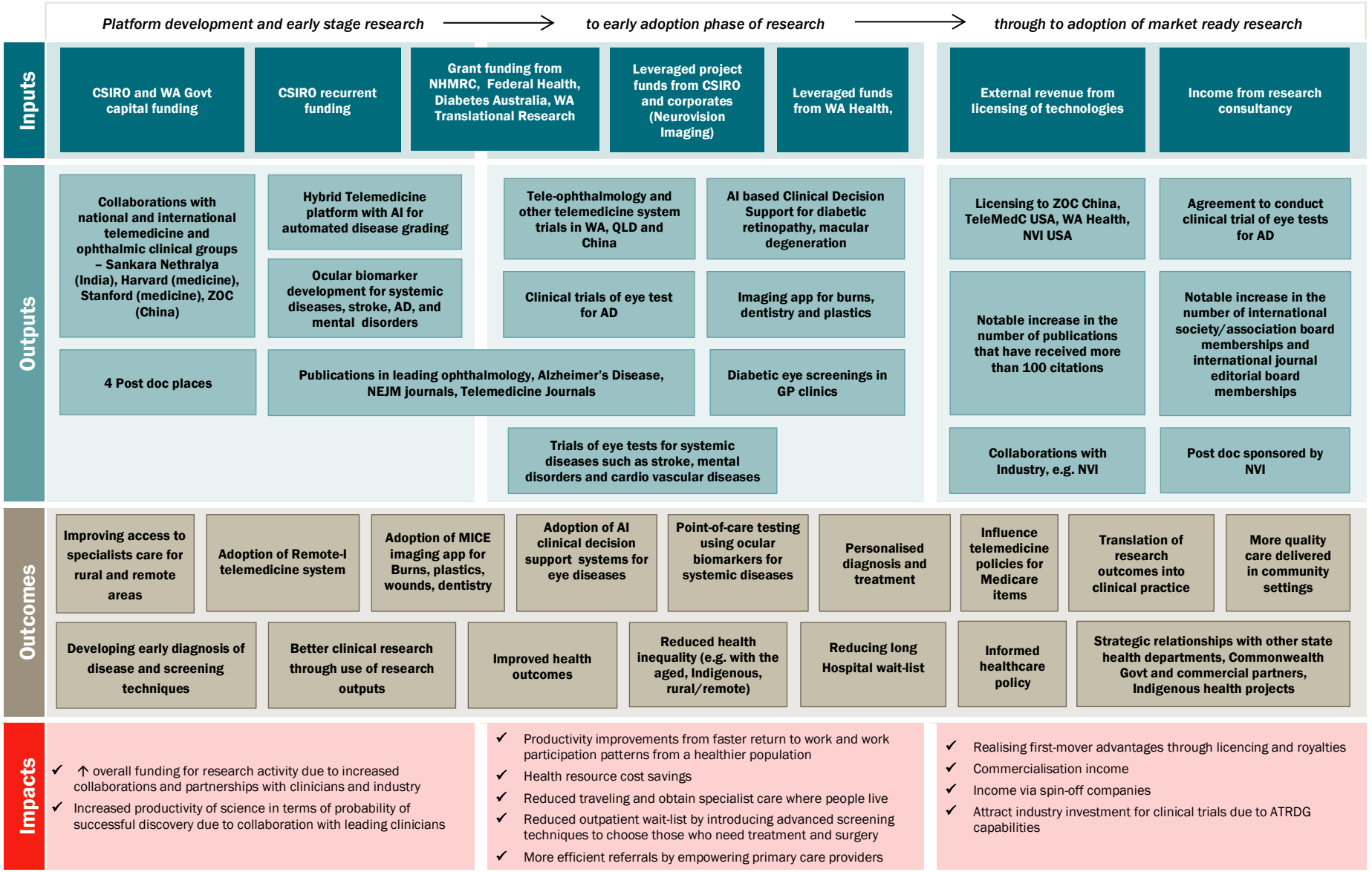
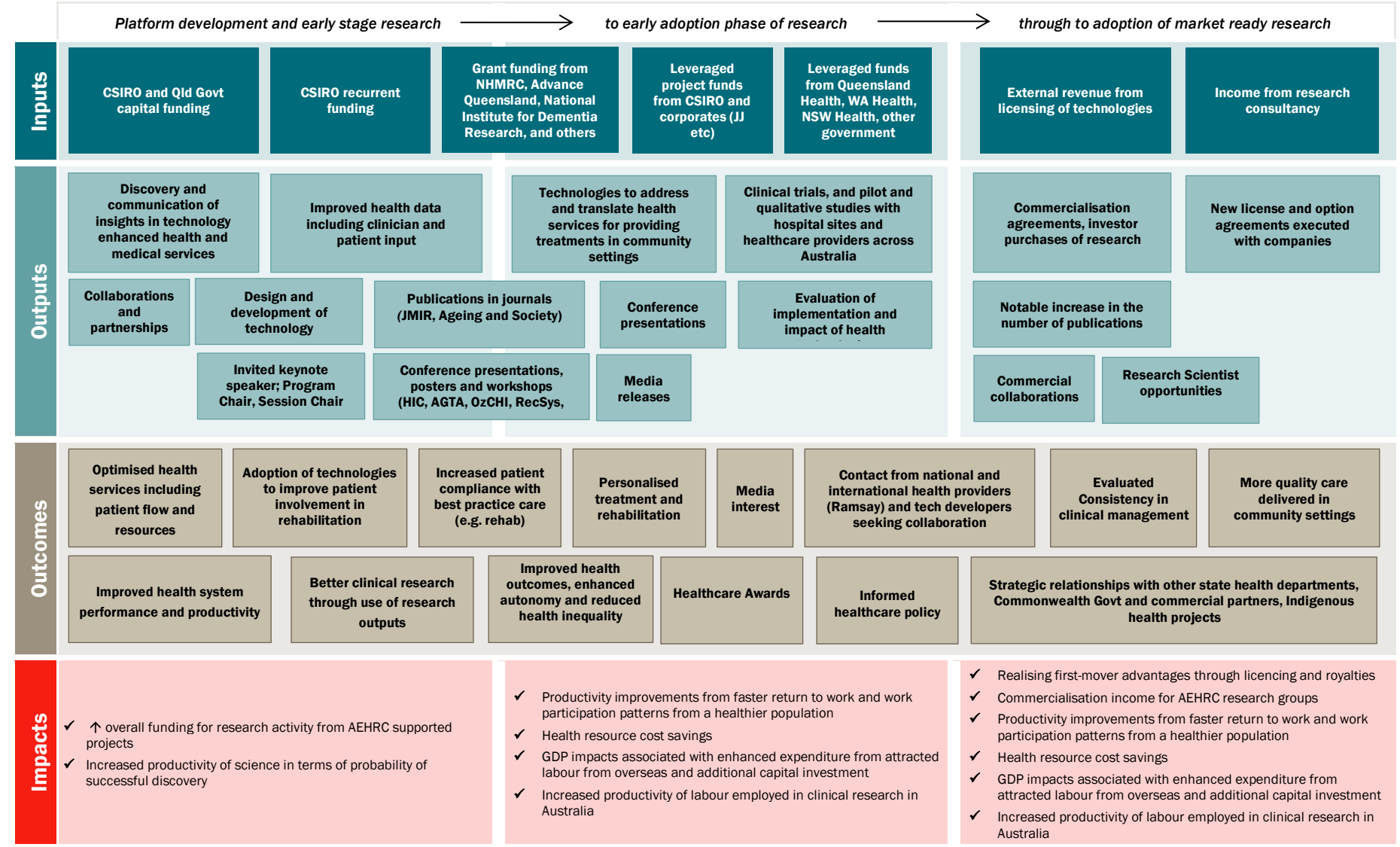
A.6 Impact map for the Australian e-Health Research Centre (Telemedicine Team)



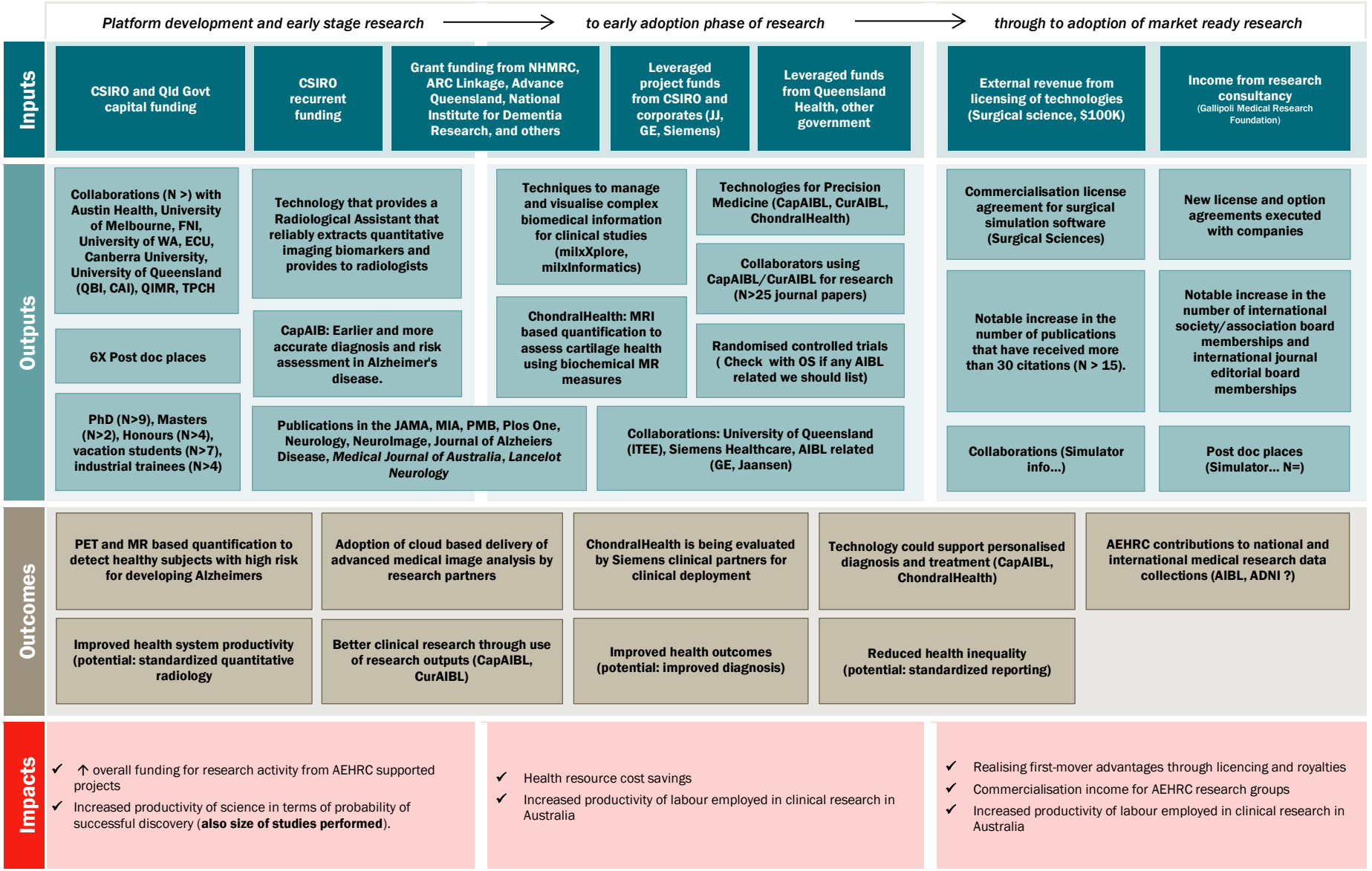
Source: CIE.

A.7 Impact map for the Australian e-Health Research Centre (Engagement and Effectiveness Team)



Source: CIE.

A.8 Impact map for the Australian e-Health Research Centre (Medical Image Analysis Team)



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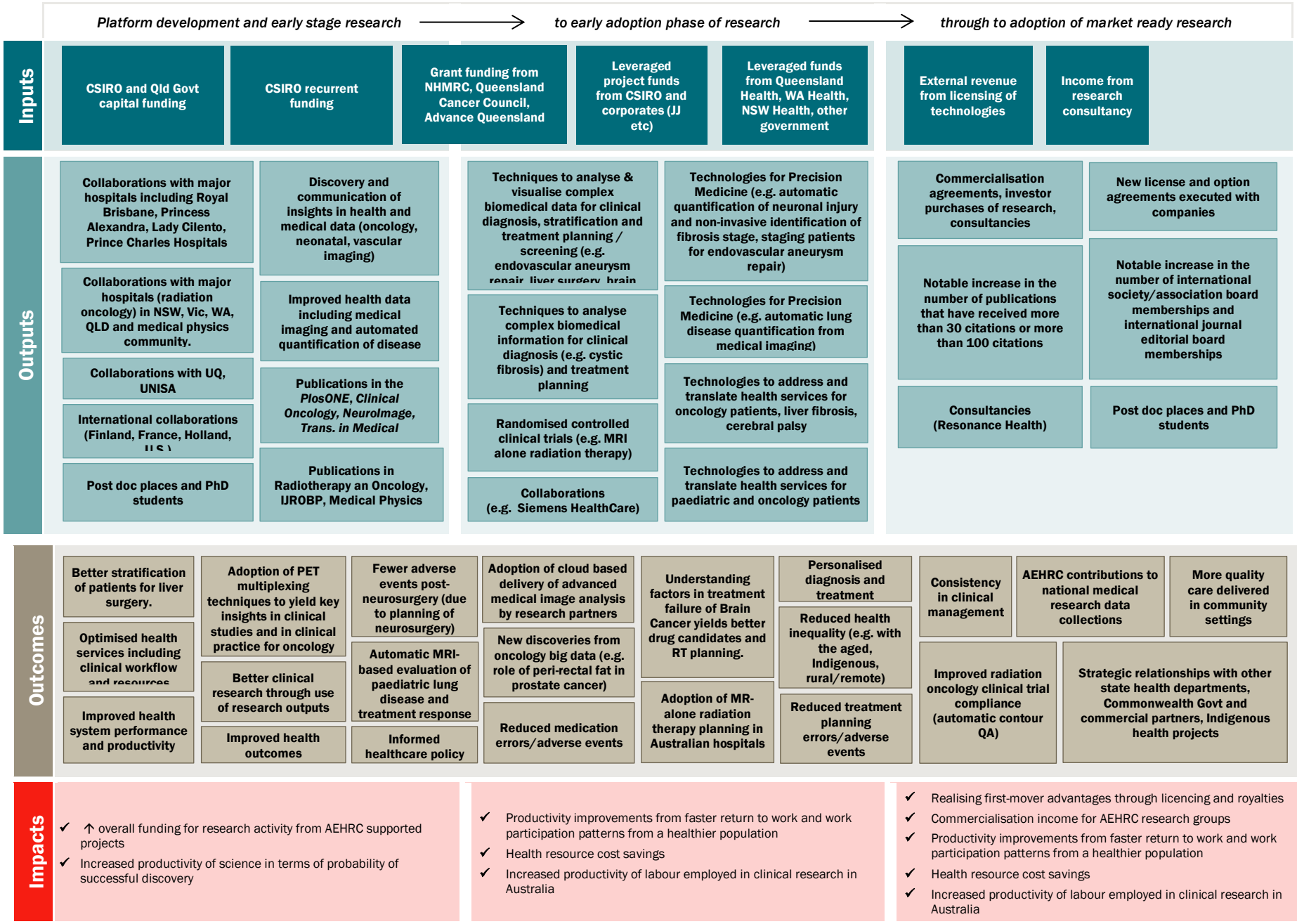
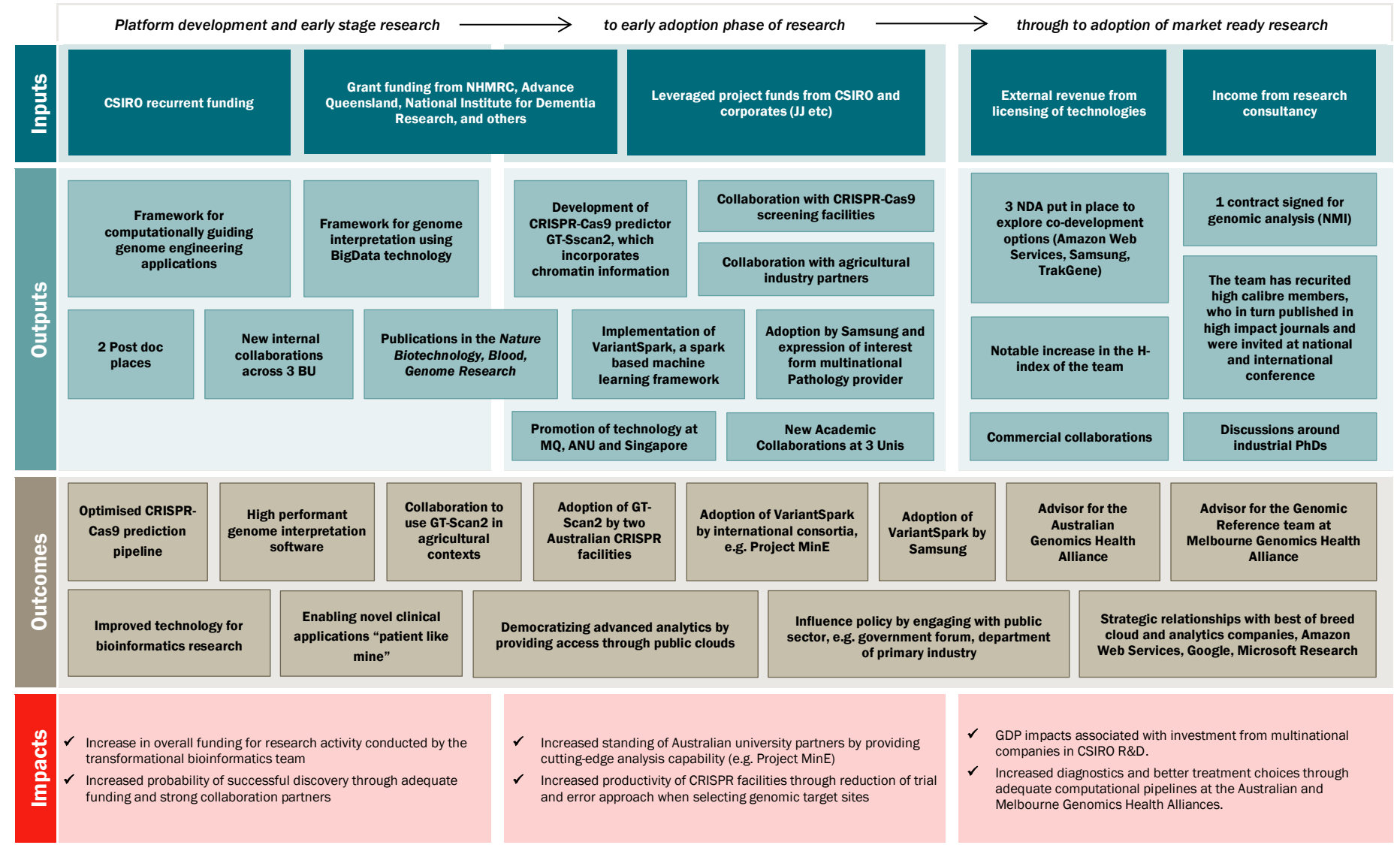
A.9 Impact map for the Australian e-Health Research Centre (Clinical imaging)



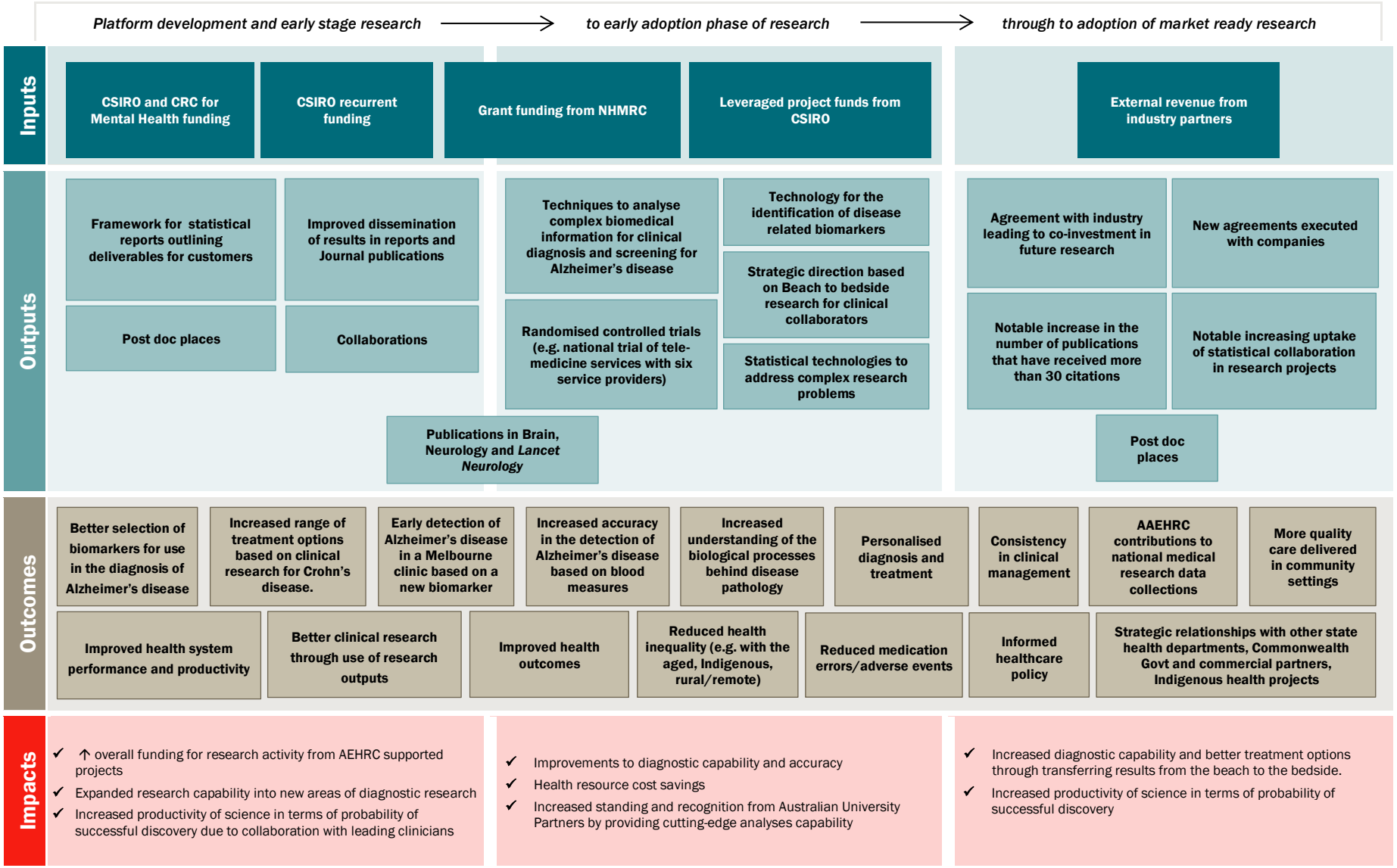
Source: CIE.

A.10 Impact map for the Australian e-Health Research Centre (Translational Bioinformatics)



Source: CIE.

A.11 Impact map for the Australian e-Health Research Centre (Biostatistics Team)



Source: CIE.

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