RESEARCH IMPACT EVALUATION

Future Grid Forum & Electricity Network Transformation Roadmap

Case Study

April 2017

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1 Executive Summary

The electricity system is central to Australia's modern lifestyle and economy. However, it is at a significant crossroad, facing complex and unprecedented challenges. These challenges include pathways for the transformation of the electricity network industry over the next decade, better customer outcomes, and rapid adoption of new technologies.

Many studies and reviews have evaluated the drivers of change now affecting the system, but most have focused on specific parts of the system or on the perspective of particular stakeholders. Australia's electricity sector accepted that given the challenges it faced, a whole-of-system evaluation was essential.

In recognition of the extraordinary circumstances of this time in the electricity sector, CSIRO convened the Future Grid Forum (FGF) in 2012 to develop and explore potential scenarios for Australia's energy future. The forum brought together more than 120 representatives of every segment of the electricity industry, as well as Federal and State governments and community stakeholders, to inform and inspire a national conversation and provide a way forward.

While the FGF identified the key alternative futures and broad responses, CSIRO recognised that a process was required to develop more detailed steps for responding to the industry's changing circumstances. To this end, following the FGF, CSIRO and the Energy Networks Association (ENA) partnered in 2015 to develop an Electricity Network Transformation Roadmap (the Roadmap) – a blueprint for transitioning Australia's electricity systems to enable better customer outcomes.

The FGF and Roadmap research identifies outcome options which will enable specific actions by businesses, policy makers and regulators, as part of an integrated pathway for Australia's energy transition over the next decade. CSIRO's FGF and Roadmap research has the potential to lead to a range of impacts, including reduced household electricity bills, reduced electricity system expenditure, and reduced greenhouse gas (GHG) emissions.

The overall benefits of the FGF and Roadmap research depend crucially on the adoption and actual achievement of the projected benefits. Ultimately, only government and commercial action can enable implementation of the FGF and Roadmap proposals. Most of this adoption takes place in the future, so the impact evaluation is associated with some uncertainty.

Looking at the midpoint of a range of impacts, our estimates suggest that the real project expenditure of $3.04 million by CSIRO could lead to:

- Total benefits (in real, present value terms) between $7.8 million and $30.3 million, depending on the assumptions made;
- Net benefits between $4.6 million to $27.3 million; and
- A return on investment ratio between 2.5:1 and 10:1.

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The impact pathway of the FGF and the Roadmap case study are summarised in Figure 1.1.

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACT
• CSIRO investment (FTE, in-kind contributions, equipment/facilities and background IP) • Funding from industry partners (cash, in-kind contributions) • Costs of adaptive development and extension by the industry.	• Develop analytical models/tools, collect data and undertake analysis. • Enable and engage with participants across the energy supply chain.	• Analytical models/tools and modelling capabilities • Reports, and papers and submissions, to COAG • Media launch and media reports.	***Uptake and Adoption*** • Adoption of advice, modelling results by government, industry and community • Communication and capacity building (diffusion of ideas, creation of common understandings) • Policy/Regulation.	***Economic impact*** • Reduced uncertainty enables decision-making • Reduction in household electricity bills. • Economic growth through improved productivity and competition ***Environmental impact*** • Environmental sustainability ***Social impact*** • Social equity and fairness • Energy security.

Figure 1.1: Impact pathway for the FGF & Roadmap project

2 Purpose and audience

This evaluation is being undertaken to demonstrate (to a range of stakeholders) the likely future social impacts arising from CSIRO's FGF and Roadmap research. This case study can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of CSIRO's activities relative to the funds invested in these activities.

The focus of the FGF and Roadmap research is the electricity sector. However, the electricity sector is only a part of a wider energy section where inputs and energy substitutes such as coal, oil and gas can be affected by government policy settings and global events. Given the scope of this evaluation, future developments in other energy sectors have not been taken into account. We acknowledge that this limitation may contain a degree of bias both in the Roadmap scenarios and our evaluation outcomes.

This case study has been conducted for accountability, reporting, communication, and continual improvement purposes. Audiences for this report may include the Business Unit review panel, Members of Parliament, Commonwealth Departments, CSIRO, and the general public.

3 Background

The challenge

The electricity system is central to Australia's modern lifestyle and economy. However, it is also at a significance crossroad facing complex and unprecedented challenges (Graham et al. 2013). The Australian energy landscape has huge potential for transformation towards 2050; and the greatest changes will be defined by the global drive to lower emissions, and by consumer choices. Australians could have an unprecedented opportunity to tailor their energy use to better meet their needs (Figure 3.1). The current challenge is to understand and prepare for the changes ahead.

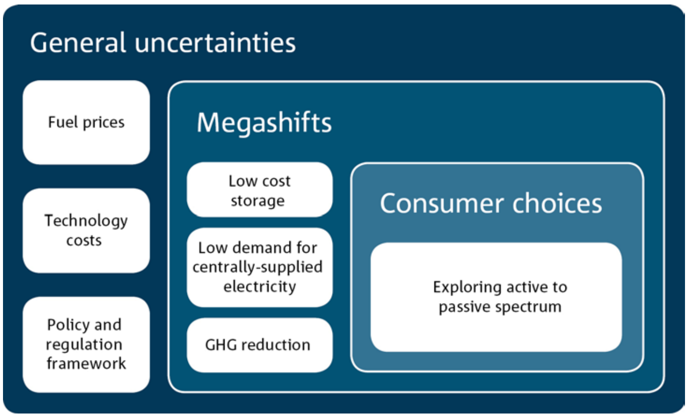

Figure 3.1: Key challenges facing the Australian electricity system

Source: Graham et al 2013.

In Australia, the change involves transforming the nationwide integrated electricity networks of almost one million kilometres while they continue to serve 10 million customers. Importantly, this change dose not impact only the poles and wires. The regulatory frameworks, commercial systems, pricing structures, and supporting control and technological systems that kee p Australia switched on 24/7 are also exposed to this generational challenge (Paterson 2015).

Many studies and reviews have evaluated the drivers of change now affecting the system, but most have focused on specific parts of the system or on the perspective of particular stakeholders. Australia's electricity sector acknowledged that the system could not be analysed and optimised by only examining its separate parts. A whole-of-system evaluation was essential.

The response

Recognising the extraordinary circumstances of this time in the electricity sector, CSIRO convened the FGF in 2012 to develop and explore potential scenarios for Australia's energy future. The forum brought together more than 120 representatives of every segment of the electricity industry, as well as federal and state governments and community stakeholders, to inform and inspire a national conversation and provide a way forward.

Flowing on from the FGF, CSIRO and the Energy Networks Association (ENA) partnered in 2015 to develop an Electricity Network Transformation Roadmap (the Roadmap) – a blueprint for transitioning Australia's electricity systems to enable better customer outcomes.

The Roadmap program is a two stage process running over approximately 18 months. The Interim Program report outlines the findings of Stage 1 (which ran from July to October 2015) and includes a refresh of the FGF scenarios. A key concepts report or draft of the roadmap was publicly released in December 2016 for stakeholder review. The final Roadmap incorporating stakeholder feedback is due to be released in April 2017. It will identify an integrated program of actions and measures that provide the 'pathway' for Australia's energy transition over the 2017-27 decade.

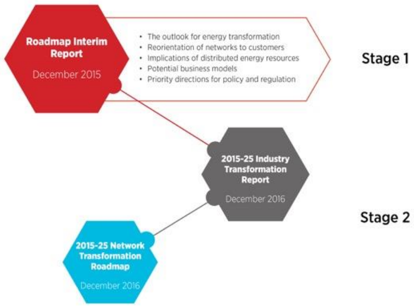

Figure 3.2: Roadmap timeframe

Source: Paterson 2015.

Like the FGF undertaken in 2013, the Roadmap program emphasises broad stakeholder engagement to help 'co-design' and prioritise transition options. The development of the Roadmap has benefited from the valuable participation of almost 200 customers representatives, supply chain stakeholders, and discipline experts.

4 Impact Pathway

Project Inputs

The FGF and Roadmap research is a collaboration between industry, government and CSIRO. As previously noted, both the FGF and Roadmap contributed to the establishment of a pathway for the transformation of the electricity network industry over the next decade. For the purpose of this evaluation, research costs of both projects incurred by CSIRO and its collaborators are included. Estimates of the funding by institution for the project are show in Table 4.1.

Table 4.1: Total investment in the FGF& Roadmap project (nominal $)

Year	CSIRO ($m)	Industry ($ m)	Total ($ m)
2012/13	1.07	0.67	1.74
2013/14	0.36	0.02	0.38
2014/15	0.05	0.16	0.21
2015/16	0.50	1.15	1.65
2016/17	0.50	0.86	1.35
Total	2.48	2.85	5.33

Source: CSIRO

Activities

This research focused on developing and exploring potential scenarios for Australia's energy future and supporting the decision-making process around what comes next. It undertook extensive whole-of-system quantitative modelling and customer social dimensions research to support its deliberations and findings. The FGF explored the future challenges and extensively modelled four scenarios to answer the following questions:

- What might Australia's electricity system look like in 2050?
- What are the issues and options that might arise along the way?
- What can the electricity sector and its stakeholders do to most effectively plan and respond?

Through 11 days of workshops over 15 months, the forum participants developed and agreed on four energy future scenarios that are most likely to occur in Australia. The Forum involved participants in a fact-building and consensus-building process to provide factual information that could support decision-making by stakeholders who are in a position to act in or direct the future electricity system.

Following its FGF in 2013, CSIRO partnered with the Energy Networks Association (ENA) on the Electricity Network Transformation Roadmap. The Roadmap sets out a pathway consisting of detailed milestones and actions for the transformation of the electricity network industry over the next decade, supporting better customer outcomes as the sector accommodates rapid adoption of new technologies. The milestones and actions are addressed across five key domains for the 10 year period to 2027 (summarised in Figure 4.1).

The Roadmap development process involved collaboration across the energy supply chain, including consumer representatives, service and technology providers, policy makers, regulators, and academia. As part of the process, new models were developed, and existing models were augmented to perform systemic analysis of the electricity supply chain.

	FOUNDATION 2017 – 2022	IMPLEMENTATION 2023 – 2027+
	2017 2018 2019 2020 2021 2022	2023 2024 2025 2026 2027 2027+
CUSTOMER ORIENTED ELECTRICITY	**Improve Trust with Customers** » Enhanced customer engagement and collaboration » Customised choices, better information on services and new connection and advisory services » Demonstrate investment reflects customer value while improving service performance and response times » Review of Consumer Protection and concessions	**Networks provide a service platform** » Open network platforms embrace diverse customer needs and aspirations » Collaborate with customers and market actors to create new value with streamlined connections » Leverage network information and digital services for personalised innovation in a dynamic market
POWER SYSTEM SECURITY	**New systems to support diverse generation** » Update Transmission Interconnection test » Review frameworks for protection systems, efficient capacity and balancing services » New market frameworks for ancillary services » Develop new power system forecasting and planning approaches to anticipate system constraints » Enhanced intelligence and decision making tools » Close focus on physical & cyber security	**Harmonised System Operations at all levels** » Transmission networks support system stability with new services. » Distribution networks provide visibility of DER and potentially Frequency Control Ancillary Services (FCAS) and delegated balancing services. » Real-time communication and controls
CARBON ABATEMENT	**A stable Carbon Policy for higher targets** » Develop nationally integrated carbon policy framework » Implement emissions Baseline & Credit Scheme » Set Light Vehicle emissions standard policy to provide incentives for electric vehicle uptake, supporting climate goals » Review Australia's emissions reduction target » Agile network connections and integration of large and small scale renewable technologies	**Reviewing scope for greater efficiency** » Review technology specific incentive schemes to focus on least cost abatement » Review scope for more efficient economy wide carbon pricing where consensus » Review Australia's emissions reduction target (2027)
INCENTIVES & NETWORK REGULATION	**Incentivising efficiency and innovation** » Ensure extensive smart meter penetration » Assign customers to new range of fairer demand-based network tariffs, with a choice to Opt Out » Enable standalone systems and micro-grids as a substitute for traditional delivery models » New innovation incentives in Regulation and Competition frameworks	**Unlocking value of distributed energy resource orchestration** » Networks pay for distributed energy resource orchestration to provide system support in the 'right place at right time' » New network tariffs that provide beneficial incentives for standalone systems and micro-grids to stay connected to the grid » New and more adaptive regulatory approaches that are customer focused
INTELLIGENT NETWORKS & MARKETS	**Essential information for an integrated grid** » Establish open standards and protocols to enable secure system operation, management and exchange of information and interoperability with distributed energy resources » Networks enhance current system monitoring and models to inform advanced system planning » Build distributed energy resource maps and feeder hosting analysis to support locational valuation of distributed energy based services	**Networks optimised with distributed energy resources** » Active network management for technical stability, enabling distributed energy resource markets and efficient optimisation. » Networks provide a suite of grid intelligence and control architectures to animate distributed energy resource markets, as well as providing system security. » Establish a new network optimisation market to procure DER services for network support. » A flexible and agile workforce to support the new optimised energy system.

Overall Customer outcomes by 2027	2050
CUSTOMER CHOICE AND CONTROL	
» Over 40% customers use onsite resources: 29 GW solar and 34 GWh of batteries. » Concessions to support those who need it most.	» Almost 2/3 customers use onsite resources, including 1/3 customers on a new stand alone system tariff.
LOWER BILLS FOR VALUED SERVICES	
» Avoid over $1.4 BN in network investment. » Average network bills 10% lower than 2016.	» Total system spend is $101BN lower to 2050. » Save households $414 pa by 2050. » Network charges 30% lower than 2016.
FAIRNESS & INCENTIVES	
» Networks pay over $1.1 BN pa for DER services. » Over $1.4 BN in cross subsidies avoided, saving $350 pa for med size family without DER.	» Networks pay over $2.5 BN pa for DER services. » Over $18 BN in cross subsidies avoided, saving $600 pa for med size family without DER.
SAFETY, SECURITY, RELIABILITY	
» Planned and efficient market response avoids security & stability risks. » Robust physical & cyber security management.	» Real time balancing, reliability and quality of supply at small and large scale, with millions of market participants.
CLEAN ENERGY TRANSITION	
» Electricity sector carbon abatement to reach 40% by 2030 – greater than current national target of 26-28%.	» Electricity sector achieves Zero Net Emissions by 2050.

Figure 4.1: Energy Network Transformation Roadmap summary diagram

Outputs

The main output of the FGF is Australia's first extensive whole-of-system assessment of the entire energy chain – from generation through to consumption. Findings from the forum are presented in a comprehensive report, *Change and choice: The Future Grid Forum's analysis of Australia's potential electricity pathways to 2050*.

The forum developed four scenarios which have far-reaching implications for the current and future electricity supply chain and would alter the electricity system in Australia:

- set and forget – where consumers rely on utilities;
- rise of the prosumer – where consumers actively design or customise solutions;
- leaving the grid – where consumers disconnect from the grid; and
- renewables thrive – where storage play a large part in entire electricity system.

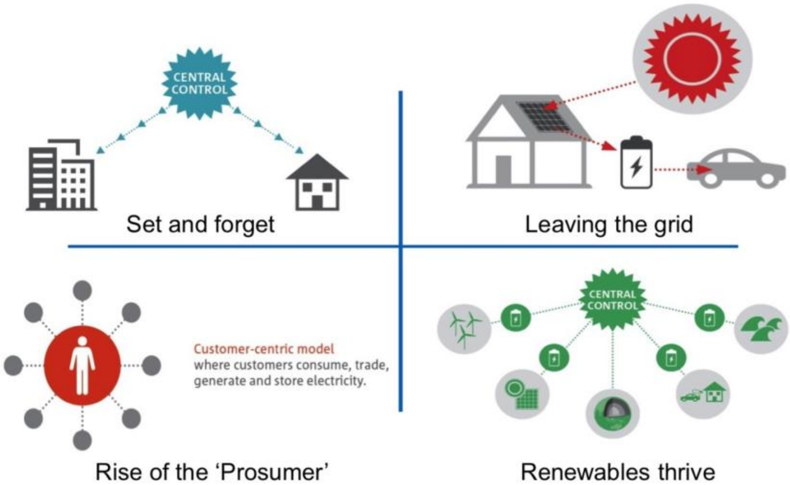

Figure 4.2: Four possible future scenarios

Source: Graham et al. 2013.

The four scenarios developed by the FGF highlighted that Australia's electricity future is very different from current and historical norms. This set of long term perspectives supports five propositions affirming the need for the Roadmap (Paterson 2015), including:

1. Disruptive change is upon us – electricity networks face significant and transformative challenge unanticipated by the architects of current industry systems.
2. The change is multidimensional – the transformative forces are multidimensional and must be addressed in a whole-of-system manner rather than in silos.
3. The pace and scale of change may outstrip current change management – regulatory mechanisms were not designed to facilitate the transformative change and they are increasingly at risk of being outpaced by disruptive threats.

4. A ‘critical decade’ of transition is ahead – change is occurring quicker and more broadly, and the 2015–25 decade will be a critical window for the Australia’s electricity system.
5. Agility, collaboration and co-design are needed – no single player or industry sector can ‘engineer’ the energy system transformation.

The Roadmap, commencing in 2015, identifies specific actions for businesses, policy makers, and regulators as part of an integrated pathway for Australia’s energy transition over the next decade. In December 2015, an interim Program report was delivered, providing early advice for decision makers. The interim Program report updated the 2013 scenarios, to ensure that the FGF scenarios were still relevant after two years, and to make any required adjustments so that they could provide a solid baseline for final Roadmap scenarios.

In December 2016, the Roadmap Key Concepts Report was publicly released following a two year work program involving hundreds of stakeholders, an evidence base of 19 expert reports, and unprecedented analysis of energy system outcomes to 2050. The Key Concepts Report identifies integrated measures which can achieve a positive energy future for Australian energy customers enabling choice, lower emissions, lower costs, and high security and reliability.

Key findings in the Interim Report include:

- Customers retain security and reliability essential to lifestyle and employment;
- Networks pay distributed energy resources customers over $2.5 billion per annum for grid support services by 2050;
- Electricity sector achieves zero net emissions by 2050;
- $16 billion in network infrastructure investment is avoided by orchestration of distributed energy resources;
- Reduction in cumulative total expenditure of $101 billion by 2050 relative to the counterfactual (a status quo/existing trends scenario);
- Network charges 30% lower than 2016;
- $414 annual saving in average household electricity bills (compared with roadmap counterfactual, and business as usual, pathway); and
- A medium family who cannot take up distributed energy resources is over $600 p.a. better off (in real terms) through removal of cross subsidies.

We acknowledge that the ‘five propositions affirming the need for the Roadmap’ suggest that a centralised body or a group of stakeholders is required to resolve the multidimensional problems of the electricity sector on the basis of the Roadmap. It is at least arguable that the failings of the electricity sector are due to the distortions and uncertainties imposed on it by government regulation. However, the research did not include analysis of a fully deregulated scenario that allows long-term market forces, rather than a social planning approach, to resolve current problems. This fact may imply that impacts arising from the FGF and the Roadmap research might be regarded as being tendentious in nature.

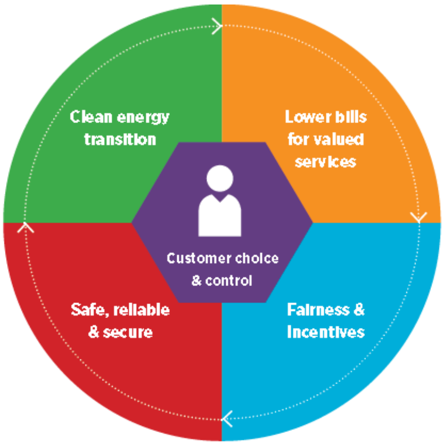

Figure 4.3: A balanced scorecard for Australia's electricity sector

Source: CSIRO 2016.

Publications

Program Quantification

Brinsmead, T & Graham, S Forthcoming 2017, *Economic benefits of the Electricity Network Transformation Roadmap: Technical report*, CSIRO, Canberra.

Customer-oriented Networks

Accenture and Energy Networks Association 2015, *Network business model evolution: an investigation of the impact of current trends on DNSP business model evolution*, Energy Networks Association, Canberra.

Accenture and Energy Networks Association 2016, *Insights from Global Jurisdictions, New Market Actors & Evolving Business Models*, Energy Networks Association, Canberra.

CSIRO & Energy Networks Association 2015, *Electricity Network Transformation Roadmap: Interim Program Report*, CSIRO report for Energy Networks Association, Canberra.

CSIRO & Energy Networks Association 2016, *Electricity Network Transformation Roadmap: Customer Engagement Handbook*, CSIRO report for Energy Networks Association, Canberra.

Customer Safety Net

Consumer Action Law Centre 2016, *Power Transformed; Unlocking effective competition and trust in the transforming energy market*, report for Energy Consumer Australia, Sydney.

Carbon & Renewable Policy Options

Energy Networks Association 2016, *Enabling Australia's Cleaner Energy Transition*, report for Energy Networks Association, Canberra.

Jacobs Group 2016, *Australia's Climate Policy Options – Modelling of Alternate Policy Scenarios*, report for Energy Networks Association, Canberra.

Efficient Capacity Utilisation

ClimateWorks Australia 2016, *Gas-electricity substitution projections to 2050*, report for Energy Networks Australia, Canberra.

Graham, P & Brinsmead T 2016, *Efficient capacity utilisation: transport and building services electrification*, CSIRO report for Energy Networks Australia, Canberra.

Pricing & Incentives

Energeia 2016, *Price and Incentives Report*, report for Energy Networks Australia, Canberra.

Energeia 2016, *Stand Alone Power Systems and Microgrids Report*, report for Energy Networks Australia, Canberra.

Regulatory & Policy Frameworks

Cambridge Economic Policy Associates 2016, *Future Regulatory Options for Electricity Networks*, report for Energy Networks Australia, Canberra.

Power System Security

EA Technology 2016, *Grid Design, Operation, Platform & Telecoms Report*, report for Energy Networks Australia, Canberra.

Marchment Hill Consulting 2015, *Embedded Generation Report*, report for Energy Networks Australia, Canberra.

Intelligent Networks

EA Technology 2016, *Network Transformation Roadmap: Innovation Gap Analysis and Plan*, report for Energy Networks Australia, Canberra.

DER Markets & Orchestration

Berkeley, L 2015, *Distribution Systems in a High DER Future: Planning, Market Design, Operation and Oversight*, report for Energy Networks Australia, Canberra.

EA Technology 2016, *Grid Design, Operation, Platform & Telecoms Report*, report for Energy Networks Australia, Canberra.

Future Workforce Requirements

Energy Skills Queensland 2016, *Changing Industry, A Changing Workforce: Electricity National Transformation Roadmap Workforce Skilling Impacts*, report for Energy Networks Australia, Canberra.

Technical Standards and Regulations

Standards Australia 2016, *Standards and the Future of Distributed Electricity*, Standards Australia, Sydney.

Outcomes

The FGF and Roadmap reports provided early advice for decision makers that there were major structural changes unfolding in the electricity sector that could impose significant impacts on customers and that would change the role that electricity networks had traditionally played. Specifically they identify that by 2050, around 25-40 percent of electricity was likely to be generated at the customer's own site, with some customers disconnecting from the grid altogether. This change was not anticipated in the original design of the grid. To be able to manage this change and to achieve the best outcome for customers in terms of cost, reliability, greenhouse gas emissions, fairness and choice, the Roadmap sets out detailed milestones and actions to overcome the various challenges of transforming the system to match the new reality. The actions include changes to regulatory frameworks and industry standards, and adopting new technologies and processes where more cost effective.

The potential users of the research outcomes include four stakeholder groups in research, industry, government (policy), and the broader community:

- Australian Energy Market Operators;
- Energy/utilities Industry;
- Commonwealth and State governments/regulators; and
- Residential consumers.

The channels of adoption include communication and capacity building such as training and research activities, and policy/regulation. There is evidence of further dissemination of the report findings and conversations. For example, the scenarios were reported to be widely debated in the industry and relationships with stakeholders and the ENA have been significantly deepened as a result of the Forum participation (McGrail 2014). Significantly, the Forum process is reported to have engendered a greater recognition for the need for change and appetite for change in the industry (McGrail 2014).

Some examples of early adoption include:

- Consumer group are using FGF and Roadmap outputs to determine impacts and protections needed for consumers (Consumer Action Law Centre 2016).
- In October 2016, CSIRO presented to the COAG Energy Council its work on the future of the electricity transmission network. CSIRO highlighted some of the challenges and potential solutions for increasing transmission network scale storage, and how batteries and intelligent control systems can assist with grid reliability and security.
- The Future Grid Research Program, a $13 million collaboration project between CSIRO and four Australian universities, builds on CSIRO's energy and electricity sector work, including the FGF. The project aims to develop Australia's capacity to plan and build the most efficient, low emissions grid for Australia.
- CSIRO has responded to a number of direct information requests from Alan Finkel who is head of the Independent Review into the Future Security of the National Electricity Market which draws on analysis in the Roadmap.
- CSIRO and ENA were both invited to attend and provide expert information to the Select Committee into the Resilience of Electricity Infrastructure in a Warming World.
- The ENA is developing an implementation plan that includes developing specific projects to deliver the parts of the Roadmap their member businesses are responsible for, as well as designing more collaborative projects to work with external stakeholders (government, retailers, regulators, etc.) on those parts of the Roadmap which will require collaboration in order to be delivered.

Impacts

CSIRO's FGF and Roadmap research has the potential to lead to a range of impacts, including reduced household electricity bills, reduced electricity system expenditure, and reduced greenhouse gas emissions. Using CSIRO's triple bottom line impact classification approach, Table 4.2 summarises the potential impacts. Of the benefits identified, economic and environmental benefits are estimated in monetary terms, as discussed in the section below. Given the constraints of data availability, potential social benefits are noted, but not assessed.

Table 4.2: Impacts of the FGF & Roadmap project

TYPE	CATEGORY	INDICATOR	DESCRIPTION
Economic	Productivity and efficiency	Electricity systems total expenditure	The electricity sector could achieve significant reduction in cumulative total expenditure, primarily due to avoided duplication of capacity in the distribution, transmission, and end-use sectors.
Economic	Productivity and efficiency	Household electricity bills	Average residential electricity bills could be reduced due to lower electricity network expenditure and more efficient electricity network utilisation.
Environmental	Air quality	Greenhouse gas emissions	Under the Roadmap scenario, the electricity sector could achieve Zero Net Emissions by 2050 due to strong power security performance.
Social	Resilience	Fairness and vulnerable customers	If adopted, the research scenarios minimises inequitable outcomes or unintended costs transfers that might arise where customers are not able to take up opportunities that would save on electricity bills.
Social	Security	Electricity systems safety, security and reliability	At a national level, a planned and efficient market response could avoid security and stability risks, and could encourage robust physical cyber security management.

We acknowledge that the FGF and Roadmap research is but one of many instigators of national energy policy initiatives. Ultimately, only government and commercial action can enable implementation of the FGF and Roadmap proposals. It might therefore be premature, to attribute to the research project the benefits for the future. This valuation provides a ball-park estimate of the potential benefits if all proposals are fully adopted, and therefore requires the need for a follow-up revision of the valuation once the results of the actual uptake/adoption become known.

5 Clarifying the Impacts

Counterfactual

The counterfactual scenario describes what happens if the Roadmap is not implemented and the status quo or extension of current trends prevails. As identified in the 2016 Roadmap Key Concepts Report, the Roadmap scenario has been simplified into three broad key elements :

- Price and incentive reform plus optimised networks and markets means distributed energy resources adoption is enabled and delivering network capacity reduction tuned to each zone substation.

- Efficient capacity utilisation is achieved through 20% adoption of electric vehicles by 2035 with managed charging.
- Electricity sector decarbonisation does more than its proportional share of current national abatement targets and accelerates that trajectory by 2050 to reach zero net emissions (100% abatement) due to strong power system security performance assisted by distributed energy resources orchestration.

Conversely, the Counterfactual scenario includes the following three broad key elements:

- Today's approach to pricing and incentive environment prevails (relying on customer opt in to efficient tariffs) resulting in slow and incomplete adoption of incentives for demand management.
- No adoption of electric vehicles, consistent with current national electricity system planning assumptions
- Electricity sector delivers abatement of 35% by 2030 and 65% by 2050 reflecting ongoing carbon policy uncertainty and lack of confidence in and coordination of resources for delivering lower emissions and high variable renewable

Attribution

CSIRO was the primary source of this research and other collaborators include the ENA, Australian and overseas consultants (whose worked was commissioned by either the ENA or CSIRO), and more than 120 representatives of the electricity industry, government and community.

Since all of the stakeholders were considered necessary to achieve the objective of developing potential scenarios for Australia's energy future and supporting future decision-making, it was appropriate to attribute benefits among the project on a cost-sharing basis. CSIRO accounted for approximately 0.22% per cent of the total research and implementation costs. Consequently, in this analysis, we use a conservative estimate and assume that that roughly 0.22% per cent of the benefits arising from the research program can be attributed to CSIRO if the Roadmap is implemented as envisaged. We acknowledge that there is uncertainty around whether the FGF and Roadmap will be the unique or primary instigator of national energy policy initiatives. To address this uncertainly, a sensitivity analysis will be undertaken in Section 7.

6 Evaluating the Impacts

Return on Research Investment Analysis

Definition

This section provides a definition of key input costs, benefits, and our method of calculating the return on investment for research (ROI) in this analysis. The process of calculating the ROI for CSIRO is a two-staged process.

Stage 1: Calculating the costs and net benefits at the program level

Input costs are costs incurred by CSIRO and its collaborators to produce the research outputs. They include costs associated with such things as staff, in-kind contributions, equipment/facilities, and background IP. Where data is available, input costs should also include usage and adoption costs borne by the end users, such as costs of any trials, further development, and market tests.

Benefits represent the reduced residential electricity bills, savings in electricity system total expenditure, and reduction in GHG emissions on the implementation of the Roadmap.

Net benefits are the difference between the present value of benefits and the present value of costs over the chosen analysis period under the chosen discount rate (in this case 7 per cent).

Stage 2: Attributing the net benefits to CSIRO and calculating a ROI for CSIRO

Input costs are costs incurred by CSIRO to produce the research outputs. They include costs associated with such things as staff, in-kind contributions, equipment/facilities, and background IP.

Benefits represent cost savings in electricity system and reduction in GHG emissions that are attributable to CSIRO based on a cost sharing basis.

Therefore, the formula for calculating a ROI for CSIRO is defined as cost savings benefits attributable to CSIRO (Present Value) divided by all CSIRO's research costs (Present Value). This ratio can also be interpreted as a "Net Benefit/Return on Research Investment Ratio".

$ROI = PV(B_t)/PV(C_t)$

Where

$PV(B_t)$ is the present value of the net benefits attributable to CSIRO at time t

$PV(C_t)$ is the present value of CSIRO's research costs at time t

Time period of analysis

CSIRO Energy has been involved in the FGF and the Roadmap research since 2012/13, hence the economic analysis starts from 2012/13.

In the FGF and Roadmap program, there are time lags between the recommendations and their adoption by the community, industry, and government stakeholders. In the FGF and the Roadmap research, these lags are assumed to be approximately 10 years (Brinsmead & Graham 2017), so that adoption will not take place until the eleventh year. On that basis, the benefits are only measured from 2027/28 onwards. In the analysis, the costs from 2012/13 to 2016/17 are included.

Brinsmead and Graham (2017) found that customer outcomes can be measured to 2050/51. In this analysis, we take a similar approach and measure the benefits to 2050/51. Thus the analysis involves a small component of ex-post analysis (relating to the period 2012/13-2016/17), but also involves a large ex-ante analysis for the benefits flowing from those activities over the period to 2050/51.

Defining the "with" and "without" scenarios

Brinsmead and Graham (2017) calculated the whole of Roadmap and counterfactual scenarios to determine the value of the entire research program benefits (where quantification is possible). The counterfactual scenario represents the pathway where the Roadmap is not implemented and a 'status quo' or extension of current trends prevails.

We believe that the best way to define the "with" and "without" scenarios is to adopt the approach employed by Brinsmead and Graham (2017). Due to data constraints, this analysis focuses on three key benefits, namely reduction in household electricity bills, electricity system total expenditure, and GHG emissions.

The focus of CSIRO's research is on understanding and furthering knowledge associated with scenarios and actions required to deliver lower costs, decarbonisation, 'fairer prices'[1], and improved energy services and reliability. This research is usually considered strategic research rather than an applied research per se. These benefits can only be delivered through collaboration and action from all stakeholders. On that basis, the conservative assumption here is that FGF contributes to 0.05 per cent of the reduction in household electricity bills, electricity system total expenditure, and GHG emissions (Table 6.1)[2].

We acknowledge that the Roadmap is but one of many current proposals for future action by business leaders, politicians, and community groups. Ultimately, only government and commercial action can enable implementation of the specific FGF and Roadmap proposals. It might therefore be premature, to attribute solely to the research project the expected future benefits. A thorough evaluation requires solid evidence to demonstrate that the FGF and Roadmap research is the unique, or even primary instigator of national energy policy initiatives. Particularly important is the maturity of research and evidence of uptake/adoption as the basis for projections. This valuation provides a ball-park estimate of the potential net benefits, therefore requires the need for a follow-up revision of the valuation once the results of the actual uptake/adoption become available.

Table 6.1: Value of the FGF and Roadmap project

	Residential electricity bills ($ per household per annum)	Electricity system total expenditure (cumulative $ billion)	GHG emissions (Mt Co2-e)
- **With program (A)**	1,800	888	0
- **Without program (B)**	2,200	988	69
- **Savings (C= B-A)**	400	100	69

Note: a) All dollars are in real terms, b) electricity bills are per house household in 2050 and c) Electricity system total expenditures are cumulative total expenditure to 2050.

Source: Brinsmead and Graham (2017)

Costs

In this evaluation, we were unable to identify usage and adoption costs borne by intermediaries and end users of CSIRO research due to the length of the project and commercial confidentiality issues. However, in principle, establishing the costs involved throughout the entire inputs to impact pathway is an important exercise of a cost-benefit analysis. This includes both the input costs incurred by CSIRO and its collaborators, as well as any usage and adoption costs borne by clients, external stakeholders, intermediaries, and end users. CSIRO and its research partners contributed $3.04 million and $3.25 million to the FGF and Roadmap project between 2012/13

[1] For Australia's network businesses, network tariff reforms are revenue neutral – that is, they will govern how network costs are shared among customers, not alter the amount of regulated revenue.

[2] This is based on a cost-sharing basis between research costs, and usage and adoption costs (estimated at $10 billion).

and 2016/17 in real terms. These contributions were discounted using a real discount rate of 7%. In our analysis, we assume that the implementation costs is $1,393.9m (2016/17 price) from 2015/16 to 2050/51 (Brinsmead and Graham 2017). Table 6.2 summarise the adjusted all costs for developing and implementing the FGF and Roadmap recommendations.

Table 6.2 Summary of the FGF and Roadmap project costs

	Present value of collaborators costs (2012/13- 2016/17)	Present value of CSIRO costs(2012/13- 2016/17)	Present value of implementation cost (2015/16 to 2050/51)
Total ($m)	3.25	3.04	1,393.9
% of total cost	0.23	0.22	99.6

Source: CSIRO

Note: PV= Present Value

We acknowledge that regulatory frameworks and mechanisms are likely to impose social costs, but no estimate is provided on the social costs of regulation due to information constraints. In addition, the social costs of subsidies and associated deadweight loss from taxation were excluded.

Benefits to 2050/51

The benefits calculated in the analysis are the net benefits from CSIRO's research, that is, the difference between the "with" and "without program" scenarios (as shown in Table 6.3). The analysis is equivalent to carrying out separate analyses for the "with program" and "without program" scenarios and calculating the difference between them. It is worthwhile noting that some of the benefits estimated in monetary terms are transfers between intermediaries in the value chain. For example, the electricity bill savings that customers receive are as a result of the reduced electricity system expenditure. They are two different ways of measuring the same impact, so aggregation of those impacts would mean double-counting the same impact. In the analysis below, we only included the reduced electricity system expenditure.

The steps in quantifying the gains from CSIRO's FGF and Roadmap program are as follows:

1. Combine annual savings (real prices) achieved from electricity system total expenditure in each year with the attribution ratio due to the program, to get an estimate of the value of the program that year. This gives an estimate of the economic value from the program for that year and all subsequent years.

2. All past costs flows from 2012/13 to 2016/17 were adjusted to real dollars using the CPI with base =100 at 2016/17. All benefits after 2016/17 were expressed in 2016/17 dollar terms. All costs and benefits were discounted to a present value using a real discount rate of 7% per annum.

Table 6.3: Benefits and costs of the CSIRO FGF and Roadmap project

Year	Benefits from the program					Discounted		
	Benefits ($m) A	Attribution rate B	CSIRO benefits ($m) C=A*B	Costs ($m) D	Net benefits ($m) E=C-D	Benefits ($m)	Costs ($m)	Net benefits ($m)
2012				1.1	- 1.1	-	1.5	-1.5
2013				0.4	- 0.4	-	0.5	-0.5
2014				0.1	- 0.1	-	0.1	-0.1
2015	4,257	0.22%	9.26	0.5	8.8	9.91	0.5	9.4
2016	2,144	0.22%	4.66	0.5	4.2	4.66	0.5	4.2
2017	- 4,569	0.22%	- 9.93	-	-9.93	- 9.29	-	-9.3
2018	- 225	0.22%	- 0.49		-0.49	- 0.43		-0.4
2019	417	0.22%	0.91		0.91	0.74		0.7
2020	428	0.22%	0.93		0.93	0.71		0.7
2021	- 68	0.22%	- 0.15		-0.15	- 0.11		-0.1
2022	- 1,231	0.22%	- 2.68		-2.68	- 1.78		-1.8
2023	- 446	0.22%	- 0.97		-0.97	- 0.60		-0.6
2024	- 1,580	0.22%	- 3.44		-3.44	- 2.00		-2.0
2025	- 1,104	0.22%	- 2.40		-2.40	- 1.31		-1.3
2026	- 1,099	0.22%	- 2.39		-2.39	- 1.21		-1.2
2027	**1,162**	0.22%	2.53		2.53	1.20		1.2
2028	**1,330**	0.22%	2.89		2.89	1.28		1.3
2029	**1,599**	0.22%	3.48		3.48	1.44		1.4
2030	**- 3,032**	0.22%	- 6.59		-6.59	- 2.56		-2.6
2031	**74**	0.22%	0.16		0.16	0.06		0.1
2032	**15**	0.22%	0.03		0.03	0.01		0.0
2033	**3,483**	0.22%	7.57		7.57	2.40		2.4
2034	**- 8,781**	0.22%	- 19.10		-19.10	- 5.65		-5.6
2035	**4,520**	0.22%	9.83		9.83	2.72		2.7
2036	**- 648**	0.22%	- 1.41		-1.41	- 0.36		-0.4
2037	**- 3,110**	0.22%	- 6.76		-6.76	- 1.63		-1.6
2038	**7,112**	0.22%	15.47		15.47	3.49		3.5
2039	**4,239**	0.22%	9.22		9.22	1.94		1.9
2040	**3,266**	0.22%	7.10		7.10	1.40		1.4
2041	**4,744**	0.22%	10.32		10.32	1.90		1.9
2042	**8,318**	0.22%	18.09		18.09	3.11		3.1
2043	**7,951**	0.22%	17.29		17.29	2.78		2.8
2044	**4,081**	0.22%	8.88		8.88	1.33		1.3
2045	**3,821**	0.22%	8.31		8.31	1.17		1.2
2046	**3,995**	0.22%	8.69		8.69	1.14		1.1
2047	**3,167**	0.22%	6.89		6.89	0.85		0.8
2048	**11,204**	0.22%	24.36		24.36	2.80		2.8
2049	**20,093**	0.22%	43.69		43.69	4.69		4.7
2050	**25,270**	0.22%	54.95		54.95	5.51		5.5

The flows of costs and benefits from 2012/13 to 2050/51 are used to calculate investment criteria. Investment was estimated for both total investment and for the CSIRO investment alone as reported in Table 6.4.

Table 6.4: Results of the cost benefit analysis

Criteria	CSIRO	Project
Present value of costs ($m)	3.0	1,400
Present value of benefits ($m)	30.3	13,939
Net Present Value (NPV) ($m)	27.3	12,539
Return on Investment Ratio (ROI)	10.0	10.0

Table 6.4 summarises the present value of the increased benefits resulting from reduced electricity system expenditure. Benefits ranges from $13,939 million ('Project in context') to $30.3 million ('CSIRO in context'). Assuming total costs of $3.0 million and $1,400 million respectively, then ROIs from the research range from 10:1 ('Project in context') to 10:1 ('CSIRO in context'). Despite the conservative estimates of the potential benefits that might be delivered by the FGF & Roadmap program, the total estimated benefits comfortably exceed the costs of the research.

7 Sensitivity analysis

While the prospects look promising, the adoption of CSIRO's research by the community, industry, and government is by no means certain. For example, the adoption of the small customer pricing and incentive reform policy options remains a key area of uncertainty. While industry consultation provides anecdotal evidence of potential adoption, there is no reliable information on the actual adoption and performance of improved customer benefits across Australia over time.

Given these uncertainties, it would be useful to look at results under different discount, adoption, and attribution rates. NPV and ROI calculations are particularly sensitive to changes in underlying parameters, so it is important to understand the results in perspective. In this section, we analyse the impact of variations in the discount, adoption, and attribution rates as well as the ROIs coming out of various cases. The results of the sensitivity analysis are shown in Table 7.1

Table 7.1: Results of sensitivity analysis (CSIRO investment only)

Assumption	Central assumption	Low assumption	High assumption	ROI (Central)	ROI (low)	ROI (high)
Discount rate (%)	7	5	9	10	10	9.9
Benefits attributable to CSIRO (%)	0.22	0.10	0.40	10	4.6	18.3
Implementation costs ($m)	Various	10% decrease	10% increase	10	11.1	9.1
Reduced system expenditure ($m)	Various	10% decrease	10% increase	10	9.0	11

Table 7.1 highlights the influence on our analysis of changes in key assumptions. The NPV and ROI ratio calculations are particularly sensitive to changes in the attribution rates. For example, an attribution rate of 0.40 per cent to CSIRO indicated that the ROI (18.3) was much higher than in the low case (4.6).

While the parameters used in the base-case scenario seemed reasonable in the light of current realities on the ground, it was nevertheless important to test the robustness of our conclusions to variations in these assumptions. The low and high alternative assumptions used in the above sensitivity analysis were brought together to estimate benefit and cost streams under pessimistic and optimistic scenarios by combing changes across all variables jointly. The results under these different assumptions are summarised in Table 7.2.

The pessimistic and central (baseline) scenarios perhaps offered conservative yet realistic forecasts of future benefits. In this the return on investment ratio for research is estimated between 2.5 and 10.

Table 7.2: Alternative assumptions for sensitivity analysis (CSIRO investment)

	Pessimistic	Central (baseline)	Optimistic
Discount rate (%)	9	7	5
Benefits attributable to CSIRO (%)	0.10	0.22	0.40
Implementation costs ($m)	10% increase	No change	10% decrease
Reduced system expenditure ($m)	10% decrease	No change	10% increase
ROIs	2.5	10	35.8

8 Limitations and Future Directions

This evaluation uses a mixed methodology to evaluate the research impact arising from the FGF and Roadmap project. It combines quantitative and qualitative methods to illustrate the nature of the technology's economic, environmental, and social impacts. In cases where the impacts can be assessed in monetary terms, a return on investment analysis (ROI) is used as a primary tool for evaluation. As a methodology for impact assessment, ROI relies on the use of assumptions and judgments made by the authors. This relates primarily to the economic indicators for impact contribution, attribution, and the counterfactual. These limitations should be considered when interpreting the results presented in this case study.

Given the scope and budget for the analysis, there are some limitations with regard to the evidence base of impacts. For example, it is unknown if or to what extent various stakeholders have adopted CSIRO research outputs. Prediction is very difficult. It is not clear how the forces of innovation, disruption, and competition change the many aspects of long term electricity industry transition. In addition, social impacts such as energy safety, security and reliability, and social equity were noted but not quantified due to the lack of reliable data. In addition, the focus of CSIRO's research is the electricity sector. However, the electricity sector is only a part of a wider energy sector where inputs and energy substitutes such as coal, oil and gas can be affected by entirely unpredictable global events. Analysing an issue as complex as major structural changes to the electricity market will involve effects on the whole economy with potentially significant price changes and reallocation of resources between different sectors. Going forward, use of a Computable General Equilibrium Model would have been useful as a means of capturing the overall result of the various interactions.

We understand that research impact evaluation is an evolving practice and suggest that as part of its evolution, it needs to address some key data constraints relating to social impacts by planning for impact and monitoring progress towards it. It is also important to engage with customers and other stakeholders to collect data/information and ensure a robust and thorough investigation of the outcomes and impacts. It is highly recommended that a follow-up revision of the evaluation be undertaken once the results of the uptake/adoption of the proposals become available.

9 References

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