Strengthening science-policy-practice interfaces for climate change policy reforms and transitions in Australia

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by

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Abstract

With changing climates across Australia causing damaging impacts to societies, environments and industries, there is growing urgency for evidence-based policy reforms and transitions that can enable climate change adaptation and de-carbonisation. Despite this urgency and the availability of an accessible body of science on climate change, many policies and practices in Australia, including in vulnerable sectors, fail to robustly consider or integrate knowledge of future climates. The overall aim of this thesis is to better understand how to rectify this deficiency through critical examination of the interfaces between scientific knowledge and decision-making systems. This thesis addresses the overall research question, *How can science-policy-practice interfaces (SPPIs) facilitate climate change policy reforms and transitions in Australia?* In addressing this question, the research utilises in-depth case studies to explore the operation and effectiveness of SPPIs for climate change adaptation and mitigation in predominantly national policy regimes. The cases span national housing regulation, environment protection legislation, forest sinks policy, urban climate transitions, and the management of ozone depleting substances and synthetic greenhouse gases (ODS and SGG).

Some 56 experts and leaders from science, policy and practice organisations contributed to the research through interviews and helped reveal the multi-institutional complexity and divergent orientations of SPPIs within policy regimes. An important finding and contribution of this research is a new definition and conceptualisation of climate change-relevant SPPIs that recognise the purposeful nature of climate change science, that multiple interlinkages need to be considered to understand operation, and that exogenously produced climate change science can clash with the experience-based knowledge that drives much decision-making. This contrasts with a common framing of science-policy interfaces as a single institution with a predominant purpose of knowledge provision suited to end-user needs.

Of concern, the research found significant weaknesses and deficiencies in the SPPIs for the national policy regimes regarding housing regulation, forest sinks, and environment protection, with divergent causes. Highly prescriptive regulatory regimes, such as for housing and forest sinks, constrained consideration of climate change science, but also motivated niche industry leaders to innovate, trial, and adopt climate-smart practice. The political nature of decisions on environmental approvals, however, despite strong science advice, results in

environmental outcomes being fragmented and subordinated to development interests, which was particularly evident in the period of this research where a very conservative national government was in power.

Effective SPPIs in contrast, identified in the niche industry leaders noted, in the urban governance transition of the Australian Capital Territory and in Australia's approach to managing ODS and SGG, were found in this research to be supported by strong two-way interactions across all key institutions, and a valuing and recognition of climate change science. In addition, and importantly, all effective cases involve interfaces that supported experimentation, and allowed for flexibility in problem-solving. Insights from both weak and robust SPPIs underpinned the formulation in this thesis of characteristics of effective SPPIs for climate change outcomes, suitable for evaluative purposes, as well as tailored recommendations for reforms to facilitate climate change outcomes.

More broadly, the research explains how SPPIs can improve the reform capacities of policies and support progress of transitions, including through their capacities to reveal the detailed nature of barriers to knowledge uptake, and to help shift the policy debate and support innovation through attention to the spaces between climate change goals and current policy and practice. These insights also have relevance for theories and/or practices of change governance, public policy and climate change adaptation, particularly regarding approaches to close the policy implementation gap.

This thesis includes a series of articles which collectively illustrate the operation of SPPIs for climate change adaptation and mitigation within key policy regimes designed to deliver to objectives such as safety, ecologically sustainable development, or minimum cost emissions reductions. Embedded predominantly in the practices of national policy implementation, this thesis generates new insights on the strengths and weaknesses of current SPPIs, and provides feasible recommendations on the reforms needed for improved practice that will facilitate a more resilient, climate-adapted and low-carbon future.

Preface and acknowledgements

When I began writing the thesis, I had, in retrospect, a limited appreciation of the roles of theory in qualitative research including the explanatory power of conceptual frameworks in exposing the uniqueness and effectiveness of a case within comparative scholarship. I was particularly concerned with how, in practice, national policies could be reformed to enhance climate change adaptation, a focus shaped by roles that I had in Australian Government climate change policy and programs (1996-2016), and growing observations of weaknesses in predominant views on the sufficiency of locally-based adaptation action and of knowledge provision for its wider societal use. Progress on this thesis challenged and expanded my initial understanding and framing of policy reform, including from its publication-based nature and the re-thinking required at multiple points as draft articles were anonymously reviewed, as well as from exploration of common factors across the case studies investigated and their potential for wider relevance.

Many people also helped enrich my thinking, and enhance my reflexive capacities, in the long part-time journey of this thesis. I would first like to thank the members of my supervisory panel for their support and advice. Darren Sinclair, my principal supervisor, provided strong support and encouragement in the progress of my research, and practical and clear guidance on research expectations as well as on draft articles and chapters. The other members of my panel, Jonathan Pickering and John Dryzek, and adviser Will Steffen, provided valuable and complementary insights which were also very much appreciated. The clarity of my thinking and writing at multiple points in the thesis development process was assisted by Jonathan, who was unfailingly helpful, and has a strong ability to detect and question the meaning of dense and complex sentences and paragraphs. With regard to the philosophical framing of my research, comments from John repeatedly challenged my assumptions, and stimulated my thinking and reflection on how I see reality. Finally, I would like to thank Will, who was supportive and interested in my research, and provided advice where needed on the state of knowledge in climate change science.

I would also like to thank co-author Jane Mummery, for the discussions, iterative thinking, and at times blunt feedback in the writing of a book chapter which is part of this thesis, and in other articles during my candidature. Jane brought new perspectives to the topics of our co-authored work, including a stimulating bridging of philosophical and conceptual approaches with very practical insights targeted to decision-makers. Further acknowledgments on individual chapters published or submitted for publication are also mentioned at the beginning of each chapter.

The University of Canberra provided a conducive environment for undertaking a PhD. The then Institute of Governance and Policy Analysis ran a valuable program of seminars that linked HDR candidates with highly experienced scholars in small group discussions. It was a supportive environment to be introduced to such concepts as ontology and epistemology, to explore the alignment of research questions with methods, and to start understanding and framing the scholarly value and contributions of research being done.

While Covid-19 made the journey more isolated than it would otherwise have been, I would like to thank colleagues and friends, many of whom have already completed a PhD journey, for discussions, encouragement and at times welcome distractions. The project opportunities and collegiality through the Canberra Urban and Regional Futures from Barbara Norman and with Maxine Cooper and Tayanah O'Donnell in particular were a much-appreciated grounding in local sustainability issues and policies, including a richness in engagement and perspectives on regional challenges and opportunities. Regular discussions on politics, sustainability and policy reform with good friends including Jacquie Shannon, Clare Wynter, Tayanah, Maria Taylor, Jane Harriss, David Ugalde, and Sango Mahanty were revitalising and helped me maintain enthusiasm for the research. More broadly, in undertaking this research I met many inspiring and active people in many roles and institutions, and I would like to express my appreciation for their generosity in sharing their time, ideas and experiences in interviews. I found much hope for Australia's future in these discussions in a period where the nation's climate change policies lacked ambition.

My partner Tony has also been constant in his support and companionship, which is immensely appreciated, and I deeply value my family's interest, discussions, and appreciation of ongoing learning.

Concerning the finalisation of the thesis, I would like to acknowledge Jane Mummery for her proofreading of various components of the thesis submitted for examination. She brought to my attention points of ambiguity and helped standardise the spelling and referencing across the chapters. Finally, I would like to thank the three anonymous examiners of my thesis; while change was not sought to the thesis, their comments were constructive and thought-provoking and will inform future research.

Publications as part of thesis

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Mummery, J. (2021). Attributes of effective national partnerships for environmental challenges – managing ozone-depleting and synthetic greenhouse gases in Australia. *Journal of Environmental Planning and Management, 64*(14), 2481–2499.

Other relevant publications, presentations and national science-policy roles during candidature

Publications

Bates, B., McLuckie, D., Westra, S., Johnson, F., Green, J., **Mummery, J.**, & Abbs, D. (2019). Chapter 6. Climate change considerations. Book 1: Scope and philosophy. *Australian rainfall and runoff—A guide to flood estimation.* Commonwealth of Australia.

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Presentations

Mummery, J. (2019). Imperatives for climate governance in the Anthropocene: Testing national policy settings in Australia. *Earthly entanglements: Politics in the Anthropocene conference 13–14 February 2019.* University of Canberra.

Mummery, J. (2018). *Bridging climate change science and regulation for infrastructure adaptation – tackling the grey rhinos.* Presentation to Future Earth Australia's Early Career Research Workshop, 3–5 December 2018, Future Earth Australia and National Climate Change Adaptation Research Facility, Academy of Science, Canberra.

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Mummery, J. (2015). *Science-policy issues for climate change*. Keynote presentation, Greenhouse 2015 conference, 27–30 October 2015, Hobart.

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List of abbreviations

ABCB	Australian Building Codes Board
ACCU	Australian Carbon Credit Unit
ACT	Australian Capital Territory
AFCAM	Association of Fluorocarbon Consumers and Manufacturers
AS	Australian Standard
BCA	Building Code of Australia
BoM	Bureau of Meteorology
CBA	Cost benefit analysis
CFC	Chlorofluorocarbon
CFI	Carbon Farming Initiative
COAG	Council of Australian Governments
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EA	Engineers Australia
EPBC	Environment Protection and Biodiversity Conservation
ERF	Emissions Reduction Fund
ESDD	Environment and Sustainable Development Directorate
FullCAM	Full Carbon Accounting Model
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HIR	Human-induced regeneration
IGA	Inter-governmental Agreement
MSP	Multi-stakeholder partnership
NACC	National Advisory Committee on Chemicals
NCC	National Construction Code

NGO	Non-government organisation
NRAC	National Refrigeration and Air Conditioning Council
ODS	Ozone depleting substance
R&D	Research and development
RDC	Rural Research and Development Corporation
RIS	Regulatory Impact Statement
RRA	Refrigerant Reclaim Australia
SGG	Synthetic greenhouse gas
SPI	Science-policy interface
SPPI	Science-policy-practice interface
UNFCCC	United Nations Framework Convention on Climate Change

Chapter 1
Introduction

1.1 Introduction

This thesis is about a clash of knowledge systems and how their discordance can be reduced to support effective climate change transitions. It responds to the disjunct between a growing body of robust climate change science that calls for significant reform in policies and practices for transitions to greater resilience in the face of a changing climate, and a plethora of policies and decision-making systems that rely on other knowledge sources and, explicitly or implicitly, continue to assume a stationary climate. Through projected trends of warming and sea-level rise, increases in severe weather, and changes to patterns of rainfall and water availability, multiple sectors including buildings and infrastructure, significant environments and natural resources, health and utility services, and finances, are exposed and vulnerable to climate change (IPCC, 2021, 2022). With Australia still grappling the aftermath of catastrophic fires, floods, and other extreme weather events exacerbated by climate change, the saliency of insights into how emerging knowledge can facilitate anticipatory and proactive policy and practice reforms, and transitions for societal resilience and climate change adaptation outcomes, is only increasing.

In this introduction, I set the stage for my exploration of how climate change science can facilitate reform of national policies in Australia in order to build adaptive capacity and transition pathways as our climate becomes more unpredictable and damaging. I begin by briefly reviewing literature that provides concepts useful to understanding the problem of the science-policy disjunct, drawing on science and technology studies, public administration, and sustainability transitions fields of literature. This comprises section 1.2. The challenge at the heart of this thesis is how society can establish effective governance mechanisms for the use of science in transitions that address climate change risks and enable societal resilience. The thesis also responds to a range of studies that reveal an ongoing mismatch between science-identified reform opportunities and current policy settings. Recognising the purposeful nature of knowledge on climate change for action to reduce risks and progress adaptation, in section 1.3 I also draw upon literature exploring how knowledge can support normative goals for societal change. The positioning of this thesis within the science-policy interface and climate change transitions literature underpins the research design, questions and methods which will be outlined in section 1.4.

As a thesis with publication, this thesis includes five articles (three published, one accepted, one submitted), and section 1.5 of this introduction briefly touches upon each of these, outlining how they link to the thesis's guiding themes and research questions. Although the articles were not drafted in the order in which they appear in this thesis, their positioning and role in the thesis reflects the evolution of my thinking over the course of my candidature.

1.2 Literature review – the role of science in climate change transitions

How society understands and responds to the science on anthropogenic climate change will be one of the most defining issues of the 21st century. There is a large body of scientific evidence on the causes of climate change and the widespread, disruptive and potentially severe risks that it poses to Earth's ecosystems, societies, cultures and industries (Steffen et al., 2015; IPCC, 2021, 2022). Business-as-usual responses to climate change are now widely understood as insufficient for keeping the environments that people and biodiversity depend upon within safe operating limits of the climate system; fundamental changes in production and consumption processes, technologies, values and behaviours will be needed (Pelling et al., 2014; Steffen et al., 2018; Tàbara et al., 2018). Section 1.2 explores areas of literature central to understanding how climate change science, including its associated applied sciences, can help drive reforms for the realisation of the fundamental changes needed – spanning the challenges in translating climate change science into action, and the potential for climate change science-policy-practice interfaces to enable policy reform and societal transitions.

1.2.1 The challenge of climate change science for knowledge and action

Science in recent decades has shed light on one of the most complex problems faced by the Earth system[1] and its biophysical and societal constituents – climate change. With sophisticated planetary models and approaches that discern and explain trends in large volumes of oceanic, atmospheric, cryospheric, terrestrial and socio-economic data, climate change science is generating a growing body of findings that attribute global warming to human activities. These findings, with high levels of confidence, project ongoing changes in

[1] The Earth System can be understood as the integrated nature of the planet's physical, chemical and biological cycles that, in combination with energy fluxes, provide the conditions for life, and within which humans are the dominant force for change (IGBP, 2015).

the climate system that have major implications for human-wellbeing, societies and natural environments (IPCC, 2021, 2022). The climate change science community has been working with national governments and global institutions, notably since 1988 through the Intergovernmental Panel on Climate Change (IPCC), to present the scientific evidence that increasingly calls for rapid and transformational change in our greenhouse gas emissions-generating sectors, and to reduce exposure and vulnerability to projected climate change impacts (IPCC, 2021, 2022). This scientific research gives urgency to the consideration of climate change in human societal development pathways and in a wide range of societal goals and practices (Pelling et al., 2014; Tàbara et al., 2018). A critical question is: How can knowledge generated from the sciences of climate change help drive decisive changes in policies and practices to enable transitions to resilient, sustainable, and well-adapted communities and industries, and that enhance the environments that they depend on?

Science that identifies growing societal vulnerabilities to climate change would appear to provide a strong incentive for action to build more resilient societies (Sarewitz, 2011). The availability of such science enhances national and community capacities to understand, avoid, adapt to and respond to the impacts of a changing climate, which in turn can reduce damage and loss from more extreme weather events and also align with wider social, economic and environmental sustainability goals (Hewitt et al., 2017). Essentially, shared and tailored knowledge of increasing risks can strengthen the demand and support for action by decision-makers and communities (Bielak et al., 2008; Arnott et al., 2020). However, a deficit in the use of climate science information and in the implementation of adaptation has been observed in multiple studies, indicating that the efforts invested in science provision and adaptation planning by both scientists and practitioners are insufficiently translated into action (Preston et al., 2011; Moss et al., 2019). We face the paradox that, at the same time as the science understanding of climate change risks is becoming more decision-relevant and accessible, societal vulnerability to likely climate change impacts is continuing to increase (Weichselgartner & Kasperson, 2010). Numerous reports identify significant changes in the Earth system, such as shifts in and loss of biodiversity and ecosystems, and nonlinearly increasing damages from extreme weather events (Weichselgartner & Kasperson, 2010; IPCC, 2022). Knowledge of climate change, with high confidence that risks and vulnerability will continue to increase, thus does not appear to consistently influence management decisions in exposed sectors (Sarawitz & Pielke, 2007; Dilling & Lemos, 2011; Moss et al., 2019).

Understanding the nexus between scientific knowledge and action has long been a scholarly preoccupation. More than 2000 years ago, Aristotle described practical knowledge or praxis – one of three forms of knowledge – as knowledge that captures the interplay between reflection and action and which involves interpretation, understanding and application to enhance human well-being (Smith, 1999). While some scholars have continued to identify a capacity for action as embedded within knowledge (e.g., Hawthorne & Stanley, 2008), recent conceptualisations of knowledge in the context of sustainability and climate change tend to position action outside of the knowledge generation process and within the fields of practice (van Kerkoff & Lebel, 2006; Mach et al., 2020). These studies recognise the importance of scientific knowledge to inform policy and action, and understand the core functions of scientific endeavour as discovering, providing explanations and predictions of aspects of the state of our world, as well as proposing options to address issues and their implications. Today, however, perhaps more than ever, scientific knowledge is being called on to not just propose solutions to be enacted by others, but to rather play an ongoing partnership role in the development, implementation, refining and learning of solutions to complex and urgent societal problems such as from climate change impacts (van den Hove, 2007; Broman et al., 2017). A science of actionable knowledge is emerging, that seeks to understand and strengthen connections between theory and practice, knowledge and action (Antonacopoulou, 2009; Arnott et al., 2020; Mach et al., 2020).

Characterisations of science outputs as actionable knowledge that is sufficiently predictive, accepted and understandable to support decision-making (Mach et al., 2020) are, however, challenged by climate change science in several ways. Unlike traditional environmental problems that can be readily observed and experienced by people, such as pollution in rivers or landscape degradation from the salinisation of agricultural soils, projected climate change impacts are more hidden from immediate perception and are difficult to fix in time and space (Naustdalslid, 2011). Experiences of changes in climate variables, for example, can readily be interpreted as variability from an understood mean climate and not recognised as an indicator of climate change (Dilling & Lemos, 2011). Further, the level of scientific expertise required to work on complex climate change adaptation problems is quite high, and different from the knowledge background of most decision-makers and lay individuals (Peterson, 2006; Briley et al., 2015). As a result, decision-makers can struggle to use the climate information and data coming out of the scientific community, and can additionally struggle to extract findings that are relevant to particular problems or policies (Lemos & Rood, 2010; Barsugli et al., 2013). In these ways, climate change science has little support from tacit knowledge, which can impact on its potential to be actionable as experience in many circumstances is central to the gaining of knowledge (Dombrowski et al., 2013; Bolisani & Bratainu, 2018).[2]

The future-orientation, long time horizons and uncertainty of climate change science also challenge policy and decision-makers. Climate change scenarios and projections typically describe possible climates over time horizons of several decades or for the end of this century; in contrast, most decision-making approaches and policies have much shorter time horizons. While governments have responsibilities requiring intergenerational perspectives, such as heritage protection and infrastructure provision, there can be pressures for a predominant focus on activities that demonstrate outcomes within electoral cycles of three to four years, and it can be difficult to allocate substantial resources to measures whose benefits will be realised in a more distant uncertain future (Carney, 2015). Private sector decision-makers also have limited capacity to detect causal impacts of climate change on short business-relevant temporal and spatial scales (Linnenluecke et al., 2015). Sustainability reporting by companies typically recognises up to six years as a long term, strategic horizon for business activity (e.g., Bansal & DesJardine, 2014). High levels of uncertainty, driven by long time horizons, increase the difficulty for decision-makers in establishing the likelihood and materiality of risks, and have also been used to justify the lack of climate change action (Mastrandrea et al., 2010). The result is that many decisions in climate-exposed sectors continue to be made with little or no regard to climate change (Preston et al., 2011; Hewitt et al., 2017), and those that do consider climate matters tend to focus on effects likely in the near term (Park et al., 2012, Wise et al., 2014).

In this way, the science of climate change may be understood as a specific kind of knowledge, distinct from the more experience-based kinds of knowledge that underpin much policy and practice.[3] The characteristics of climate change science and impacts knowledge identified in this section – including requiring explicit learning, being removed from visibility in people's daily perceived reality and experience, having non-familiar, specialised

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[2] Dombrowski et al. (2013) describe three kinds of knowledge: (i) experiential knowledge which is based on perception and reflection of our interaction with the environment, (ii) skills which are about how to do something and based on experiential knowledge and practice, and (iii) knowledge claims which span what we think we know from explicit learning and that are often shared through language.

[3] While there are clearly multiple knowledge systems, including Traditional Knowledges, which are relevant to understanding climate change, this thesis is positioned within the Western Knowledge system which seeks understanding and explanation through the application of testable methods.

terminology and language, and high levels of uncertainty – form tremendous hurdles for non-experts to overcome in translating science into actionable knowledge (e.g., Dabelko, 2005).

A further challenge to the ready use of climate change science is its contested nature in parts of the community. Climate knowledge has become politicised and polarised in Australia and other countries, less due to community understanding and critique of the science itself, and more because the science has become synonymous with global and national emission controls which will impact particular interests (Sarewitz, 2011; Carrozza, 2015). That climate change science concerns complex environmental problems that will require socio-economic change, opens the science as the basis for reform to be challenged by vested interests concerned that solutions appear to limit their liberties, for example from businesses and governments with interests in fossil fuel and energy-intense sectors (Boussalis & Coan, 2013). A number of scholars have identified that climate change denialists have deliberately heightened doubts about the central findings of mainstream climate science, as part of efforts to defend the status quo and stymie strong emissions reduction policy and action (Hodder, 2010; Oreskes & Conway, 2010; Dunlap & McCright, 2011). As the most widely recognised and internationally accepted authority on climate change, the IPCC is the biggest and most obvious target for challenge by sceptics (Porter et al., 2018; Pérez-González, 2020).

The growing vulnerability of society to climate change impacts now suggests a need for stronger science roles in societal processes. Greater involvement by decision-makers and publics in areas of climate change science can increase capacities to understand, interpret and act on the science findings. Executives who report greater engagement with scientific information, for example, express greater concern about their company's vulnerability (Linnenluecke et al., 2015). There is now a burgeoning literature exploring aspects of the science system and its relationship to decision-making and society which frequently calls for stakeholders to be partners in scientific processes. A key focus of this literature, which is explored further in section 1.2.2, is on ways for scientists, policymakers and practitioners to work more deliberatively and collaboratively for the generation of knowledge that is actionable and tailored to addressing societal challenges (Arnott et al., 2020).

1.2.2 Science policy and practice interfaces for climate change reforms

Science-policy interfaces (SPIs) provide a useful conceptual framework for exploring the uptake and use of science in policy design and development. In recent decades, scientific knowledge has played important roles in informing policy-making processes to improve or solve environmental problems, including through clarification of the causes and magnitude of problems and evaluation of possible solutions (e.g., Totlandsdal et al., 2007; van Enst et al., 2014; Dunn et al., 2018). Policymakers are thus a key audience and user of environmental science. This has underpinned a growing body of literature on the interfaces between science and policy, their natures and modes of operation, problems, and potential for success (Bielak et al., 2008; Moore et al., 2014; van Enst et al., 2014). SPIs have been defined as 'social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making' (van den Hove, 2007, p. 824). The *raison d'être* of the SPI is to help negotiate and mediate, and close the gap, between science and policy in order to improve understanding of the issue at hand, of possible options for action, as well as for more evidence-based justifications of decisions (van den Hove, 2007; Sutherland et al., 2013; Sarkki et al., 2014). Ultimately, SPIs seek to facilitate a better handling of environmental problems (van Enst, 2014).

Traditional approaches to the interface between science and policy have been described as linear or technocratic relations where 'science as truth speaks to power, and power responds' (Rapley et al., 2014). The linear model assumes that facts are discoverable, objective, and socially and politically neutral, and can be revealed by science. Once the problem has been revealed by science, responsibility moves to policy and decision-makers to address it in the best interests of society or an organisation. However, where differing interests, values and beliefs mean that there is no agreement on a common goal, or when the approaches or costs to reaching that goal are perceived to be problematic, the linear model fails. This is especially the case if the science is uncertain and the decision stakes are high, or when the science has little influence on the root causes of the policy responses being considered, such as with anthropogenic climate change (Sarawitz, 2004). Despite this, the linear model remains widely used in climate change science, as exemplified in the approach to science review adopted by the IPCC (Beck, 2011; Rapley et al., 2014).

In response to the limitations and failures of the linear model, social scientists have described co-production approaches in which the goals of policy and the means of achieving them emerge from inclusive and iterative processes that consider both scientific and non-scientific matters (Hulme, 2009). Central to co-production understandings of SPIs is recognition that the interface between science and policy domains is one of active exchange for the joint construction of knowledge. While co-production interfaces can have a variety of forms, ranging from processes, organisations, individuals, projects, or collective understandings, three types of SPIs are commonly described in the literature: boundary organisations, stakeholder participatory processes, and knowledge brokers (Van Buuren & Edelenbos, 2004; Pielke, 2007; van Enst et al., 2014).

Boundary organisations are formal institutions that bridge the domains of science and policy to collect and make available scientific knowledge for policymakers. Through the synthesis and translation of science to suit the needs of non-scientific audiences, boundary organisations increase the perceived levels of salience and legitimacy[4] of scientific knowledge (van Enst et al., 2014; Serrao-Neumann et al., 2020). Processes of participatory knowledge development, involving knowledge producers, users and key stakeholders, focus on joint fact finding and knowledge co-production (Karl et al., 2007; Pohl, 2008; Hegger et al., 2012). The goal of such processes is to create common understanding and knowledge in a participatory way, and through exchange enhance the legitimacy of produced knowledge (van Enst et al., 2014). Finally, individual science-policy mediators or knowledge brokers can facilitate the creation, sharing and use of knowledge (Pielke, 2007). Such mediators create awareness and acceptance of the different policy and science processes, and raise the perceived levels of salience and legitimacy of the scientific knowledge involved in the policy process (Pielke, 2007; Meyer, 2010; van Enst et al., 2014).

Complex environmental problems such as climate change are well suited to analysis using interactive SPIs (Head & Alford, 2015; Kowarsch et al., 2016). Such problems are typically complex, and involve multiple temporal and spatial scales, governance levels and socio-economic contexts simultaneously. They are further characterised by high uncertainty, a divergence of viewpoints and values, and indeterminacy. Climate change adaptation is a good example of a wicked problem; there are many potential synergies and tradeoffs, knowledge gaps on how climate change and potential interventions will affect socio-ecological systems, and challenges in balancing the timing of investment that will deliver benefits in an uncertain future against short-term priorities. As a result, it can often appear unclear what the most appropriate adaptation policies are and when they need to be implemented. Thus, there is an obvious need for SPIs on climate change adaptation so that

[4] In this context, salience is understood as the relevance of information for the decision-maker and issue of concern, and legitimacy reflects knowledge production processes that are unbiased in conduct and treatment of different interests, and respectful of stakeholders' values (Cash et al., 2003; van Enst et al., 2014).

scientific knowledge can inform policy and decision-making, including for long-term resilience. Such SPIs will need transdisciplinary science that involves all key stakeholders in deliberation and policy learning on response options that can address areas of contestation, and that build capacity and empowerment for action (Kowarsch et al., 2016).

An emerging problem is that many SPI studies focus more strongly on the production of actionable knowledge, rather than on how policy and decision makers use science, and an inadequate understanding of decision-making processes and contexts has been found by multiple scholars (McNie, 2007; Dunn & Laing, 2017; Dunn et al., 2018; Weichselgartner & Arheimer, 2019; Dewulf et al., 2020). Inflexible institutional rules and policies which reflect historical climate can be widespread and act as barriers to the use of more recently established climate change science (Moser & Ekstrom, 2010; Dilling & Lemos, 2011; Lövbrand, 2011; Serrao-Newman et al., 2020). For example, an expectation of quantified evidence on the costs and benefits of taking action, can mean that more uncertain future-oriented climate information is incompatible with decision models or the evidence requirements for policy reform (e.g., Jones et al., 1999; Productivity Commission, 2012). Practitioner preferences for the use of previously established and tested practices, and the resource and technical capacity demands of gaining support for and learning different processes, also constrain uptake of new knowledge on climate change, such as for coastal management (Tribbia & Moser, 2008; Serrao-Newman et al., 2020). A failure to adequately consider policy and practice needs has also resulted in science-based products that poorly link to decision systems, for example climate change adaptation guides and climate services developed with insufficient attention to usability and applicability (Kirchhoff et al., 2015; Stults et al., 2015; Hewitt et al., 2017; Buontempo et al., 2018). This mismatch is compounded by the limited attention given to actionable knowledge within scholarship on policy science, public administration, and political science concerned with decision-making (Dewulf et al., 2020).

References to science-policy-practice interfaces (SPPIs) are now increasing in the literature, and, while often used synonymously with SPIs, there is recognition that practitioners[5] have active roles in environmental governance that are separate to policy roles. ‘Science and policy do not always translate into practice. Practice may rely on informal,

[5] Practitioners in this context span actors who draw on knowledge in the design, implementation, management or monitoring of projects or programs, and in the implementation of policy. Practitioners relevant to climate change transitions include engineers, planners, natural resource managers, and health professionals.

rather than scientific knowledge. Practice may also diverge from policy and occurs even in the absence of policy' (Milman & MacDonald, 2020, pp. 1–2). Importantly, practice is critical for implementation and, in the context of the observed adaptation implementation deficit, 'practitioners indicate greater capacity and preparedness for action where an understanding of climate science and impacts is embedded directly into existing policies, plans, operations and budget structures' (Moss et al., 2019, p. 469).

It is clear that across vulnerable and exposed sectors and their policy settings and practices, much still needs to be learned about the nature and operation of interfaces between science, policy and practice (SPPIs) that can facilitate effective climate change adaptation. Empirical studies of how climate information is used and valued in decision-making, and how to institutionalise interactive and multi-actor processes between knowledge producers and decision makers, can help address this need (Weichselgartner & Arheimer, 2019). Major knowledge gaps also exist in understanding how the problem-solving and transformative potential of science-practice collaborations can actually be realised, an issue which is explored further in section 1.2.3 (Arnott et al., 2020; Jagannathan et al., 2020).

1.2.3 Knowledge for transitions

Understanding of the unprecedented challenges of climate change to societies across the globe, underpinned by the work of the IPCC, is driving recognition of the need for systemic change to avoid potentially catastrophic outcomes (Geels, 2019). Rapid shifts away from a fossil-fuel based society, and towards resilience and adaptiveness in a changing climate, will be needed in coming decades, spanning activities of institutions and communities from urban development, energy, agriculture, water, finance, health, environment, and infrastructure sectors, among others. The deep connections and interdependencies between these sectors and climate change, the magnitude and extent of current and future vulnerabilities, and the potential for synergies and tradeoffs, indicate that a climate-smart society cannot be achieved with technical fixes alone but will require more radical shifts in societal regimes (EEA, 2019).

The field of transitions research emerged in the 1990s in response to the realisation that new research approaches would be needed to investigate and address the dynamics of large-scale and multi-faceted real-world challenges of sustainability (Loorbach et al., 2017). Grounded in innovation and environmental and sustainability research, and with a focus on the challenges arising from unsustainable production and consumption patterns in socio-technical systems, transitions research focuses on bridging scientific disciplines with tacit knowledge to inform the development of more effective system solutions (Loorbach et al., 2017; EEA, 2019). While there has been some critique of early transition approaches for their limited attention to socio-political dynamics and a tendency towards technocratic accounts of change, in recent years the field has diversified significantly. Through connections with established disciplines such as political science, science and technology studies, and development studies, subsequent transition approaches have encompassed growing consideration of issues such as politics and power, and the role of everyday users and practice (Li et al., 2015; Köhler et al., 2019). Socio-technical studies are now bridging with socio-ecological approaches to frame opportunities to build resilience and adaptive and transformative capacity, and with socio-institutional approaches to understand the governance systems, cultures, structures and practices within which transitional change may occur (e.g., Smith & Stirling, 2010; Haase et al., 2014; Loorbach et al., 2017; Ehnert et al., 2018).

A prime example of a complex transition is occurring in the energy sector where an increase in renewable energy use is suggesting a shift away from fossil fuels, with disruptive implications for technology and energy systems that reflect sunk costs and vested interests, and changes to institutions, values and routines (Loorbach et al., 2017; York & Bell, 2019). While the energy supply system in most developed countries is still dominated by fossil fuels, renewable innovations such as solar photovoltaics, wind energy and electric vehicles are rapidly emerging, and in some countries the previously locked-in electricity regime is becoming destabilised and reoriented towards the niche innovations (e.g., EEA, 2019). The emerging dimensions of transitions research, including nonlinear change over long time-horizons, multiscale horizons, and a coevolution of knowledge and practices, have similar relevance to exploration of the SPPIs for climate change adaptation transitions – on which there is significantly less literature.

Transition and transformation are often used interchangeably within the scientific literature and both recognise that systemic and nonlinear societal change is needed to keep humanity within a safe operating space (Patterson et al., 2017). However, the origins and focus of the concepts differ – with transitions arising more from the sustainability research community to analyse change in societal subsystems, and transformations from global environmental change research with application to large-scale shifts relevant to planetary boundaries (Loorbach et al., 2017). Etymologically, as explained by Hölscher and colleagues

(2018), transitions mean *going across*, and transition analysis focuses on the processes and dynamics of change to explain *how* shifts to alternate states are supported, and transformations mean *change in shape* with transformation studies highlighting *what* it is that changes and *what* the outcomes might be at a systemic level (Folke et al., 2010; Hölscher et al., 2018). This thesis focuses on transitions and has a strong interest in how SPPIs can, for example, enable change and overcome policy lock-in.

In seeking to understand transitions, how to constrain undesirable transitions such as from climate change or ecosystem collapse, and how to accelerate desired transitions, transitions research has long interacted with policy and governance concepts and strategies. Where sustainability is a transition goal, public policy is central to shaping the directionality of transitions, and recent studies have identified the influence of central government, participation and power in sustaining existing regimes, and the nature of successful transition-oriented policies (de Gooyert et al., 2016; Kern et al., 2019; Köhler et al., 2019). The concept of societal regimes is central to transition studies, and it refers to the configuration of dominant social elements such as technologies, institutions, routines, and cultures, that have emerged historically in interaction with external factors and develop path-dependently through internal optimisation and incremental innovation processes (Geels, 2002; Loorbach, 2017). In this way, regimes help explain path dependency or the lock-in of existing socio-technical systems, as well as allow for the role of niche innovation and changing internal and external pressures as agents of change for regime shifts or transitions. Change then occurs to enable the progress of transitions through varied processes of experimentation and niche innovation, multi-level dynamics that facilitate niche application, and wider social movements or collaborative relationships between multiple actors or institutions that can support niche uptake (e.g., Köhler et al., 2019).

Recent studies also point to the importance of policy mixes for stimulating and enabling transitions (EEA, 2019; Kern et al., 2019). Policy mixes recognise that solutions for complex challenges extend beyond a single policy domain, and that attention is needed on the characteristics of multiple policy elements, including their coherence, consistency and comprehensiveness, alignment with societal problems and stakeholder interests, and accountability and implementation approaches (Rogge & Reichardt, 2016). Through this focus, policy mixes provide a useful perspective to explore such areas as the market failure leading to underinvestment in research and development (R&D), negative environmental externalities from development processes, and the institutional factors that constrain or support steps in a transition process (Weber & Rohracher, 2012). A challenge for the design of policy mixes is in finding effective ways to examine and respond to pre-existing policies, which may be locking in unsustainable practices, to enable the constructive layering of existing and new policies to support desired change (Schot & Steinmueller, 2018; Kern et al., 2019; EEA, 2019).

Finally, the inherently uncertain and exploratory nature of transitions emphasises the need for evolving knowledge to support governance. Actionable knowledge is critical for innovation and social learning through multi-directional interactions, and there is a need for the transitions community to more systematically investigate the role of new knowledge for the initiation and governance of transitions (van Mierlo & Beers, 2018; Turnheim et al., 2020). An important question that needs greater research attention is how SPPIs can support and leverage transitions where the state of knowledge is constantly evolving (e.g., Dunn et al., 2017). Dunn and colleagues (2017) identified that the interplay between SPPI factors contributed to enabling sustainable urban water transitions in Rotterdam, in particular through the large-scale co-production of knowledge through government funded programs, experiential based learning through demonstration projects to test and showcase innovation, and a strong long-term policy vision.

There is also a need for further empirical research, including case studies to illustrate concepts and ideas in tangible ways relevant to leaders, policymakers and practitioners, that addresses gaps in sectoral and geographical coverage, such as on transitions for climate change resilience and adaptation, and for studies that shed light on transition processes, including approaches to overcoming policy lock-in (Dunn et al., 2017; EEA, 2019; Turnheim et al., 2020). This thesis aims to address this need through the development of case studies that bridge science-policy-practice interfaces and transitions for policy and practice reforms that can facilitate climate-smart outcomes.

1.3 Climate change science, policy and practice in Australia – an emerging problem

Australia has a highly variable climate, with frequent extreme weather events, and is highly exposed to the impacts from even low levels of global warming. Climate and weather-based natural disasters are common, with, for example, natural disasters in 2016 alone (not an abnormal year) costing between $9.6 and $11 billion, including social costs (Deloitte Access Economics, 2016). Such disasters, which will be exacerbated by climate change, have resulted in loss of life, significant damage to infrastructure and housing, major reductions in agricultural productivity, and impacts to essential service provision, among other impacts. The IPCC has identified that Australian ecosystems, settlements and infrastructure, and water supplies are particularly vulnerable to climate change (IPCC, 2014). Importantly, the severity of climate change impacts in Australia, particularly from flood, heatwave and sea level rise, to people and infrastructure could be reduced considerably by emissions mitigation and effective adaptation action (IPCC, 2014, 2022).

Australia's science and research sector has been central to the identification of climate change risks to communities, natural environments and resources, and economic sectors, and to the assessment of vulnerability and understanding of emissions mitigation and adaptation options and their implications (e.g., Bicknell & McManus, 2006; Howden et al., 2010; Yuen et al., 2012). The Australian Government has a primary role in funding climate and climate change science capacities through a Constitutionally-based meteorology responsibility, targeted programs supported by matching funding from publicly funded research agencies, and indirectly through higher education expenditure on R&D. Investment to date, along with Australia's relative research isolation in the southern hemisphere, has positioned Australia to develop a world-class climate modelling and research capability, and deliver globally important insights on, for example, the role of Antarctica and the Southern Ocean in global and national climate, as well as robust national and regional climate change projections (e.g., CSIRO & BoM, 2015). However, the Australian Government has substantially reduced funding for climate change science and adaptation research over the last decade, with annual expenditure on core climate change science halving since 2013, and funding for the National Climate Change Adaptation Research Facility (NCCARF) ceasing (Tangney, 2019; O'Donnell & Mummery, 2017).

Despite strong climate change science, Australia's climate change policy developed slowly and in the context of the country's dependence on fossil fuels. Conservative governments have, in particular, articulated a narrow definition of Australia's national interest as its comparative advantage in, and export revenue dependence on, energy-intensive and high-emitting processed minerals, coal and natural gas, and agricultural sectors (Christoff, 2010; Head, 2014). The narrowness of this export portfolio has amplified the power of the industry lobbies from these sectors, and facilitated a political culture reluctant to introduce policies that could challenge this economy and underpin low-carbon and resilience transitions (Tangney & Howes, 2016). As stated by Christoff (2010, p. 214),

> Australia's climate discourse … emphasises the immediate (and usually overstated) costs of mitigation to jobs, investment and GDP, rather than the potential longer term damage of climate change to non-economic assets, principles and values (such as ecological conditions, equity and lifestyle choice).

Reflecting this culture, several senior conservative government leaders in Australia have politically challenged the legitimacy of climate change science, likening experts to religious zealots or doomsayers (Tangney, 2019).

As a result, Australia's climate change policy basically comprises voluntary and no regrets initiatives, which meet commitments for action without fundamentally changing the country's dependence on fossil fuels or vulnerability to climate impacts (Head, 2014; MacNeil, 2021). Australia's keystone emissions reduction measure since 2015, the Emissions Reduction Fund, pays industry to reduce emissions through a reverse auction approach, and there are questions about its effectiveness and capacity to achieve its goals in a changing climate (e.g., Meng et al., 2015; Roxburgh et al., 2020). Prior to this, more progressive national governments have had short-lived success with more substantive measures such as a legislated economy-wide carbon price, but the policy was quickly reversed by the conservative Coalition government (2013 to 2022) (Lowe, 2020; Crowley, 2021). While Australia has met its initial Kyoto Protocol targets and claims to be on track to achieving its 2030 and 2050 targets, meeting these future targets will likely be challenging. There has been strong reliance on reduced emissions from land use clearing since 1990 to date, including carryover credits, but further carryovers are not supported under the Paris Agreement. Emissions have continued to grow in the stationary energy, transport, and industrial processes sectors to 2019, and future targets rely on as-yet-unidentified technologies to substantially reduce emissions (Crowley, 2021; DISER, 2021a, 2021b).

Despite the shortcomings of current Australian emissions reduction policy, a small number of climate institutions established by Labor governments between 2007 and 2013 have managed to continue to contribute to national decarbonisation efforts and at times identify the need for measure reform (MacNeil, 2021). Key among these are the Climate Change Authority, which undertakes reviews and provides scientific advice to the Australian Government, and the Clean Energy Finance Corporation and the Australian Renewable Energy Agency which support innovation in and deployment of lower-carbon energy sources.

Adaptation has also failed to gain strong traction at the national level, affected by uncertainty in the science, and an assumption that the responsibility and capacity for adaptation resides predominantly with state and local governments, communities and private sector organisations (Head, 2014; DAWE, 2021). Early initiatives to address knowledge gaps and uncertainty through research following the Council of Australian Government's 2007 adaptation framework have not been continued, and there has been a failure in national coordination to translate emerging knowledge into policy for resilience and adaptation across vulnerable sectors. By way of example, the influential Garnaut Climate Change Review, delivered by a highly respected economist in 2008, identified major risks to Australia from climate change, such as potential impacts on infrastructure sub-sectors equivalent to one percentage point of GDP, yet proposed only an insubstantial forward agenda on adaptation (Garnaut, 2008; Christoff, 2010; Head, 2014). Likewise, the Finkel report on a proposed forward agenda for the energy sector in the context of climate change, noted the collapse of the South Australian grid in 2016 from an extreme weather event, but failed to propose any measures to manage physical climate change risks to the sector (Finkel et al., 2017). Other prevailing policies and practices that expect short-term and deterministic answers to emerging problems, and rely on widely used cost benefit and risk assessment methods, also rarely robustly consider climate change. Such policies and practices further tend to prioritise short term economic business cases, and require determinacy in the hazards presented to justify action – all of which inhibit effective adaptation (Productivity Commission, 2012; Tangney & Howes, 2016). Various local plans and initiatives have flourished in Australia, notably in reducing local government emissions and in strategies for green buildings and reduced water use; however, constraints in accessible knowledge and financial and legal capacities limit the implementation of on-ground reforms in planning and services in response to climate change issues (Preston et al., 2011; Head, 2014; Gibbs, 2019). Recent analyses of adaptation in Australia recognise deep barriers to adaptation action, spanning a lack of expertise and understanding of risk reports – including from cognitive barriers – to a lack of incentives, and policy and institutional settings, such as planning provisions or building standards, that act very slowly or inhibit consideration of future climate (Waters et al., 2014; Gibbs, 2020). There has been little research on how to overcome these deep barriers and how SPPIs can contribute.

There is also relatively little literature on the functions of national leadership for adaptation action in Australia, particularly in the context of the centralism trend evident since mid-20th century and the existence of constitutional powers to implement national treaty commitments under the United Nations Framework Convention on Climate Change (UNFCCC) (e.g., Granberg & Glover, 2014). Glicksman (2010, p. 1165) finds that:

> federal leadership is likely to be necessary for some adaptation measures because: state and local authorities may lack the resources required, they will likely seek a competitive advantage relative to other jurisdictions in fighting for scarce resources such as water; the actions of one jurisdiction may have severe interjurisdictional externalities; and coordination of policies across multiple jurisdictions may be needed to ensure effectiveness and reduce transaction costs.

In addition to national collaboration and revenue collection roles, and responsibilities for issues with international dimensions including biosecurity, the Australian Government also has significant funding and regulatory roles in sectors traditionally managed by the states but which are vulnerable to climate change. These include electricity and water supply security, health, aged care, national infrastructure including for communications and capital city airports, and natural disaster management, as well as education. Relative to this breadth of leadership and coordination role, the 2021 National Climate Resilience and Adaptation Strategy 2021–2025 (NCRAS) frames a narrower, and in key areas as yet unspecified, role for the Australian Government that is primarily constrained to science and information provision, including a commitment for national impacts assessment and national monitoring of adaptation progress (DAWE, 2021).

In summary, there are a range of studies in Australia that have discussed adaptation and knowledge use. Few, however, address on-ground usability and use of produced knowledge, the role of policy in the use of knowledge and the role of the Australian Government in enabling effective SPPIs on matters of national significance to support climate-wise policy and practice. There is a need for more empirical evidence on how policy can underpin the usability and usefulness of produced knowledge, and how SPPIs can help overcome barriers to climate change science uptake into decision-making.

1.4 Research design and methodology

Social research can be understood by its nature as emergent, with research findings emerging through iterative processes of negotiation and interpretation of meaning or understanding, and research designs allowing for pursuit of new paths of discovery as they emerge (Lincoln & Guba, 1985). Robust meanings and understandings, in turn, while by no means guaranteed, depend upon clear and transparent research methods. This section provides a brief overview of my research design and methodology, including research logic (section 1.4.1) and strategy (sections 1.4.2, 1.4.3. and 1.4.4). Each article also includes a section which describes the methods used.

1.4.1 Framing research logic and paradigm

The theoretical work of this thesis is inspired by and builds upon two research approaches that explore how governance and agency can support the tackling of complex societal problems regarding climate change: sustainability transitions and science-policy interfaces (Kowarsch et al., 2016; Loorbach et al., 2017). As described in sections 1.2.2 and 1.2.3, sustainability transitions research recognises the need for societal change and the need for processes that can navigate societies toward desirable solutions. Science-policy interface research, in the context of complex environmental challenges, recognises that the transdisciplinary, collaborative and deliberative nature of science has transformative potential through learning, the building of capacity and empowerment for action. Both approaches investigate complex real-world phenomena and recognise that the interactions and feedbacks in systems of study generate systemic uncertainties, persistence, thresholds and surprises. Transitions and such SPIs are both clearly complex phenomena that are context-dependent, multi-dimensional, involve multiple actors, and are contested. They also share an interest in enhancing understanding about the role of agency and governance in supporting (or constraining) desirable change (Loorbach et al., 2017; Moss et al., 2019). Research design in these areas therefore needs to be integrative, have aims to contribute to societal change, and involve scientists, policymakers, practitioners and other stakeholders (Loorbach et al., 2011). Unsurprisingly, to reflect the contextualised insights and interpretations inherent in such research, qualitative research methods that can draw insights from a range of areas such as complex adaptive systems theory, science and technology studies, institutional theory, and post-normal science, are predominantly utilised (Geels, 2011; Zolfagharian et al., 2019). The similarities, differences and complementarities of these approaches are outlined in Table 1.1.

Table 1.1. Overview of sustainability transitions and science-policy interface research approaches.

	Transition research	**SPI research**
Origin and context	• Emerged in the 1990s to support development of new national frameworks for pervasive environmental problems.	• Burgeoned in recent decades in recognition of the importance of science in policymaking to address environmental problems.

	• Research recognises challenges to sustainability transitions because of behavioural, institutional, cultural and infrastructure lock-in mechanisms within existing systems.	• Research recognises gaps between knowledge producers and users, and that path dependencies and lock-ins can result in suboptimal historic knowledge becoming embedded in decision-making processes.
Goals	• Goals are to understand historical and contemporary transitions and their enabling factors in societal systems, and to inform and influence the speed and direction of change in these systems.	• Aims are to understand and enhance functioning of interfaces to help close the gap between science and policy. • Ultimate goal for scientific evidence to improve environmental decision-making.
Objects of change or reform	• Radical and nonlinear changes to the structures and practices of a societal system so that it shifts from an unsustainable towards a sustainable state.	• Reform or change to policies and/or practices from improved science. • Enhanced interfaces for wider institutionalising of processes linking knowledge and policy.
Change dynamics	• Transitions are multi-dimensional and multi-actor processes and identify key driving forces and supporting and hindering activities from diverse actors. • The multi-level perspective describes regime stability and change from forces at landscape, regime and niche levels. The multiphase model depicts how niche innovations can grow, become valid alternatives, and help establish a new regime.	• Knowledge co-production processes between science, policy and practitioner actors that enable knowledge transfer, social learning and input to governance processes and decisions. Strengthened and new interactions between actors are also sought.
Drivers of reform	• Endogenous and/or exogenous drivers which span innovation and experimentation, and new coalition building with potential to destabilise existing regimes.	• Transdisciplinary science builds trust so that lessons learned and evidence for reform can be considered in policy and decision-making. • Interfaces that can support innovation and experimentation on more sustainable approaches.

This thesis advances the dialogue between sustainability transitions and science-policy interfaces approaches – in particular, regarding the question of how to position climate change science as an agent of reform and transition for societal sustainability. My interest in the bridging of approaches has been strengthened by several scholars, including Marmorek et al. (2019), who have suggested that approaches that draw on and combine complementary and robust approaches may in fact build our capacity to resolve the complex and systemic challenges of climate change. In addition, van den Hove (2007) and Kowarsch et al. (2016), who characterise SPIs as having a normative purpose to improve tangible environmental outcomes, point to a research question of how such improvement can occur, thus conceptualising the interfaces as going beyond delivery of actionable science to learning, empowerment and action by non-science actors.

I take up a critical realist research perspective in this research. Drawing on the framework of Bhaskar (1975), critical realism is understood through its separation of ontological and epistemological commitments. A realist ontology acknowledges the existence of a mind-independent, structured and changing reality, which is combined with an epistemological relativism or fallibilism that acknowledges that knowledge is a social product, not independent of those who produce it (Bhaskar, 1975). In this way, critical realism distinguishes between the subjective, discursively bound and socially constructed nature of scientific knowledge, and the independent reality that is the object of that knowledge (Vincent & O'Mahoney, 2018; Yucel, 2018). Knowledge about reality is in this way partial, incomplete and fallible (Maxwell, 2012). Critical realism can be distinguished from social constructivism, in which scientific knowledge is understood as entirely socially constructed and reality is grounded in our experience (Denzin & Lincoln, 2008; Yucel, 2018). Critical realist methods can therefore bridge the epistemological knowledges of domains, constructed through lived experiences and interactions with others, and ontological reality, in this thesis relating to climate change (Cruickshank, 2003).

The critical realist paradigm is appropriate for my research because it enables a research design to build knowledge about climate change governance by connecting empirical findings regarding the observed experiences of societal actors, with scientific knowledge on the reality of climate change, and theories about underlying social structures and mechanisms. In this way, it aims to provide a more complete picture of reality (Yin, 2009). This framework enables study of the interaction of mechanisms or entities within a domain of investigation, such as how scientists, policymakers and practitioners varyingly perceive climate change and the need for action and transitions, including the factors considered critical to enabling or constraining change, and how and where their interests may be subordinated or given prominence in societal structures. This focus highlights that attention needs to be paid to the processes taking place within regimes that can lead to the construction of policy and practice, and to change itself, as well as to the deep causal mechanisms which may be invisible to the researcher focused only on actual events (Vincent & O'Mahoney, 2018). Critical realist transition research, then, can aim to shed light on the underlying dynamics within a particular regime that might be a pre-condition for a transition to occur (Bosman et al., 2014; Zolfagharian et al., 2019). Importantly for this thesis, attention to both underlying dynamics and multiple perspectives can bring rich and in-depth insights to how climate change science can be understood, valued and used to influence and assist the reform of policy and practice, and hence enable transitions, for societal resilience.

1.4.2 Research questions and methods overview

This study has two goals, firstly to develop a critical understanding of SPPIs in Australia relevant to achieving robust climate change outcomes, and secondly to use this understanding to develop recommendations for improving the operation of SPPIs to progress policy reforms and transitions for long-term societal benefit. The following question and sub-questions guide the research in this thesis.

> How can science-policy-practice interfaces facilitate climate change policy reforms and transitions in Australia?
>
> (i) How can climate-relevant SPPIs be conceptualised?
>
> (ii) What are the lessons learned from SPPIs for climate change policy reforms and transitions to date?
>
> (iii) What are the characteristics of effective climate-relevant SPPIs that support achievement of climate change adaptation and mitigation outcomes?

The context-specific nature of these questions, and their focus on explaining a whole, or a part of, a policy reform or transition regarding the role of SPPIs, point to qualitative research methods such as case studies, historical event analysis, thematic assessments, and discourse analysis. This is supported by the assessment by Zolfagharian and colleagues (2019) on the methodological and philosophical underpinnings of transition research, which found that qualitative and, in particular, case study methods are most frequently used in, and contribute valuable insights to, transition research.

While the research methodology to explore these questions did benefit from iteration, three broad research steps can be described: (i) literature review synthesis and framing of research context; (ii) individual case studies relevant to both SPPIs in policy reforms and transitions, and (iii) comparative analysis of the case studies with regard to the research questions. Figure 1.1 provides an overview of the research process for this thesis. Further detail on the case study research is in section 1.4.3.

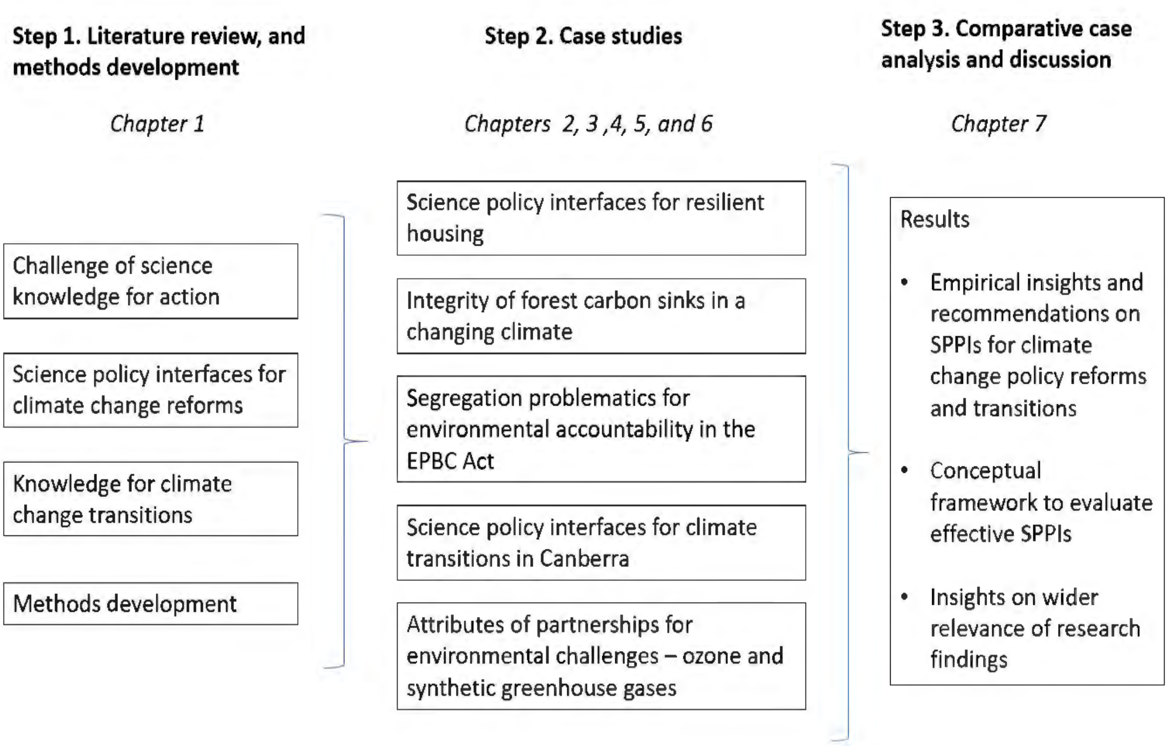

Figure 1.1. Overview of research process

1.4.3 Qualitative case study and comparative case study research

Through critical realism, qualitative case study research allows for in-depth description and analysis of how SPPIs function, including the factors affecting interface operation, and what is achieved. Case study methods involve exploration of how and why questions for select cases within real-life, contemporary contexts or settings (Yin, 2009). In this thesis, a multiple case study approach is used to explore the operation, effectiveness, and context-dependence of SPPIs for climate change policy outcomes and transitions. The SPPI cases were selected to span a range of sectors, reflect differing levels of effectiveness, and have access to science information. Cases were sought from both contemporary policy areas where a changing climate highlights the need for significant reform, and historical cases where lessons can be learned from how transformative outcomes were achieved. They span legislative, incentive and quasi-regulated policy instruments regarding housing, forest sinks, and environmental protection, and transitions regarding the management of ozone depleting substances and synthetic greenhouse gases in Australia and in achieving climate change goals in the city of Canberra. All of the cases address areas where government has a significant role in facilitating effective long-term outcomes, and where there is considerable potential to manage or reduce risks (also see section 1.3 and Table 1.2). Other case areas also could have been researched, some of which were considered before being rejected. National water policy was, for example, not pursued in this thesis as a substantial body of relevant work exists, and while there are opportunities to further research climate change SPPIs in electricity sector policy, significant barriers to engagement were found early in the thesis, notably difficulty in engaging with potential respondents, which were exacerbated by Covid-19.

Table 1.2. Characteristics of case studies selected.

Case	**Context**	**Climate change relevance**	**Key policy instruments**
Housing regulation	• Housing construction sector and industry is significant in Australia's economy and is an important employer. • Housing critical for social resilience.	• Housing highly exposed to climate change impacts. • Significant unrealised potential for adaptation to reduce likely impacts.	• Building code policy is overseen by an inter-jurisdictional ministerial committee. • The Australian Building Codes Board, a standards writing body established by the Commonwealth, State and Territory Governments, is responsible for the National Construction Code.
Forest sinks	• Forest carbon sinks very important to Australia's national emissions profile and	• Risks to long-term stability of forest sinks from climate change.	• Commonwealth Government established the Emissions Reduction Fund to incentivise

	national and private company targets.	• Risks to national objectives recently identified.	and achieve emissions reductions, including through forest carbon sinks.
Environment protection	• Australia has a unique biodiversity and more than 1,800 species and ecosystems identified as threatened or endangered.	• Many of Australia's unique ecosystems and species are extremely vulnerable to climate change, particularly drought and heatwaves.	• Commonwealth Government responsible for matters of National Environmental Significance through legislation (Environment Protection and Biodiversity conservation Act).
Urban climate governance in Canberra	• Australia's population is highly urbanised and cities have a central role in effective climate change responses. • As a medium sized city reliant on negotiations for key resources with surrounding State and national institutions, a Canberra case can provide insights on governance capacities.	• Canberra is vulnerable to a warming and drying climate and exposed to impacts from more intense rainfall and bushfire events. • Canberra was the first city in Australia to purchase all of its energy from renewable sources.	• Territory policy, strategies and regulations regarding renewable energy, water supply and disaster management.
Ozone depleting substances (ODS) and synthetic greenhouse gas (SGG) management	• A number of ODS and SGGs have very high global warming potentials.	• Constraining emissions from ODS and SGGs critical for limiting rapid climate change. • Australia contributed significantly to global action in this field.	• National legislation and regulation (Ozone Protection and Synthetic Greenhouse Gas Management Act).

While the capacity to generalise from case study research can be limited, the research engages a multiple case study design to show different perspectives on climate change SPPIs in Australia and to identify common themes that transcend the cases. A focus on policy instruments as the object of investigation, and of transitions in the Australian context, provides some replication logic, so that particular cases are broadly comparable and represent conditions where the phenomenon under study can be expected to be found (Yin, 2009). Furthermore, through iterative consideration of the links between the empirical studies and areas of SPPI and climate change adaptation theory, this research aims to generate knowledge which goes beyond atheoretical case study analysis alone.

1.4.4 Data collection and analysis

Data collection for the case studies has been based on a combination of document reviews, interviews, and participation in a number of workshops and seminars. Policy documents were sourced and reviewed from parliamentary, government and partner agency websites, and spanned legislation, standards, program documentation including procedures, and progress and review reports. Expert and scholarly reports, and other publicly available material relevant to the target policies and their associated implementation practice, were also sought through search engines. This document review provided insights on the approach to and effectiveness of the policies in the context of climate change governance. For all policies, considerable literature and reports are available that critically engage with the approaches to and effectiveness of climate change governance. Further information on the document analysis relevant to the case studies can also be found in the methodology sections of each article.

In-depth interviews were the main data collection technique, and 56 people participated in semi-structured interviews. Participants spanned policymakers, advisers, and regulators from the Australian Government, state and territory departments and agencies, scientists from both climate change and sectoral research perspectives, and both industry and non-government organisation (NGO) practitioners (see Table 1.3). This number was required as the sectoral cases selected for analysis largely had limited overlap. The key criteria for interviewee selection were recognised expertise in the target sector, and a body of experience that involved operation at the interface between science and policy, and/or practice. This requirement brought informed views to the issues under consideration and enabled a probing discussion that could identify both strengths and weaknesses in current interfaces in the context of climate change, and the potential for reform, feasible reform options, and transitions. Initial interview participants were selected based on the boundaries of the research and from publicly identifiable organisational roles, as research progressed the number of interviewees was increased through snowball sampling (Ritchie, 2003). Deliberate attention to multivocality and the targeting of differing viewpoints in each case helped address the risk of a reduced diversity of perspectives that could arise from snowball sampling (Ritchie, 2003).

Table 1.3. List of interview participants

Type of participant	**Case**
Research – climate change	6
Research – applied and case specific	12
Policy – government (national or state)	9
Regulator (government)	3
Practitioner – industry and NGO	18
Practitioner – adviser or consultant	8
Total	56

This research was conducted with approval from the Human Research Ethics Committee (University of Canberra) (approval number HREC – 17 – 126, see Appendix A). Requirements of the approval included the provision of a Participant Information Sheet that described the research, the participation sought, the rights of the participant, and data confidentiality and data storage processes. Written consent was also required from participants using a consent form that clarified the nature of participation in the research. In the case of telephone and virtual interviews (which comprised the majority of interviews due to the impacts of Covid-19), the participant was provided with copies of the documentation prior to the interview and verbal consent was obtained after discussion of the information sheet and consent form.

Interviews were semi-structured, with discussion based on the responses to a series of questions that were nuanced for scientists, policymakers and practitioners. Questions and probes were typically open-ended, developed to suit the context of the interview, and designed to promote rich conversation around the respondent's experiences. In alignment with a critical realist paradigm, the interview questions were also designed to probe interactions and underlying factors, and to explore multiple perspectives, in order to gain detailed insights on the phenomenon of interest (Zachariadis et al., 2013; Brönnimann, 2022).

Interviews were recorded where participants agreed, and detailed notes also taken. Eleven participants preferred a non-recorded discussion,[6] including when there was interest in making personal observations on the topic separate from organisational positions. Table 1.4 describes the indicative line of questioning drawn upon.

Table 1.4. Indicative line of questioning

Introductory questions • Could you please explain your role and how it relates to climate change science or the impacts of climate change? • Can you tell me a bit about your work to date in this area?
General views on climate change science and decision making • Is the science of climate change and impacts adequate and robust for decision-making? How so? • What are the attributes or characteristics of effective science-policy-practice interfaces for climate change? Why are they effective?
Use of climate change science in practice (practitioners only) • How does climate relate to the business of your organisation? • How is climate change currently reflected in organisational processes? • Can you give me a good example of how climate change science or risk is being incorporated into strategies, policies, practices or investments? Why was that example successful? • How do you/your organisation access climate change science? • Where climate change projections suggest that new business strategies may be needed in the future, how can climate science contribute to decisions for change or reform? • What are the barriers and enablers of organisational or sectoral capacity to incorporate climate change science in policy and decision-making? • How do you consider the climate change science-practice interface operates for your organisation or practice? • What does your practice/organisation need from the climate change science and/or policy community for effective interfaces?
Climate change science for decision makers and policy (scientists only) • Can you tell me about roles you've had providing climate change science to policy or decision makers, and the lessons learned? Why do you think they were successful or not? • Do you have a clear view on the confidence that can be placed on climate change science for different types of policy or decision-making? How can uncertainty in the science be addressed?

[6] Several government and adviser interviewees requested to not be recorded or attributed, even anonymously. There was concern that with a small number of senior people in responsible agencies they could be identifiable. I agreed to the conditions in an attempt to elicit a more open and critical commentary and enable discussion to enter areas that go beyond government rhetoric or formally agreed policy. I recognise this can lead to less complete records of interview as there is reliance on recall and notes alone.

- How can climate change science be used in framing and addressing impacts and risks?
- What approaches or mechanisms provide effective interfaces regarding climate change science for policy or decision makers?

Climate change science for decision makers and policy (policymakers and regulators only)

- How is climate change science considered or reflected in policies/regulations of sectors vulnerable to climate change impacts? If not reflected, why not?
- How do current policy or regulatory settings act to facilitate consideration of a changing climate or is this constrained? Examples? Why are the examples successful or unsuccessful?
- What institutional arrangements and reforms are needed to enable and improve effective climate change science-policy-practice interfaces that can support policy and regulatory success in a changing climate? Why? How can they be implemented?

Some limitations are also recognised in the method of data collection. The use of snowball sampling, a non-random sampling technique, can potentially limit the span of interviewee perspectives with implications for the generalisations that can be drawn from the interviews about effective ways for science to facilitate transitions in Australia's sectoral practices. The focus on expert interviewees and on the organisational breadth of interviewees helped manage this risk. Covid-19 impacts also made data collection more difficult, as several interviewees became unavailable due to family illness or significant increases in demands from changing work practices. Where difficulties emerged regarding interviewees from a relevant organisational sub-category, notably large energy-intensive companies interested in offsets, particular attention was given to scrutiny of relevant company documents and announcements, scanning of key blogs and NGO reports that track private sector behaviour and action on climate change, and consideration of general coherence of findings with those from related research, to manage any risks of information gaps.

As a former public servant with responsibilities for managing climate change science and adaptation policy and programs, and with current related advisory roles, I, as the researcher, had close links to the topic itself, including previous engagement with numerous experts in the field. Such closeness to the topic necessitated continued self-reflexivity to ensure that my own motivations and perspectives did not unknowingly influence or overshadow those of the participants (Haynes, 2012). I achieved this through attention to methodological reflexivity (Lynch, 2000), by regularly seeking to be aware of my own opinions, assumptions and prejudices, particularly in the semi-structured interviews, and by ensuring that meanings and explanations emerged from the data rather than my own perspectives. For example, my perspectives on the relative importance of the science in decision-making, and of the reform urgency of policies to reflect that science, may substantively differ from other research participants and thus impact the way in which I conceptualised the issues emerging from discussions. Recognising this, I sought to reflect on and ensure that I captured the ways that my research participants approached the topic, including the potential need to clarify domain-specific assumptions regarding language use. Nevertheless, this research is underpinned by recognition that no social research method or theoretical framework can be completely free from the researcher's opinion, as every instance of framing contains a value judgement or omission, whether implicit or explicit, made by the researcher.

The data generated were inductively interpreted, through continued attention to the potential for and identification of explanatory or influencing factors, and where credible inferences or principles could be drawn from the analysis and synthesis undertaken. Sense-making from the data was supported by analysis of interview information and findings from the literature review to understand the operation of SPPIs, and a thematic assessment across the data sources to identify gaps and needs, practice realities, enabling factors or barriers, and outcomes sought for policy reforms or climate change transitions (see examples given in Table 1.5). Thematic assessment is a useful method for exploring the varied perspectives of different research participants, and for highlighting their commonalities and differences (e.g., Nowell et al., 2017). The stages of theme development and assessment used in this thesis involved (i) data familiarisation and the highlighting of meaning; (ii) theme construction including classification and definition; (iii) theme review including relating themes to established knowledge; and (iv) theme finalisation. The thick description obtained from the in-depth study also underpinned a capacity to differentiate perspectives from the varied types of participants, and to tease out common characteristics. This analysis approach was undertaken first with respect to the individual cases, and secondly to compare the cases.

Table 1.5. Example of thematic analysis of data.

Sub-theme	**Description**	**Example of interview comment with relevant categorisation**
Science uncertainty (barrier)	Evidence on how uncertainty is understood and acts as a barrier to climate action in different contexts	**Scientist consultant** • *'Uncertainty problematic, it turns people off and they don't know how to handle it. Agencies can deal with risk and scenario planning, but disregard science presented as uncertain'.*

		Industry adviser • *'Interesting that a lot of organisations take action where there are high levels of uncertainty, like projections of demand for fossil fuels, but get paralysed about climate change … they see uncertainty in future climate projections as a reason for inaction'*. **Industry** • *'Climate uncertainty very hard. Tried to take modelling information to Board. Want 95% confidence which I expect we won't get'*.
Why interfaces important? (needs)	Evidence on why interfaces important and their function	**Technical adviser** • *'Researchers and decision-makers can be driven by quite a narrow band of factors…there's an incentive problem to collaborate. A consultant or other body that can speak your language and translate information can build enthusiasm'*. **Consultant** • *'Intermediaries important role – climate science very difficult to use and contextual sophistication needed of practice to link science with what needs to be done'*. **Science** • *'Interface between science and user community not well developed in Australia. Has been too much science push. The lack of knowledge brokering a fundamental barrier to science use'*.
Policy science uptake (barriers)	Evidence on limitations of existing practice regarding causal factors affecting climate science use	**Adviser interface organisation** • *'Economists tend to set framing of many policies – focus on mean and averages and exclude tail risks and ignore damage functions. Economic framing very influential – need a whole different way of building evidence'*. **Regulated utility** • *'Our business and decision-model is based on meeting consumer needs and managing risks within 5 year determinations. Companies have sought funding to build resilience and got knocked back – resonated through sector'*. **Policy analyst** • *'Climate change seen as a sustainability or environment issue. It's not yet part of core policy or strategy business'*.
Drivers of reform (achieving outcomes)	Evidence on factors needed to drive reform regarding the	**State government** • *'Leadership critical. In Australia leadership at middle and bottom-up, and essential if policy weak. Missing step-change possible from top-down leadership, science and standard-setting'*.

	integration of science in policy and practice	**Consultant** • *'Policy reform critical to address bigger science risks. Insufficient and poor policy where risks pervasive, large scale and increasing lets communities, companies, businesses only react to impacts and not incentivise resilience'*.

The quality of research needs to be judged using criteria relevant to its own paradigm's terms, and the nature of critical realist research suggests the utility of attention to contingent validity, inclusivity of the research process, trustworthiness in the research findings, and societal relevance of the research results (Lincoln & Guba, 1985; Healy & Perry, 2000). While it is impossible to analyse all social contexts in the case studies selected, the emphasis on *why* issues in the interview questions is designed to elicit findings of where causal impacts are contingent on their environments or on underlying factors within regimes of practice. Inclusivity in the research process is a key criterion for researchers with a critical realist paradigm, as the seeking of multiple perceptions from participants and peer researchers strengthens the explanatory capacity of the research regarding why things happen.

In this research, the interviewees were selected to reflect a diversity of perspectives and interests on a case, and the credibility of research findings confirmed through triangulation through their convergence, or at least lack of contradiction, with other data sources (Miles & Huberman, 1994). For example, at several points through the data collection and analysis stages of the research, I tested emerging and partial ideas with colleagues and professionals in workshops, seminars and informal meetings. These events provided me with additional insights about how societal actors and decision-makers understand, access and use climate change science, and perceive the need for and directions of climate change transitions. Examples of such events included the 2018 National Climate Change Adaptation Research Facility (NCCARF) and Engineers Australia conference, the 2018 Future Earth Australia Early Career Researchers workshop, a 2019 international conference on politics in the Anthropocene, the 2020 international KE4CAP (knowledge exchange for climate adaptation platforms) workshop, and University of Canberra's Canberra Urban and Regional Futures (CURF) annual forums, for example on building resilient cities.[7]

[7] A list of presentations delivered during candidature is in the section Publications as part of thesis near the beginning of the thesis.

1.5 Structure of the thesis

Utilising a by-publication model, the main body of this thesis comprises a number of published articles and book chapters, and introductory and concluding chapters. The structure of the thesis is illustrated in Figure 1.2.

Chapter 1. Introduction

PART 1. SCIENCE-POLICY-PRACTICE INTERFACES FOR POLICY REFORM

Chapter 2. Science-policy practice interfaces for resilient housing in a changing climate: a reform agenda for Australia's building regulation (published article)

Chapter 3. Environmental integrity of forest offsets in a changing climate: embedding future climate in Australia's sinks policy regime (submitted article)

Chapter 4. Overcoming segregation problematics for environmentally accountable policy in a changing climate: the case of Australia's EPBC Act (accepted book chapter)

PART 2. SCIENCE-POLICY-PRACTICE INTERFACES FOR CLIMATE CHANGE TRANSITIONS

Chapter 5. Science-policy-practice interfaces for city climate change transitions: a case study of Canberra, Australia (published article)

Chapter 6. Attributes of effective national partnerships for environmental challenges – managing ozone-depleting and synthetic greenhouse gases in Australia (published article)

Chapter 7. Discussion and conclusions

Figure 1.2. Outline of thesis structure

The case studies are categorised into two themes, first SPPIs for policy reform, and second SPPIs for climate change transitions, reflecting the importance of government and policy for climate change transitions. While transitions can involve many policy instruments, actors, and other factors such as technologies over time, policy action is an integral component of transitions, with critical roles in overcoming market and system failures, including underinvestment in research and development, and in reconfiguring markets, user preferences and cultural perceptions to foster transition progress (Edmondson et al., 2019). Importantly, policy action can alter state capacities and change incentives for collective action and to encourage social adaptation (Patashnik & Zelizer, 2013). Legislation and regulation are important forms of policy for achieving climate change objectives as the capacity to compel or limit certain behaviours provides greater certainty regarding the achievement of sought outcomes. Regulation is widely understood as the rules of implementation of legislation, and can support climate change goals through, for example, specification of minimum standards to protect communities, requisite levels of environment protection, conditions for resource access and use, and obligations for compliance. At the same time, however, policy, legislation and regulation that fail to adequately address or anticipate climate change can act as a barrier to reforms for adaptation and resilience or for the achievement of decarbonisation goals (Waters et al., 2014).

Within Part 1, Science-Policy-Practice Interfaces for Policy Reform, Chapter 2 provides a case study of how housing regulation in Australia reflects and addresses the science-identified risks of climate change. Housing construction is regulated through a well-established body of codes and standards that predominantly seek adherence to prescribed minimum standards, and housing and housing occupants are also increasingly vulnerable to climate change impacts. This case study explores the climate change science, policy and practice interface components of housing regulation to ascertain whether the interfaces act as barriers to adaptation outcomes, and whether and how the regulation needs reform to address foreseeable risks from a changing climate. Chapter 3, a case study on how a changing climate needs to be considered in government initiatives to accredit forest carbon sequestration in order to ensure long-term resilience, explores the SPPIs of a more recently developed and incentive-based instrument, framed by methods established through legislation. Similarly to Chapter 2, this case study draws on a multi-perspective exploration to identify what reforms, if any, are needed to strengthen the SPPI to maximise the robustness of instrument implementation and long-term outcomes in a changing climate. Chapter 4 provides a case study of Australia's national environment protection legislation, and takes a somewhat wider perspective in considering its operation for accountability purposes in a changing climate. This study identifies segregation problematics, including between science and policy and practice, that need to be addressed for the legislation's primary objectives to be achieved.

Comprising Part 2, Science-Policy-Practice Interfaces for Climate Change Transitions, Chapters 5 and 6 both explore and illustrate how SPPIs can contribute to and facilitate climate change transitions. There are relatively few successful large-scale climate change transitions in Australia where substantial shifts towards more sustainable practice outcomes have generated sustained outcomes. Chapter 5 investigates transition steps and processes in the city of Canberra, where SPPIs provide a framework to explore reforms and governance approaches for climate change mitigation and adaptation in a particular context.

This chapter responds to the growing call for urban climate-wise transitions and for insights into how SPPIs can help bridge implementation gaps between urban transition goals and actions realised (e.g., Bai et al., 2019; Bansard et al., 2019; Solecki et al., 2021). Chapter 6 identifies the attributes of a successful national science-policy-practice partnership that robustly built a shared understanding and management approaches for ozone-depleting and synthetic greenhouse gases in Australia, including through regulatory processes that enabled innovation and its large-scale uptake.

Each of the case study chapters contribute to addressing the overarching and sub research questions (see section 1.4.2). The varying policy and regulatory contexts provide a richness to the capacity of the thesis to conceptualise SPPIs and their operation for climate change outcomes in Australia, and, further, identify characteristics of effective SPPIs. The schematics of case study SPPIs were developed as part of the cross-case analysis. They represent the dominant influencers and operation of the SPPIs and can be found as annexes to Chapters 2, 3, 4, 5 and 6. Chapter 7 then synthesises the findings of the thesis in relation to the research questions, presents the discussion and conclusions of the thesis, and identifies areas that would benefit from further research.

1.6 Contribution of the thesis

In addressing the knowledge gaps using the methods identified in this Chapter, the thesis will make a series of contributions to scholarship on how SPPIs can facilitate climate change policy reforms and transitions, particularly concerning adaptation. To the best of my knowledge this thesis is the first to conceptualise SPPIs of existing policy regimes in a way that facilitates evaluation of their capacity to access and use climate change knowledge to support reforms for resilient, adapted and low-carbon futures. Further, with the science of climate change clarifying the need for urgent societal action, and informed by the conceptualisation of SPPIs, this thesis identifies critical reforms tailored to overcome barriers and build capacities in the science, policy, and practice communities that were co-participants in this research. Chapter 7 provides a comprehensive discussion on the contributions of the thesis to empirical understanding as well as to key relevant areas of theorisation.

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PART 1

SCIENCE-POLICY-PRACTICE INTERFACES FOR POLICY REFORM

Chapter 2

Science-policy-practice interfaces for resilient housing in a changing climate: A reform agenda for Australia's building regulation

Abstract

Communities and households expect that homes and other buildings will be resilient and safe for occupancy in the long term. A growing concern, then, is that scientific knowledge of increasing near-term risks to buildings in Australia that could cause significant damage and impact on the wellbeing of occupants, is not yet well integrated into building policies and regulations. This paper investigates the climate change science-policy-practice interface (SPPI) of Australia's building regulation with a view to enhancing housing resilience using a case study method. Attention to SPPIs is found to provide a more nuanced understanding of barriers to the use of climate change science in regulation, and of ways to tailor reforms to address them. Consideration of the science embedded in regulation and practice, distinct from assumptions that science is exogenous to end uses, can usefully help focus the initiation of such reforms. The paper outlines steps to address identified weaknesses in all SPPI building regulation components in Australia for resilience in a changing climate. It is suggested that a disaggregated analysis of regulation as a SPPI may be helpful in designing reforms in other countries where building codes are yet to comprehensively address physical climate change risks.

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2.1 Introduction

Climate change presents unprecedented and major risks of damage to buildings in coming decades. Increases in the intensity and frequency of extreme weather events along with shifts in climatic patterns, projected with climate change, will exceed thresholds of building safety and performance more frequently (Lenton et al., 2019; Steffen et al., 2019). The scale of building exposure to climate change impacts is large and global, with some $570 billion (AUD) of assets exposed in Australia's property market to climate change and extreme weather in the near-term (Steffen et al., 2019). The long life of buildings, and the demonstrated cost-effectiveness of preventative measures for extreme weather event impacts, call for proactive climate change adaptation (Hurlimann et al., 2019; Schäfer et al., 2019). Science can help with the design and implementation of proactive approaches by increasing understanding of the challenges, supporting policies robust to a changing climate, encouraging learning, and exploring socially acceptable pathways towards resilient futures (Kowarsch et al., 2016).

However, recent studies find that the regulation that governs the building sector in Australia fails to adequately integrate climate change (Hurlimann et al., 2019). This is a concern as building regulation is a key instrument for realising climate resilience in buildings. While urban planning and zoning requirements can limit the exposure of buildings to certain spatially described hazards, building codes and standards and their implementation practices determine the actual locational exposure of buildings to weather-related hazards, and their capacity to withstand extreme weather events of specified return periods (Hurlimann et al., 2019; King et al., 2013). Building codes and standards are also key policy instruments that influence occupant health and well-being, such as in the context of more intense heat waves. There is now growing evidence of gaps in the operation of building regulation in Australia to ensure resilience and occupant health and well-being in examples of the extreme current as well as the projected future climate (Hatvani-Kovacs et al., 2018; Miller, 2014). Such gaps are also likely not unique to Australia. In a survey of 12 countries (members and affiliates of the Inter-jurisdictional Regulatory Collaboration Committee (IRCC)), Meacham (2016) found little action to address resiliency to climate change impacts through building regulations (p. 481), a finding attributed to the complexity of the problem (p. 484).

A key challenge now for science, policy and practice is reform of building regulation to integrate relevant scientific knowledge and ensure that buildings are resilient to future climate conditions. Resilience is now a core analytic concept for urban scholarship, and there is growing interest in its reflection in implementation practice by communities concerned with minimising loss of life and damage impacts from hazards and climate change (Moullier & Krimgold, 2015; Romero-Lankao et al., 2016). Understanding of urban resilience as the ability to change and adapt in response to stresses and pressures without compromise to core functionality has relevance to housing research. Importantly, it highlights capacities for learning, re-organisation and development from feedbacks in dynamic socio-ecological systems in order to maintain housing functionality (Crabtree, 2009; Folke, 2006; Romero-Lankao et al., 2016). Recent scholarship is also finding that addressing emerging resilience challenges, such as from climate change, will benefit from greater innovation through interdisciplinary co-analysis approaches and wider dialogues about desirable urban and housing futures (O'Brien, 2012; Robinson & Cole, 2015).

Reforms of housing resilience in a changing climate will thus likely need to draw on wider knowledge and governance systems than utilised in traditional building codes and standards, and tease-out embedded understandings of the purpose of the regulation (Eisenberg, 2016; Visscher et al., 2016). Science-policy practice interfaces (SPPI) provide a useful lens for analysis of these issues as they highlight the interactions and processes connecting science to practice (e.g., Moss et al., 2019). While there are numerous studies on energy efficiency and building regulation in the context of climate change (e.g., Sun et al., 2016), structured analyses of how building regulation can act as an interface between science and policy, with the regulation accessing robust science to support resilience and adaptation outcomes, are scarce. Australia provides an informative case study for this analysis due to its highly variable climate, National Construction Code, and strong climate science capability.

This article helps address this deficiency with two aims: first to understand better how building regulation can be considered an SPPI in the context of climate change; and second to explore in more detail how this SPPI operates to identify tailored reforms that can enhance resilience outcomes from Australia's building regulation. Scholarly and practitioner literature are drawn on to address these aims, and for the second, expert views are also sought to respond to three more specific research questions: (i) How well is relevant climate change science integrated in Australia's building regulation?; (ii) Are there elements of the building regulation SPPI that act as barriers to resilience outcomes?; and (iii) What regulatory reforms, if any, are needed to build the SPPI for resilience?. The article argues that reforms are needed in building regulation to address foreseeable risks and to ensure that pathways exist for the uptake of improving knowledge. It seeks to contribute to SPPI and adaptation literature relating to the built environment, conceptually and empirically, including on overcoming barriers to reform.

The rest of this article is structured as follows. Section 2.2 frames the utility of and how building regulation can be considered as an SPPI, drawing on scholarly literature, and responds to the first aim. Section 2.3 outlines the methods and data sources for the analysis in this paper, and section 2.4 provides context to the case study on the climate change SPPI for building regulation in Australia. Section 2.5 outlines the findings relevant to the first two research questions of the second aim, and section 2.6 then reflects on areas for reform and future research in response to the third research question.

2.2 Framing building regulation as a SPPI

Building regulatory frameworks, spanning policies, codes and design standards, administrative processes and organisations, and implementation practices, can be explored as a form of SPPI. SPPIs are understood as social processes which link actors and institutions involved in generating, interpreting and applying scientific knowledge in policies and practices (e.g., Kettle et al., 2017). This definition recognises that SPPI scholarship is evolving beyond approaches that see science and practice as separate and emphasise knowledge production to meet end-user needs; to research that positions SPPIs more centrally in capacity building, learning and implementation approaches for today's complex environmental challenges (United Nations Environment Programme, 2017). Bringing an SPPI focus to building regulation that poorly integrates climate science points to the need to better understand the actual application of science in practice, how policy frames science in guiding practice, and how the connections between science, policy and practice are enabled and operate.

Climate and other science data are embedded in building codes and standards. New standards which followed the devastation of the city of Darwin by Cyclone Tracey in 1974, for example, incorporated engineering findings on failure mechanisms and construction techniques to withstand extreme wind (Mason & Haynes, 2010). Typically, historical climate data determine design values in building codes, which assume that past conditions will adequately represent climate through the building lifespan (Eisenberg, 2016; Productivity Commission, 2012). There is now robust future-focused climate knowledge that projects increasing hazards within building lifespans that could exceed critical thresholds for stability and safety (Warren-Myers et al., 2020). Science can bring new knowledge to SPPIs, so that practices are informed by up-to-date and tested knowledge of changing risks and environmental conditions. This function is critical as failure to embed climate knowledge into policies and practices is a primary reason for adaptation efforts stalling after the planning phase (Moss et al., 2019). Gaps between science and decision making for resilience, where deficiencies exist in the use of science information and in the provision of decision-relevant science, do however challenge the integration of climate science in building regulation (Hurlimann et al., 2018; Warren-Myers et al., 2020).

Policy defines the building regulation purpose, including the priority afforded climate change relative to other goals, and frames how regulatory institutions and processes engage with science. Building regulations have long histories in many developed countries and have generally evolved incrementally to align with government and community expectations on safety, aspects of public health, and cost effectiveness (Eisenberg, 2016; Van der Heijden & De Jong, 2009). Many outline minimum standards with prescriptive compliance provisions to achieve these expectations, although current reform directions emphasise performance solutions and stronger environmental and sustainability measures (Burgess & Thomson, 2015; Sun et al., 2016). While reforms to address greenhouse gas emissions and energy efficiency performance are now widespread, responses to the systemic, intergenerational and uncertain nature of climate change impacts appear limited, and building regulations in many countries tend to exclude consideration of large-scale hazards from climate change (Eisenberg, 2016; Sun et al., 2016). The building industry can also be powerful and resist changes to minimum standards and cost-minimisation goals, which can act as a barrier to enhancing resilience outcomes (Eisenberg, 2016).

Institutions and processes for maintaining, revising and amending building regulation can ensure that relevant knowledge is operationalised. They include organisations established to administer codes and the breadth of their mandates, stakeholder consultation mechanisms, and formal processes for revising codes including advisory committees and regulatory impact assessment and cost-benefit analysis methods. It is reasonable to expect that building regulation with mandatory power, strong climate change goals, and formal mechanisms for the co-production of knowledge and for the adaptiveness of science-practice interfaces, will be more effective in achieving resilience outcomes (Eisenberg, 2016; Moss et al., 2019; Sun et al., 2016).

Relatedly, practice within a SPPI spans the operationalisation of the policy and knowledge in initiatives, decision-systems and routines. Practice determines the actual resilience outcomes from regulation implementation, and it is framed by the policy settings of the regulation, wider industry and end-user norms and knowledge networks, and compliance and enforcement regimes. Practice networks can span public and private builders, regulators, investors and peak industry bodies, research, education, and community actors and organisations. Contributions from practice to a SPPI include lessons from experience, for example where extreme weather events have impacted on building construction costs or timelines and led to risk reduction practices, and insights from interfaces between practitioners and end-users. While building regulation practices have been described as path dependent and resistant to measures that enhance resilience, examples of leading practice which far exceed minimum requirements are also becoming more common (Australian Sustainable Built Environment Council and Cooperative Research Centre for Low Carbon Living, 2019; Warren-Myers et al., 2020).

2.3 Methodology

A case study method is used to explore how regulation for buildings in Australia facilitates or constrains realisation of climate change resilience in housing. This allows for in-depth analysis of how the practice of regulation accesses and uses science, within the context of the sector, and what tailored reforms are needed to achieve resilience outcomes. Australia provides an instructive context for this case study as the building sector is important economically and socially, nationally coordinated regulation is in place, and robust climate change science capacities exist. Further, recent extreme weather events have revealed vulnerabilities in the sector, and several reports have called for regulatory reform to improve climate risk management (Maddocks, 2011; Senate, 2018; Shearer et al., 2016).

Data sources for the case study come from documents and interviews. To address the first research question, how well building regulation integrates relevant climate change science, a gap analysis is undertaken of formal policy and regulatory documents (identified through web searches on Australia's National Construction Code and Australia's Building Code Board). Wider scholarly and practitioner documents, including studies on the resilience of Australian housing in a changing climate, and science reports on future climate change projections developed by national research agencies, were identified through web searches and informed a thematic analysis of barriers to science uptake and areas for reform (research questions (ii) and (iii)), along with the interview data. Documents drawn on are identified and cited in sections 2.4, 2.5 and 2.6 of this paper.

Semi-structured interviews (n=22) were undertaken with experts from the building industry (companies and peak industry bodies (n=8)), consultancy firms (n=6), and engineering (n=3) and climate science organisations (n=5). Interviewees were initially sought from peak industry bodies and national research organisations, with additional people identified through the snowball method. The primary criterion for interviewee selection was expertise and experience relevant to the research questions, and interviews were conducted by telephone or Zoom conferencing between November 2017 and July 2020. Most experts interviewed had work histories exceeding a decade in the field, and experience in more than one organisational category. Interview data in the paper is categorised according to organisational type, notably industry (Ind), consulting (Con), science (Sci), or engineering (Eng), and quotations from interviews are used to illustrate key concepts and points in the following style (Ind1 or Eng3).

2.4 Case study context: Australia's building regulation

Over the last 50 years Australia's building regulation has evolved from a series of disparate State based systems to a nationally unified framework. The first edition of a consolidated Building Code of Australia (BCA) was released in 1988, followed by an Inter-government Agreement (IGA) in 1994 that sought a more nationally unified and performance-based framework. The Agreement also established the Australian Building Codes Board (ABCB) to administer the code and arrangements for States and Territories to enact legislation adopting the code (Burgess & Thomson, 2015).

The principal building regulation in Australia, the National Construction Code (NCC), now spans the Building Code of Australia (BCA) and the Plumbing Code of Australia (PCA) and outlines requirements for the design, construction, and performance of new buildings and major renovations. It also references around sixty specific Australian Standards (AS) developed and maintained by Standards Australia. As with such codes elsewhere, the regulation aims to ensure minimum levels of safety, health and amenity in design and construction, including from climate hazards such as cyclonic wind (Australian Building Codes Board [ABCB], 2014). In developing and implementing the NCC, the ABCB draws on its membership from federal, state and territory governments, the Australian Local Government Association, and industry. Recent studies indicate progress in operationalising performance-based provisions regarding fire, but find that implementation continues to predominantly follow prescriptive elements (Armstrong et al., 2017).

There is general acceptance that the BCA has delivered safety and economic benefits to Australians (Armstrong et al., 2017; Burgess & Thomson, 2015). However, there are examples of housing whose performance failed in extreme weather. The excess mortality of 500 deaths and 3000 morbidity reports from prolonged indoor thermal discomfort in the 2009 heatwaves of south-eastern Australia (Bi et al., 2011; Senate, 2018), and damages from flooding including loss of amenity, costly repairs, and mould growth concerns to more than 28,000 houses in Queensland in the 2010-11 summer (King et al., 2013; Mason et al., 2012), are examples. There is also growing evidence that climate change could lead to building materials deteriorating faster, exposed buildings suffering more damage, and occupants facing greater risks (Hurlimann et al., 2019; Senate, 2018). Coastal impacts are affecting housing in several regions (Senate, 2018), and the Australian Government has estimated that up to 247,000 existing buildings, with a current replacement value up to $63 billion, are potentially at risk from coastal inundation this century (Department of Climate Change, 2009).

Beyond the NCC, Engineers Australia (EA), the peak professional body to advance the science and practice of engineering for the benefit of the community, has developed national guidelines for responding to the effects of climate change in coastal and ocean engineering, and to rainfall and runoff in construction (Bates et al., 2017; National Committee on Coastal and Ocean Engineering, 2017). The guidelines reflect professional concerns that climate change is affecting buildings and structures, and they act as a form of voluntary regulation that seeks good rather than minimum practice (National Committee on Coastal and Ocean Engineering, 2017).

2.5 Australia's building regulation climate change SPPI – issues and challenges for resilience

This section presents results on how well climate change science relevant to buildings is reflected in building regulation, where gaps exist, and whether elements of the regulatory SPPI present barriers to realising resilience outcomes.

2.5.1 Is relevant climate change science reflected in Australia's building regulation?

Buildings in Australia have been exposed to intense heatwave, rainfall, and fire events that exceeded design thresholds or spatial understandings of risk, and impacted occupant health (Bi et al., 2011; Steffen et al., 2019). With more intense weather extremes projected, there is growing recognition of the need for adaptation in the building sector (CSIRO & BoM, 2015; King et al., 2013; Senate, 2018). Of relevance to buildings, the IPCC identified that adaptation in Australia can substantially reduce near-term (2030-40) risks of flood damage to settlements, morbidity and mortality during heatwaves, and damage and loss from wildfires (Reisinger et al., 2014).

Australia's climate change science is robust, with projections tested through global coupled model inter-comparison projects (CSIRO & BoM, 2015). National projections reflect regional variations in climate, span average and extreme variables, and include information products and tools for risk identification and analysis (see, e.g., Climate Change in Australia, n.d.). They are supported by wider research into the drivers of and variability in Australia's climate, and into risks such as from tropical cyclones, flooding, and bushfires, from a range of research institutions. Further, requirements for adaptation in parts of Australia's built environment have been investigated, including the implications of climate change for deterioration of concrete, and for urban environmental health, including indoors, from a warming climate (Hatvani-Kovacs et al., 2018; Senate, 2018; Wang et al., 2010).

Findings from the review of how building regulation reflects climate change projections are summarised in Table 2.1. The climate change risks and projections identified align with findings from Australia's national projections and the IPCC where near-term action can deliver significant risk reduction (CSIRO & BoM, 2015; Reisinger et al., 2014). Tropical cyclones, weather-based risks with damaging consequences, covered by the NCC, are projected to alter with climate change and are also included as a key risk.

Table 2.1. Extent of climate change integration in building regulation.

Key climate change risks and projections	**Regulatory elements relevant to climate risks**	**Extent of integration of climate change**
Increased heatwaves and heat stress	• BCA Section J, Volume 1 Energy efficiency verification methods for office buildings identify thermal comfort (Australian	Incomplete • Recognition of need to ensure occupant comfort not compromised by energy efficiency measures in commercial buildings (occupant

Projection: More frequent and hotter hot days (very high confidence)	Building Codes Board, 2019a); Figure 2 Definitions Vol 2 Climate zones for thermal designs (ensure adequate insulation and ventilation) (Australian Building Codes Board, 2019b) • AS. 2019 Standard on NatHERS (Nationwide House Energy Rating Scheme) heating and cooling load limits (Australian Building Codes Board, 2019c)	comfort not a goal). Residential buildings not addressed • BCA climate zones based on prevailing static climate • Standard specifications based on historic climate and average annual energy use. Future climate or heatwave-specific data not recognised
More intense flood events Projection: Extreme rainfall events (20–year return value) to increase in intensity (high confidence) (medium confidence for only south-western Western Australia)	• ABCB Standard 2012.3 Construction of buildings in flood hazard areas to avoid collapse of buildings (including residential) in up to Defined Flood Event (ABCB, 2012a) • BCA Volume 2, Part 3.10.3 Flood hazard areas, 2.1.1 (Structural stability and resistance to rainwater actions), 2.2.1 (withstand surface water from storm with 1 in 100 year AEP) (Australian Building Codes Board, 2019b) • ABCB Information Handbook: (non-mandatory) Construction of buildings in flood hazard areas (Australian Building Codes Board, 2012b) • EA Australian Rainfall & Runoff Revision Projects	Incomplete in mandatory regulation • Standard does not mention climate change or recognise projected increasing risks in many regions, or apply to storm surge • Defined Flood Event in Standard an event with annual exceedance probability (AEP) of 1 in 100 (stationary climate) • Handbook Appendix B notes additional state requirements, e.g., New South Wales definition of flood hazard areas include projected flood zones in 2050 and 2100 from sea level rise (Australian Building Codes Board, 2012b) • EA interim guideline recognises climate non-stationarity in risk assessment for long-term projects, outlines process for incorporating climate change risks into decisions involving estimation of design flood characteristics (Bates et al., 2015)

	(Risk Assessment and Design Life; Interim Climate Change Guideline) (Geoscience Australia, n.d.)	
More intense tropical cyclones, wider areas exposed Projection: Greater proportion of high intensity storms (stronger winds and greater rainfall) (medium confidence) Greater proportion of storms may reach south of 25 degrees South (low confidence)	• BCA Volume 2 Acceptable construction practice, including for residential buildings) spanning roofing, fastening and materials etc for identified wind regions. Table 3.0.3b on design events for safety, and Table 3.0.1 wind regions (ABCB, 2019b) • AS 1170.2 Structural design actions - Wind actions (SAI Global, 2011) • AS 4055 – Wind loads for housing (SAI Global, 2012)	Effective regionalisation of tropical cyclones in current climate Incomplete • BCA and AS design wind speeds based on prevailing climate and post-event analyses, and not future scenarios • Specifications for protection of buildings up to a Category 4 cyclone • Wind driven water ingress from tropical cyclones not considered
Bushfires more intense and widespread Projection: Increase in average forest fire danger index and a greater number of days with severe fire danger (high confidence)	• BCA Vol 1 G5 Construction in bushfire prone areas adopts AS Bushfire Standard AS 3959 to improve fire resistance performance of buildings, including residential. Construction requirements depend on Bushfire Attack Level category (Australian Building Codes Board, 2019a; SAI Global, 2018)	Recent improvement but incomplete • Specifications that buildings maintain structural stability up to 240 minutes • Increasing intensity and spatial risks from climate change not fully addressed • Smoke from bushfires not considered (Hanmer, 2020)
Sea level rise and increased storm surge Projection: Sea level rise through 21st century (very high confidence), rises at faster rate in 21st century	• EA Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering (National Committee on Coastal and Ocean Engineering, 2017)	Not integrated in mandatory regulation • Coastal wave action or storm surge not considered in NCC • EA guidelines call for use of future climate change scenarios in sensitivity analysis and review of design assumptions

than last four decades (high confidence) Storm surges likely to increase non-linearly with sea level rise		

The NCC and AS are clearly based on historic data and seek to ensure the structural stability of buildings through wind and cyclone, rainfall, bushfire, and flood events under the prevailing climate (Con1; Ind5; Australian Building Codes Board, 2014). While the ABCB is confident that these provisions have delivered adequate resilience to date to ensure life safety (Australian Building Codes Board, 2014), evidence that climate change will exacerbate risks to buildings is not integrated in the NCC. This is increasingly problematic, as practices which manage current climate risk will not necessarily position communities to adapt to future climate (Dilling et al., 2015). It is only the voluntary guidelines of EA that explicitly address the non-stationarity of Australia's climate, and provide guidance for its integration into decision-processes. Interviewees across organisational types considered that the NCC needed to more deeply address climate change, with an industry leader stating that beyond 'the BCA not integrating climate change science, the data, hazard factors and structural loads currently used are not adequate for the environment a building might experience' (Ind5).

Several gaps in the climate change coverage of the NCC will, if not addressed, likely result in increasing impacts on buildings and occupants in the near-term. Heat stress is of concern as heatwaves can result in excess morbidity and mortality (Bi et al., 2011). Recent studies confirm many Australians are exposed to heat stress indoors, that indoor overheating during summer is mostly under-regulated, and that climate change will further increase the risk of indoor overheating (Hatvani-Kovacs et al., 2018).

The NCC also incompletely covers risks from tropical cyclones and bushfires. Wind-driven rain from cyclones can cause water damage to buildings, is projected to become more intense with climate change, and is not addressed in the BCA (Boughton et al., 2017; Miller, 2014). Most Australian houses and apartments are quite leaky by international standards, which proved problematic in the summer of 2019–20 as they failed to keep out fine particulate bushfire smoke that is damaging to human health (Ambrose & Syme, 2015; Hanmer, 2020; Vardoulakis et al., 2020). Further, while the ABCB considers that sea level rise and storm surge are better managed through land use planning (Australian Building Codes Board, 2014), this differs from how the NCC addresses other risks such as from flood and bushfire which have changing spatial footprints. Building exposure in coastal areas is increasing, and EA's guidelines for coastal engineering advise the use of climate change scenarios to review design assumptions for construction (National Committee for Coastal and Ocean Engineering, 2017). The gap between knowledge and regulation regarding physical climate change risks, and between minimum and good practice, can only be expected to increase should these coverage deficiencies continue (Ind4; Eng1).

2.5.2 Are SPPI components barriers to resilience outcomes?

Issues and challenges are evident in all components of the building regulation SPPI concerning climate change. This section elaborates on these and responds to research question (ii) on whether there are elements of the regulatory SPPI that constrain improvements to housing resilience. Key barriers identified are summarised in Table 2.2.

The future-orientation and levels of uncertainty that characterise climate change science challenge its use in both policy and practice (Moss et al., 2019). Engineers and industry consultants confirmed the building sector generally 'does not know how to use climate change data and risk information', and 'lacks understanding about the implications of changes in return periods which bring big risks of real concern to communities' (Eng1, 3; Con1). There is a 'disconnect in language, where climate change uncertainty and longer-term projected risks are often misunderstood' and excluded from short-horizon risk assessment or decision making (Eng1; Sci4; Con6). This aligns with a survey finding that some 85 per cent of Australian developers expressed little incentive to address climate change because the environmental impacts and costs occur beyond the timeline of development (Shearer et al., 2016). Not surprisingly, key information sources, such as the climate change in Australia website or knowledge of more rapid cement deterioration risks under climate change, are not being used by industry (Con1, 4, 6). Further, there are limitations in the available science relevant to industry, including on the regionalisation of climate information, the best projections data for use, and event return periods for high population areas (Con4; Sci2, 4). Overall, the climate change science interface with industry is poorly developed; industry is unaware of available science, and science is not engaging well with industry processes, including provision of suitable tools, education and interpretation (Ind5; Sci2, 4, 5; Con1, 4).

A lack of drivers for building regulation to connect with climate change science can largely explain the poor science practice interface (Ind4, 5, 6, 7). The goals of the IGA that frame the BCA relate to minimising impacts on safety, housing affordability, regulatory and compliance imposts on industry, and cost-effectiveness (Senate, 2018). The goal of the NCC is for efficient achievement of nationally consistent, minimum necessary standards; there are no explicit references to climate change. 'The ABCB is basically hampered with respect to climate change – it lacks a policy mandate from Building Ministers' (Ind5). Further, while the NCC claims to provide minimum performance levels for the sustainability of buildings (Australian Building Codes Board, 2019a), sustainability is not in the definitions section of the NCC and commonly understood dimensions of sustainability that span conservative resource use over intergenerational timescales, community well-being, the precautionary principle, and the need for proactive climate action, are not prioritised in the BCA (Australian Building Codes Board, 2019b). In contrast, EA's guidance is framed by a Code of Ethics that requires attention to sustainability and future generations, and a Climate Change Policy outlining engineers' responsibilities for climate change risk assessment, proactive action, and consideration of science advances (Engineers Australia, 2019; National Committee for Coasts and Ocean Engineering, 2017).

Following the NCC goals, elements of regulatory amendment processes make it difficult for climate change to trigger reform. Application of the Council of Australian Governments' Best Practice Regulation Guide requirements for quantified net societal benefits from any amendment result in use of historical data in post-hoc rather than anticipatory reviews (Council of Australian Governments, 2007; Productivity Commission, 2012; Senate, 2018), and downplay potentially catastrophic future risks with greater uncertainty. Similarly, approaches to cost-benefit analysis in Regulation Impact Statements (RIS) emphasise impacts that can be readily monetised, discount future risks from lower-probability events plausible within a building's design life, and rarely value resilience (Deloitte Access Economics, 2016; Productivity Commission, 2012). An expectation of consensus also means that amendments are slow. The Victorian Bushfires Royal Commission, for example, noted that the Bushfire Standard AS 3959 had been under review for 9 years before devastating bushfires in 2009 provided the impetus to complete it (Maddocks, 2011). The BCA has been described 'as a behemoth, like an oil-tanker running up to an iceberg that can't change its course' (Eng1).

In the context of climate change risks, building regulation policy does not currently support an effective SPPI. Administrative processes for NCC amendment allow for technical advice, but there is no requirement for the ABCB to regularly and transparently engage with scientists to understand increasing risks, or to assess the adequacy of regulatory settings in a changing climate. Climate change experts for example are not listed in the reference group which developed the 2012 ABCB handbook on construction in flood hazard areas (Australian Building Codes Board, 2012). Less than full transparency exists with ABCB determinations on the need for regulatory reform in response to risks of more intense tropical cyclones from climate change. In this case a 2010 finding of net benefit for reform was overturned following a further consultancy employing a different method that excluded a southward extension of hazard zones (a risk of low probability but potentially catastrophic implications) (Australian Building Codes Board, 2010b, 2014; CSIRO, 2007; Productivity Commission, 2012). Similarly, monitoring of outcomes of the 2019 Standard on NatHERS heating and cooling load limits (with an energy efficiency, and not future climate or heatwave, focus), identified in the ABCB's 2019–20 Business Plan to understand heat stress in residential buildings (Australian Building Codes Board, 2019d, 2019c), does not appear informed by resilience science. Parts of the building industry also seek to maintain a weak climate change SPPI, arguing against amendments to consider climate change (Ind5, 6; Housing Industry Association, 2017). 'Some powerful industry players oppose reform and have resources for advocacy'; 'they can present studies that narrowly highlight worst case potential cost outcomes and influence political leaders' (Ind2, 5, 7).

Again in contrast to the NCC and AS processes, EA in their development of guidance engaged openly and substantively with the climate change science community. Recognising significant risks from changing rainfall patterns and floods for construction, EA established a multi-year work program to update the Australian Rainfall and Runoff Handbook (AR&RH) in partnership with scientists. An agreed work program included 20 multi-year research projects to clarify changing climate risks, better understand uncertainties, define effective methods, and develop guidance products (Geoscience Australia, n.d.). Further, the technical committee established to develop interim guidance on climate change for AR&RH included independent members from the climate science community. The interim guidance has been described as 'good, simple to use guidance, with clear assumptions' (Con1). 'The process got the right people together – it recognised that planning and decision-making continue with science uncertainty' (Con2).

Without a policy requirement for housing resilience in a changing climate, industry practice has bifurcated. A forward-looking group delivers to triple bottom line performance and networks to enhance leadership and innovation, and another group of industry organisations and companies deliver to minimum standards within short construction horizons and resist change (Con1, 2; Ind3, 5). In large, industry practitioners rely on experience from past developments and market analysis with a five year backwards-looking span (Con1; Ind5). Most practitioners do not engage with scientists but obtain advice from consultants, aren't aware that the NCC is based on historic data, and do not undertake professional education on climate change (Ind4, 5; Con1, 2). Views that ensuring housing resilience to climate change will be cost-prohibitive are also common in the building industry (Ind5). Further, weaknesses in compliance and enforcement mean that, for example, standards to address risks to housing may not be strictly followed, resulting in potentially costly implications during or after the build (Ind5; Shergold & Weir, 2018; STA Consulting Engineers, 2020).

Table 2.2. Key SPPI barriers to Australian building regulation enhancing climate change resilience.

SPPI component	Barriers to resilience and adaptation
Science	• Uncertainties on future risk profiles from diverse scenarios inhibit integration in policy and practice. • Science gaps on how climate change affects prescriptive risk parameters (such as 1:100-year design events) impact on perceptions of salience. • Knowledge of cost-effective pathways to climate change resilience immature. • Long-term climate change risks perceived beyond horizon of building and construction decision-making. • Science agencies acting in contractual mode limits proactive research or engagement on wider public good issues (Sci4, 5; Ind5, 6; Con2).
Policy	• Goals narrowly defined on historic health, safety and risk provide no mandate to comprehensively consider climate change. • Minimum standards fail to incentivise and drive uptake of innovation for resilience or adaptation (Ind4). • Regulatory amendment processes with strict requirements for quantified costs and benefits constrain consideration of intergenerational or systemic climate change risks. • Siloed progress of high energy efficiency standards can adversely affect resilience and occupant comfort. Trade-offs need to be understood. • Weak compliance and enforcement a disincentive for good practice. • Drivers for ongoing climate change science engagement and learning, such as from formally established knowledge co-production mechanisms, are lacking. • Development sector powerful; some influential groups oppose change.
Practice	• Little engagement with scientists in mainstream industry.

	• Capacity gaps in accessing and translating future-oriented climate change science into practice. • Assumptions that enhancing resilience will be cost prohibitive, and customer demand limited. • Institutions reinforce practice based on experience, with deeply embedded supply chains and a lack of incentives for reform for resilience. • Learning opportunities limited – general industry reliance on consultants for advice, and no requirement for accredited professional climate change training.

Nevertheless, interest in responding effectively to climate change is growing in the building sector. Collaboration among progressive industry organisations in Australia and with government departments and research agencies is increasing, and lessons can be learned from current reforms into energy efficiency. The Australian Sustainable Built Environment Council, for example, demonstrated the net benefit and significance of low carbon outcomes from aspirational standards, and supported governments improving the energy performance of commercial buildings in the National Energy Productivity Plan (Ind4, 5; Australian Sustainable Built Environment Council, 2018). Development of the guidance by Engineers Australia and a new Green Star voluntary rating tool on resilience by the Green Building Council of Australia, which includes more robust physical risk assessment and community-scale considerations, were also informed by practitioner experience in building performance in extreme events such as tropical cyclones (Eng2; Ind6). Feedback from residential end-users is also influencing practice as leading companies are surveying residents to find that liveability matters, and engaging with science on how yield, investment return, and sustainability objectives can be met simultaneously (Ind4). Uptake of the Green Star rating tool being developed for homes will likely generate further insights into how resilience outcomes can be cost effectively realised, and increase awareness across the sector (Con4; Ind6).

2.6 SPPI informing reform of building regulation

This paper demonstrates the value of a strong climate change SPPI in building regulation for societal resilience in a changing climate. Buildings are climate-sensitive, and their regulation in Australia depends on science knowledge for performance in particular climate regimes that currently excludes climate change. Regulation is framed by policy that de-prioritises climate change to other societal goals, and implementation through practice reflects policy settings as well as knowledge from professional networks and experience. The social processes or SPPIs that link science and practice are thus important to bridging the disconnect between knowledge and prescriptive regulatory measures, and to addressing foreseeable risks to buildings from climate change.

There is increasing scholarship on climate change and building regulation, with recent studies identifying barriers to climate change adaptation (Hurlimann et al., 2018; Warren-Myers et al., 2020), assessing regulatory systems or industry structures and their capacities for reform (Eisenberg, 2016; Shearer et al., 2016; Visscher et al., 2016), and exploring solutions to specific or emerging challenges from climate change (Hatvani-Kovacs et al., 2018; Sun et al., 2016). Through an SPPI lens, this paper extends this scholarship to provide a more nuanced understanding of how regulation can facilitate practice to build resilience, particularly through attention to the processes that connect with science and policy. There is potential for appreciation of the multi-dimensional nature of barriers to resilience within a regulatory framework to inform approaches that can help address the adaptation implementation deficit (Visscher et al., 2016). More specifically, this paper can inform research and practice in two key areas:

- Understanding the nature and significance of barriers to adaptation: Regulation can be a barrier to or enabler of climate change science uptake (e.g., Waters et al., 2014). Exploring the features of regulatory SPPIs provides insights on this duality and the operation of specific barriers. For instance, regulatory barriers can arise from a failure to update specifications to reflect a changing climate, from processes that ignore changing science, or from deficiencies in accessed science that underestimate risks.
- Targeting regulatory reforms for climate change resilience: Assessment of the SPPI components and the strengths or gaps in their interfaces provides a well-founded basis for targeting reforms in building regulation. Appreciation of the science embedded in policy, and its assumptions and limitations, is critical for such targeting. Further, a focus on how the regulation and its policy framing drive the requirement for use of information, and allow for engagement with climate change science, highlight that a focus only on provision of salient science, as may occur through traditional SPPI approaches, will likely be ineffective.

Weaknesses across all three components of SPPIs are found that act as barriers to building regulation integrating science and addressing resilience. The result is a disconnect between science and practice which could see increases in risks with disastrous consequences (Eng1, 3; Sci3). Little confidence can be placed in the ABCB finding that the BCA is adequate for future climate hazards associated with a low emissions scenario (ABCB, 2010a), as some recent extreme weather events in Australia have exceeded the worst-case projection for 2070 (Bates, 2017). Policy barriers appear to be the most significant in the climate change SPPI for building regulation. The framing of policy goals obstructs processes that could link climate knowledge to understandings of policy adequacy or incentivise practice to address future risks. This aligns with findings that a strict application of the COAG RIS process limits the scope for climate change projections to be considered when assessing changes to the BCA (Productivity Commission, 2012). Current policy framing has limited practitioner and community awareness of potentially unacceptable future outcomes for housing with climate change, including for occupant health and well-being.

Four key reform areas for the building regulation SPPI that address identified barriers and can enhance its capacity to achieve resilience outcomes are proposed from this analysis:

1. Amendment to IGA and NCC goals. Explicit incorporation of enhancing resilience for climate change in the sustainability goals of the NCC, and a requirement for the design and construction of buildings to consider future climate risks, is critical to addressing gaps in the regulation and deficiencies in processes for amendment and science engagement. This will require inter-jurisdictional agreement through the Building Ministers' Forum which will take time. In the interim guidance should be co-developed by officials and scientists on the interpretation of sustainability to include climate change, and on steps to practically consider the systemic and intergenerational dimensions of physical climate change risks and value resilience outcomes in amendment processes.
2. Comprehensive and transparent assessment of the NCC and associated standards regarding housing exposure and vulnerability to future climate change is needed to underpin regulatory reform. Assessment using an 'assess-risk-of-policy' approach to climate change scenarios can address limitations of 'predict-then-act' approaches, widely used in risk assessments and cost benefit analyses, that depend on initial robust characterisation of risk and uncertainty (Ind4; Lempert et al., 2004). Barriers to science use can be overcome through methods that focus first on the sensitivity of available policy options, and second on uncertainties associated with the options.

Regulatory amendment strategies can then be identified that are underpinned by science, robust against most risks, and recognise residual risks.

3. Co-production partnerships are needed to strengthen the currently weak interfaces between knowledge producers, policy developers and practitioners. Partnerships spanning science, industry, community, insurance, emergency management, regulator and policy interests can address knowledge and process deficiencies, including for iterative and agile approaches that embed science and design pathways towards resilience (Sci4; Ind5). Commitment and investment will be key to maintaining partnerships with capacities to help reform regulation amendment processes, practitioner guidance on risk, uncertainty and resilience pathways, and learning networks that can drive uptake of resilience practice. Importantly, mechanisms need to be co-developed for regulation to recognise and incentivise best practice (Con1, 2, 4, 5; Ind1, 2, 4, 5).
4. Tailored accessible science is needed for resilience solutions, with priorities driven by knowledge gaps about key risks, and climate-based prescriptive regulatory measures that need updating. Better estimation and scenarios are needed of possible high impact (and not just most likely) changes in the climate system, changing risks relative to design events, safety factors and risk zones, and compound event risks (Sci2, 4, 5; Eng1, 3; Con1, 4). Industry leaders are also seeking greater engagement with scientists on approaches to operationalise risk and resilience in a changing climate (Ind2, 5). One coordinated source of credible and accessible information is preferred, and there are concerns that 'Australia is now far behind other countries like the UK where tailored data and training in its use are freely available' (Con2, 5; Eng1, 3; Ind3, 4). Investment in improving knowledge of physical climate risks needs to be proportionate to the scale of increasingly exposed housing, and the potential for damage and loss, and impacts on health and well-being.

Beyond the regulation itself, society needs to have confidence in the robustness of building practice. An open national dialogue supported by practitioners and scientists is needed to enhance community and industry understanding of climate change risks, and the interactions and trade-offs between building resilience, the costs of stronger regulation, and likely damage and maintenance liabilities. The growing mismatch of interests between regulatory efficiency goals, and community concerns about property durability, recovery following disruptions, and occupant health and well-being, requires a proactive shift towards resilience. Such a dialogue could draw on insights from leading practice in the sector, and lessons learned from proactive shifts in disaster risk management towards preparedness from recovery, the incorporation of future risks in spatial hazard planning, and anticipatory approaches being developed by the finance sectors. The 2015 Australian Infrastructure Audit report also calls for 'a national debate about reform' of infrastructure decision making system to increase resilience in the face of increasing extreme weather events (Infrastructure Australia, 2015).

2.7 Conclusion

This paper demonstrates the value of a SPPI lens for analysing how building regulation can support climate change resilience in Australia. Conventional regulatory processes assume a static climate, and typically operate to restrict focus on longer-term future risks, particularly where uncertainty levels are high. This case study found that the framing of goals in Australia's mandatory building regulation subordinates climate change, and constrains the capacity of processes and practitioners to understand and act on changing risk profiles. Further, gaps in readily accessible science that relate to regulatory provisions on safety and structural stability point to the need for more proactive and cross-disciplinary knowledge co-generation. The paper identifies reforms to the regulatory SPPI so that national regulation can recognise a dynamic climate, benefit from co-production of knowledge and effective implementation processes, and address the mismatch between narrow efficiency goals and wider societal concerns regarding resilience and wellbeing. Institutional reforms are needed as the regulatory deficiencies are not just technical failures in the operation of the SPPI. More widely, a similar disaggregated analysis of regulation as a SPPI could be transferable to reform design processes in other countries, such as IRCC members, where building codes are yet to comprehensively engage with and respond to significant physical climate change risks.

Importantly, the case study also identified the existence of 'grey rhinos', a metaphor for missing the big, obvious things that are coming at you (Wucker, 2018), in this case foreseeable risks to housing and home occupants that are not being considered in relevant regulation. Key among these in Australia are the risks to human health of more intense and frequent heatwaves, from prolonged bushfires of the extent and intensity of the 2019–2020 summer, and from likely increasing damage to buildings from more intense rainfall associated with tropical cyclones or east coast lows. The paper also adds weight to research findings which question the adequacy of minimum standards in building regulation in the context of increasing risks from climate change, and that recognise that a lack of science embedding in policies and practice can constrain adaptation action.

While the role of the finance and insurance sectors, disaster risk management, and leading building companies in responding to climate change and linking science to practice were not substantively considered in this paper, there is a need for further research to explore lessons learned from their more successful SPPIs in driving reforms of relevance to resilient housing. Further investigations are also needed to support a more informed dialogue on the implications of changes in the building code in a changing climate for housing and insurance affordability, land use planning, and social liabilities. A systems perspective is particularly relevant to such investigations recognising the high levels of interdependencies in the built environment. It is now urgent to ensure that the scientific confidence in climate change trends and resilience knowledge can incentivise the reform of policies and regulatory settings to ensure that building structural stability and human well-being are not sacrificed for the prioritisation of cost-efficiency goals.

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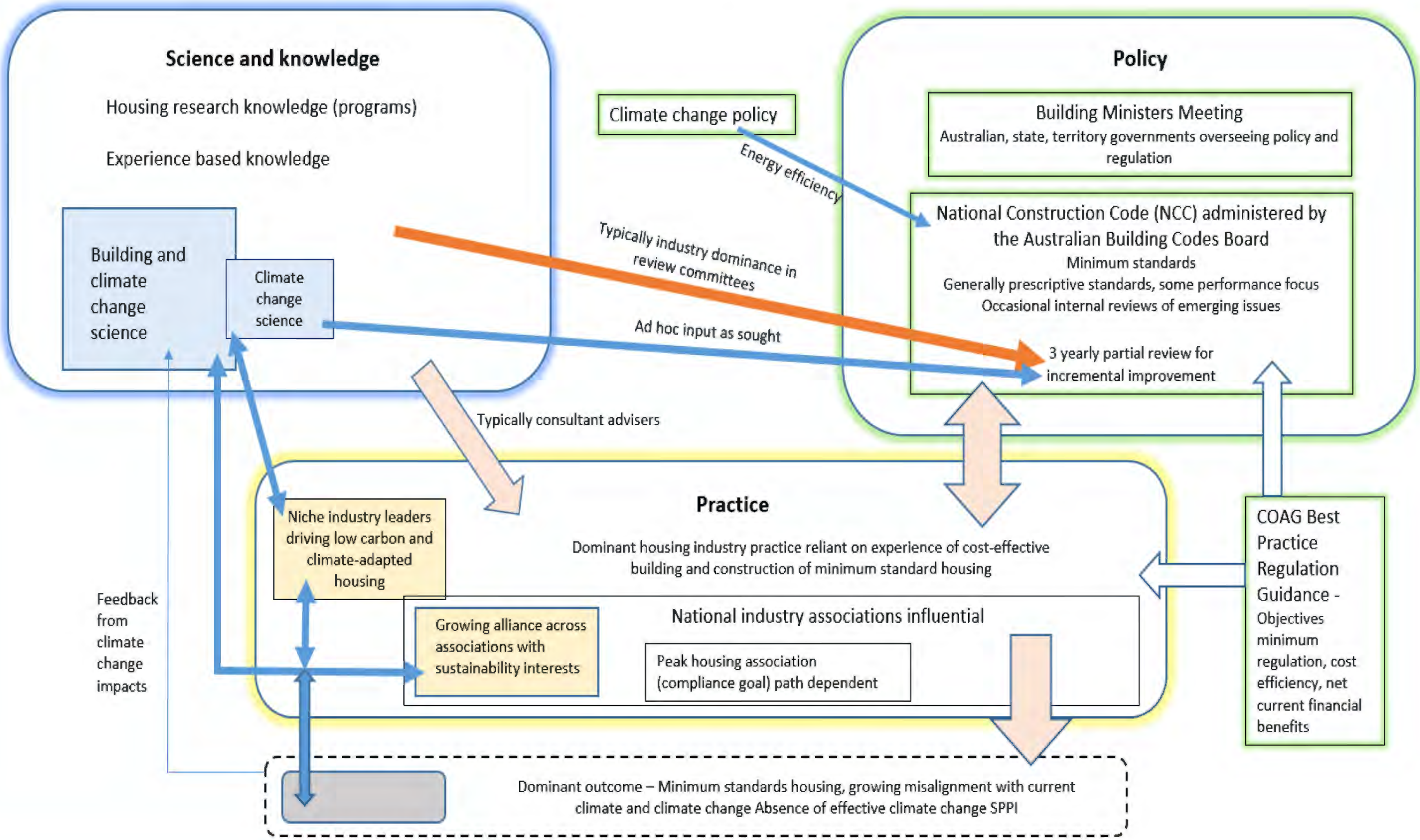
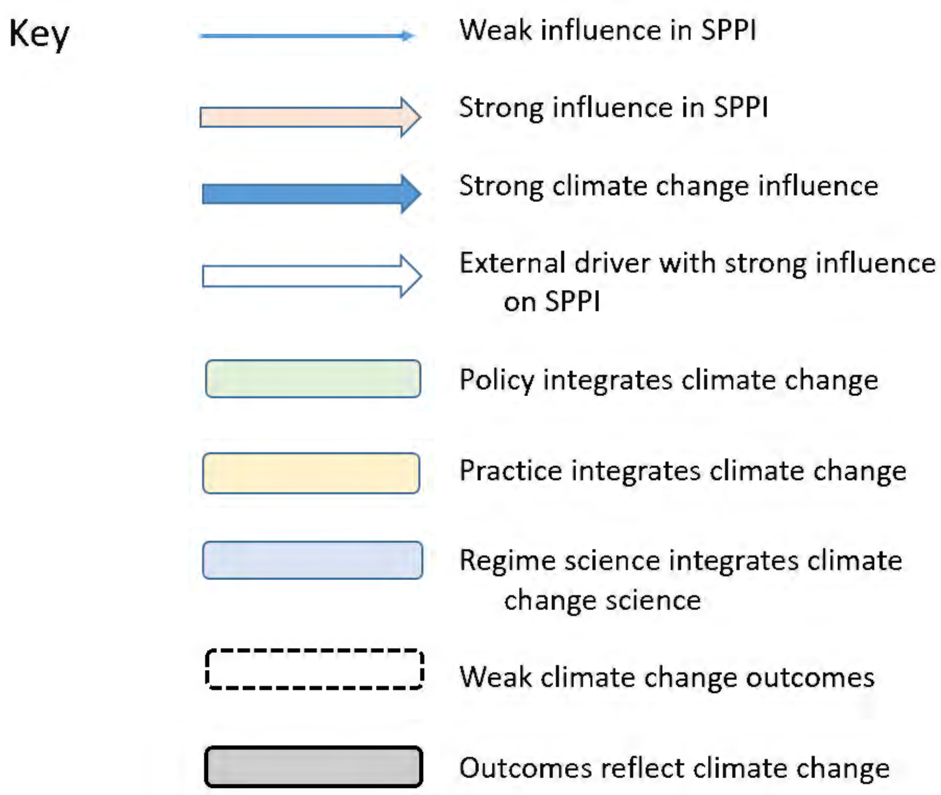
Annex Chapter 2. National housing regulation – climate change SPPI




Key
Weak influence in SPPI
Strong influence in SPPI
Strong climate change influence
External driver with strong influence on SPPI
Policy integrates climate change
Practice integrates climate change
Regime science integrates climate change science
Weak climate change outcomes
Outcomes reflect climate change

Chapter 3

Environmental integrity of forest offsets in a changing climate: Embedding future climate in Australia's sinks policy regime

Abstract

Forest carbon sinks are important to Australia's climate policy, and recent government and business net zero commitments will likely increase demand for forest carbon offsets. At the same time, forests in parts of the country have suffered from prolonged drought and bushfires, and a growing body of research suggests that future climate change could have significant implications for forest carbon sinks' permanence. This article draws on expert views to explore how incorporating knowledge on the physical risks from climate change can strengthen the environmental integrity of Australia's forest sinks policy. It finds challenges to and opportunities for strengthening the science, policy, and practice interfaces for forest carbon in a changing climate, and proposes reforms to strengthen the capacity of forests to be a long-term contributor to Australia's emission targets and climate adaptation policy. These reforms may have relevance to other countries with vulnerable forests and interests in forest carbon offsets.

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3.1 Introduction

Forest sinks have contributed to Australia cost-effectively meeting (modest) national emissions reduction targets and participating successfully in international climate change treaties and mechanisms (Hamilton & Vellen, 1999; DISER, 2021). The urgency now for rapid and substantive cuts in greenhouse gas emissions to avoid dangerous climate change requires national emission reduction policies to have high environmental integrity and effectiveness. Robust accounting, underpinned by scientific evidence, is a prerequisite for ensuring environmental integrity. In particular, scientific knowledge is critical for the establishment of baselines, to understand the nature of risks and how management practices affect sequestration, and to inform management for the sustainability of sequestered carbon, all of which contribute to meeting integrity standards of additionality, permanence, and the avoidance of leakage (e.g. Baker et al., 2010; Verkerk et al., 2020). The focus of this article is on permanence, which ensures the credited carbon reductions endure and deliver carbon benefits over timeframes relevant to the atmospheric life of greenhouse gases.

Recent research on climate change and forest carbon sequestration suggests considerable risks to Australian forest carbon sinks this century, which could result in impermanence in parts of the sinks estate and challenge risk management approaches (Bennett et al., 2020; Roxburgh et al., 2020). Such science indicates that knowledge of future climate change needs to be robustly integrated into Australia's forest sinks policy, and into private company and land management practices incentivised by that policy, for their enduring integrity. While physical risks to forest sinks from climate change are noted in numerous studies, relatively little research examines how to integrate future climate into relevant policies and initiatives (e.g. Nolan et al., 2018). Addressing this gap is timely as many forest sinks projects supported by the Australian Government's climate policy are in regions with lower and less reliable rainfall, which could face greater water constraints and challenges to sequestration in the future (Fleming et al., 2019; CSIRO & BoM, 2015).

This article addresses this gap through two research questions: (i) How can the growing knowledge of future climate change be robustly integrated into policy and practice for forest carbon sequestration in Australia?; and (ii) What reforms, if any, are needed to enhance Australia's science-policy-practice interfaces for forest sink permanence in a changing climate? The focus of the research is on Australian Government policy and initiatives, reflecting the sphere of government with responsibility for international treaties and national emissions reduction measures, including those that encourage private action.

Further context regarding Australia's forest sinks policy, the state of knowledge on likely climate change impacts on forests, and key practitioners engaged with the policy is in section 2. Semi-structured interviews with experts from each of these science, policy and practice cohorts provide the key data source to explore the research questions, and section 3 describes the qualitative thematic analysis approach taken. Section 4 then provides the thematic results of the study, and section 5 discusses the results of this analysis with regards to the research questions and draws on these findings to propose reforms that would enhance the environmental integrity of national policy and climate-adapted implementation in a changing climate. These findings may have wider relevance, as forests continue to be important in global climate change initiatives, such as in the allowance for offsets in multilateral market rules under the Paris Agreement agreed in the 2021 Glasgow Climate Pact, and in national inventories and action by countries and businesses seeking forest offsets to help meet net zero targets.

3.2 Context

3.2.1 Government policy and initiatives

The importance of land use change and forestry to Australia's emissions profile and climate change policy is illustrated by the nation's reliance on a substantial drop in emissions from forest clearing in the 1990s to meet the Kyoto Protocol's first commitment period (2008-12) target, and in studies which identify a potential for low-cost increases in carbon in the landscape to offset a significant proportion of total national emissions (Hamilton & Vellen, 1999; Garnaut, 2008; Bryan et al., 2015; Mace & Hare, 2019; Pears & Baxter, 2019). To realise these opportunities, Australian Government initiatives have improved land sector carbon accounting through a National Carbon Accounting System and funding of a cooperative research centre on greenhouse accounting (1999-2006), built the capacity of farmers to earn carbon credits through the Carbon Farming Initiative (CFI, 2011-2015), and, since 2014, incentivised new emissions reduction practices and technologies through the Emissions Reduction Fund (ERF, which absorbed the CFI).

The ERF, with funding of some AUD 2.4 billion at September 2020, is a key national emission reductions measure (CCA, 2020; DISER, 2021). Through the ERF, registered projects that comply with an approved method can earn Australian carbon credit units (ACCUs) for emission reductions, each equivalent to one tonne of carbon dioxide emissions avoided. Most emission reductions and ACCUs issued under the ERF come from vegetation management, particularly from methods that credit carbon storage from regrowth of vegetation (HIR, human-induced regeneration) or from preventing land clearing (avoided deforestation) (CCA, 2020). Typically, the methods that guide ERF projects are regulatory technical documents that prescribe requirements for project eligibility, forest biomass estimation, and monitoring and record keeping (CER, 2021a). Several methods indicate that total carbon stocks are to be estimated using the modelling tool FullCAM (Full Carbon Accounting Model) (Richards & Evans, 2004), supported by specified measurements and equation sequences to determine project stocks and emissions. The methods rely on historic and current, as embedded in sequestration, climate data. Risks to the permanence of collective ERF sinks are managed by the government through the risk of reversal buffer (effectively a flat 5 per cent 'tax' applied to all carbon payments), the 25- or 100-year permanence requirements, where a further 20 per cent reduction in ACCU payments is applied to projects that select the shorter timeframe, and the need to restore losses from fire or other disturbances. The government and other credit purchasers also pay for credits based on audited measurements of achieved sequestration. Beyond the ERF, voluntary action by businesses, including in offsets, is supported through Climate Active guidance and standards for carbon neutral certification (DCCEEW, 2022).

With the election of a more progressive Labor government in 2022, the ambition of Australia's climate change policy has increased with national 2030 and 2050 targets now enshrined in legislation (Albanese & Bowen, 2022). An independent review of ACCUs is also underway, following concerns raised about aspects of the ERF, with a goal to ensure the integrity of ACCUs and the ongoing strength and credibility of the scheme (Bowen, 2022; Macintosh et al., 2022).

3.2.2 Impacts of climate change

A growing body of research exploring climate change impacts on forest sinks is highly relevant to the ERF, as the majority of HIR and avoided deforestation projects are in semi-arid regions with lower and less reliable rainfall (Fleming et al., 2019; Nolan et al., 2019). These research findings need particular attention, as emissions reduction policies in Australia are developed separately from climate change adaptation policies (DISER, 2021). Climate change impacts research builds on well-established knowledge that climate and climate variables shape the broad-scale nature, distribution and diversity of forests in Australia (Engelbrecht et al., 2007; Gordon et al., 2018; Bennett et al., 2020). The vulnerability of particular forest types to the variability and extreme weather events that characterise Australia's climate, and the capacity of those forests to lose carbon stocks in such events, also have a long research history. Drought is well understood as a cause of tree die-off; Australian studies in diverse regions have recorded drought-induced forest dieback mortality rates of 18-30 per cent (Matusick et al., 2013; Silcock et al., 2016; Fensham et al., 2019). High temperatures and heatwaves have been implicated in canopy, stem and plantation mortality in more temperate and higher rainfall regions (Butt et al., 2013; Matusick et al., 2013; Ruthrof et al., 2018; Roxburgh et al., 2020). High intensity wildfires can also reduce the regenerative capacity of forests and increase the likelihood of future severe fires in southern Australia (Fairman et al., 2019; Collins et al., 2021).

Climate change projections reveal that extreme weather events could occur more often, and several studies project declining forest carbon sequestration rates that may exceed or challenge ERF risk management mechanisms (CSIRO & BoM 2015; Hobbs et al. 2016; Gordon et al. 2018; Roxburgh et al. 2020). Mitchell and colleagues (2014) found droughts capable of causing significant tree mortality could increase from 1 in 24 years to 1 in 15 years by 2050, accompanied by a doubling of associated heat waves. With semi-arid woodlands already experiencing temperatures up to 46°C, warming in coming decades is highly likely to exceed known thermal tolerance ranges (48 to 54°C) and increase mortality rates (Curtis et al. 2014; Nolan et al. 2019). Climate change is now also challenging the assumption that post-fire regrowth will fully re-sequester carbon as the severe fire events of the 2019-20 summer burnt traditionally wet forests that lack epicormic resprouting capacities, and shorter inter-fire intervals can increase the risk of woody plant extinction in regions likely to become hotter and drier (Enright et al. 2015; Roxburgh et al. 2020).

Collectively, forest extent could contract in some regions as a result of climate change, with lateral and poleward range shifts for open woodland and subtropical forest species likely (VanDerWal et al., 2013; Keenan, 2017). Scenario-based estimates find a 20-40 per cent loss of the eucalypt climate space in open woodland regions under mid-range or high climate scenarios (Butt et al., 2013), and that 20-50 per cent of sequestered abatement could be lost by 2050 because of climate change (Roxburgh et al., 2020). The national climate change and biodiversity assessment recognised that the climate change underway could equate to the magnitude of temperature shift since the Last Glacial Maximum, which resulted in landscape-scale biome shifts (Steffen et al., 2009). Beyond such shifts, considerable regional variability can be expected from climate change impacts, knowledge gaps remain, and it is possible that under some conditions sequestration could increase (e.g. Battaglia & Bruce, 2017).

3.2.3 Changing regime actors and needs

The forest sinks regime is also changing in Australia. Forest sequestration measures initially targeted farmers through the CFI, with landholders offered an additional income stream that could diversify traditional agricultural businesses and deliver environmental services. In part triggered by the 2015 Paris Agreement, private investment in forest offsets has dramatically increased in recent years, particularly from fossil-fuel intensive companies. In Australia, corporate partnerships established in 2020 alone include between Greening Australia and oil and gas producer Woodside, with offsets central to Woodside's plans to reach net zero by 2050, and between advisory firm Pollination Group and global banking giant HSBC to facilitate up to US$3 billion (AUD$4.15 billion) in 'natural capital projects' including to sequester forest carbon (Mazengarb, 2020). Shell Australia also acquired Select Carbon in 2020, an Australian company managing a carbon farming portfolio over 9 million hectares (Shell Australia, 2020). With features attractive to private investment such as redeemable ACCUs, adequate governance, and some 85 million hectares of cleared land, commitments of the Business Council of Australia and global mining companies BHP and Rio Tinto, among others, in net zero targets by 2050 could substantially increase investment in carbon offsets in Australia (e.g. BCA, 2021; Bryan et al., 2015).

While privately created sinks contribute to Australia's target, new private actors bring considerable resources to offsets that are not subject to national methods, and debate continues on whether voluntary carbon markets align legitimately and credibly with the architecture of the Paris Agreement (e.g. Kreibich & Hermwille, 2021). Policy on climate change, in turn, emerges from dominant narratives and discourses, rather than objectively weighed evidence, and is influenced by powerful actors (Shanahan et al., 2011; Langston et al., 2019). It seems apparent that science needs now to find ways to engage with those actors to facilitate the uptake of climate change knowledge in policy and practice, with ultimate benefits for investors, project participants, and national and organisational targets.

3.3 Method

With improving climate change impacts knowledge, the strengthening of Australia's forest sinks initiatives requires, it would seem, better coherence of policy goals and settings, and implementation practices, with this scientific evidence. It is argued here that such coherence depends on inclusive science-policy-practice interfaces (SPPIs), which can facilitate knowledge co-generation for problem solving through iterative engagement across inter-related policy, science, industry end-user and other stakeholder actors and organisations (e.g. Van Enst, 2014). In the Australian context, a forest sinks SPPI would link the following stakeholder groups. The national government is a dominant actor with responsibilities as described in section 1. Industry practitioners, particularly carbon brokers that deliver forest sinks projects, are also key actors, and as noted there is growing investor interest in offsets from fossil-fuel intensive private actors. Science actors span forest researchers with understanding of the climate-sensitivity of forest types and how forests are impacted by extreme weather events (Burke, 2016; Bennett et al., 2020; Keenan, 2017; Roxburgh et al., 2020), and climate science researchers with understanding of likely changes in Australia's climate (CSIRO & BoM, 2015).

With this framing of SPPI actors, interviews were sought with experts from each of these stakeholder groups to explore their perspectives on (i) how future climate change knowledge can be robustly integrated into Australia's forest sinks policy and practice, and (ii) what reforms, if any, are needed in Australia's SPPIs to enhance forest sink permanence in a changing climate. The resultant one-on-one semi-structured interviews provided the data for analysis in this research (Yin, 2014). Interviewee selection was purposive, based on identifiable expertise to illuminate the operation and needs of Australia's national forest sink initiatives in a changing climate. The use of internet searches of senior people in relevant organisational structures, professional networks, and the snowball technique, resulted in 17 interviewees from science, government policy and regulation, and industry and land management organisations, each with significant seniority and expertise on the forest sinks regime. Most interviewees had work histories far exceeding a decade in the field, and all had experience working in partnerships across research, government, and industry. Difficulties were experienced in engaging with and getting responses from the large fossil-fuel intensive companies investing in forest sinks, and several government and research potential interviewees who had agreed to participate unfortunately withdrew, indicating problems from COVID-19 on work pressures or family health. Interviews were conducted in person or by Zoom videoconferencing between January and October 2021, with each interview lasting from 40 to 85 minutes. Interview questions were informed and tailored by a review of scholarly and grey literature on forest sinks and climate change impacts, and organisational roles and activities from agency websites. Interviews were recorded where research participants agreed. An overview of research co-participants is provided in Table 3.1.

Table 3.1. Research participants.

Research co-participant categories	**Number**
Science	8
Industry (carbon broker)	4
NGO land management	2
Government and regulator	3
Total	17
Participants with sub-national focus	2
Researchers with 10+ years of experience of science-policy	15

Interview data were then analysed using a thematic analysis approach, which can help reveal themes and patterns in a dataset focused on a generalised topic (e.g. Braun & Clarke, 2014). The thematic analysis proceeded according to the following steps: (i) familiarisation of the content in the interview records, (ii) identification of possible themes, including where supported across organisational categories, and (iii) review and finalisation of themes. Thematic findings revealed strong awareness of climate change challenges and opportunities for forest sinks initiatives (elaborated further in section 4 and Table 3.2), and a consistent call for reforms to enhance the SPPI for the long-term sustainability of forest sinks in a changing climate (elaborated further in section 5). Importantly, the themes identified were supported by experts across organisational categories. Analysis of documents identified in the literature review was also undertaken to corroborate and enhance the validity of identified themes from the interview data, through checking the broad coherence of the results with existing documentary analysis or research findings (Yin, 2014). Some verbatim quotations from the interviews are incorporated into the analysis to illustrate and support the interpretations made (Sandelowski, 1986). Participant views are attributed in citations according to organisational categories, notably industry (Ind), science (Sci), land management (Lm) or government (Gov), and are cited in the following style (Ind1 or Sci3).

3.4 Results

Five themes emerged from the thematic analysis and were supported by interviewees from more than one organisational category. The themes, described further below, are that (i) policy and methods need reform to reflect a changing climate; (ii) regime collaboration mechanisms are weak; (iii) prescriptive methods constrain science uptake and innovation; (iv) industry and practitioner leadership is strengthening; and (v) motivations are diverging across the regime.

3.4.1 Policy and methods need reform to reflect a changing climate

The majority of participants identified the impacts of climate change on carbon stocks and sequestration across Australia to be an important issue that needs central consideration in forest sinks policy and methods. All science, industry, and NGO participants assessed the current knowledge of climate change impacts to be adequate for its integration into policy and management. In particular, with regard to the application of science, participants argued that understanding of the direction and magnitude of change for many forest systems is robust for risk and uncertainty assessment of the bounds of possible future sequestration rates, and capacity can be increased now to incorporate climate change science into sequestration methods (Sci1,7,8).

That forests are responding to a climate that has already changed, and is projected to change further in ways that could negatively impact carbon stocks and forest extent, was understood by participants as revealing a need for improved collaborative approaches to learning and reforming policy. Multiple examples were provided of observed forest change exceeding envisaged impacts. For example "we are seeing widespread tree stress and death from drought and heat in many regions", bushfire impacts were 4-fold greater than the worst case risk assessment scenario, and some "drought-stressed forests are unable to recover after fire, even after a year" (Sci1,5,7). Further, "most productive forests were previously considered too wet to burn frequently; this is changing and in the future we could see loss of carbon dense forests with big changes to carbon stocks" (Sci5). The sharing of this experience, along with retrospective climate study findings, was seen by science participants as critical for robust risk assessment involving climate change scenarios, and user-relevant regional risk knowledge. The uptake of such knowledge in policy and methods for HIR projects was identified by many interviewees as having urgency, as such projects are typically located in areas with lower and less reliable rainfall, where regeneration potential is predominantly weather-dependent.

Beyond experiential learning, participants across industry, NGOs and science communities identified the need for greater knowledge on a) the capacities of forests to cope with multiple impacts, b) when such impacts will be tipping points for forest structural or ecosystem change, and c) how the spatial distribution of major risks will change (Ind2; Sci2,3,6). Accessible, decision-ready knowledge, however, was described by participants as requiring incentivising policy, mechanisms and resourcing (these issues are further explored in section 5). In this context, concern was also expressed by science participants that the strong research programs in the 1970-90s that built knowledge of species-specific responses to drought, heatwaves and elevated CO_2 conditions of future climates no longer exist. This lack, without address, will impact on knowledge generation for future management.

3.4.2 Regime collaboration mechanisms weak

Most participants linked the environmental integrity of forest sinks policy to science-based accounting, and adaptive and anticipatory learning and management in the context of climate change. However, both research and industry participants identified weak interconnections with government as a problem for policy development and implementation. Leading carbon brokers in Australia, managing extensive areas for forest sinks, expressed frustration with formal collaboration mechanisms, indicating for example that "the Government has the right rhetoric on co-design and partnerships, but these are slow to evolve; the reality is that industry is not consulted early and has little capacity to actually influence methods" (Ind1). Further, government-organised "workshops with lots of people often don't get to the crux of key issues; the politics seems to be taking over and the science gets subordinated in methods discussions" (Ind2). Research and industry participants identified a deficiency in national scale conversations between scientists and [non-carbon] forest managers, further seeing this deficiency as limiting the development of a shared understanding of the significance of climate change for forest growth and the identification and uptake of opportunities for knowledge co-production.

Contributing to this weak interface, several participants stated that technical capacities regarding evaluation and incorporation of scientific evidence in policy and ERF methods have declined in the national government (Ind1,3; Sci1). The agency1 responsible for the ERF was perceived by several participants as having a huge turnover of staff, and not enough ongoing knowledge (Ind2; Sci2). Consequent weaknesses in audit processes, including in feedbacks to methods development, were identified by participants across regime domains (Ind3; Sci3; Gov3). Further, research and industry participants identified that Government-provided tools are also starting to lose currency: "the last FullCAM update by the Government was suboptimal, based on poor consultation and not drawing on all the best data" (Ind2,3).

3.4.3 Prescriptive methods constrain science uptake and innovation

Weak collaboration has also resulted in rules-based and prescriptive ERF methods which were perceived by industry participants as inflexibly focused on details, with poor capacities to cope with change, including for climate-sensitive local implementation (Ind1,2). That current prescription constrains consideration of climate change was raised as a concern by both industry and science participants. Challenges discussed included that the version of FullCAM available for use in methods, for example, assumes landscape carbon neutrality which is not valid in changing environmental conditions, and does not draw on climate change scenarios (Ind2,3; Sci5). Carbon broker participants argued that other models should be able to be leveraged that better meet the criteria and address appropriate uncertainties (Ind1,3).

Prescriptive methods were also described by participants as inhibiting cross-regime dialogue on emerging technologies that could enhance implementation (Sci1,6). Technologies such as air seeding of vegetation, techniques to increase soil moisture retention, high-resolution remote sensing and drone data and surveys for monitoring and verification, may deliver the outcomes sought, useful datasets, and potentially reduce compliance costs, but are prevented by specified methods (Ind1,2; Lm1; CMI, 2021b). As explained by a science participant, with climate change "our forests are moving into uncharted territory, and experimentation will be needed to avoid forest loss and degradation" (Sci7). Participants were also confident that innovation could deliver efficiencies and co-benefits that would strengthen the ERF (Ind1,2; Gov1). The US-based Verra standards for climate action, including more tailored risk ratings and thresholds, allow for industry flexibility to write

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[1] The Clean Energy Regulator is responsible for administration of the ERF. Outcomes of the current ERF review may have implications for agency responsibilities.

methods that meet standard integrity tests, and were identified by one participant as a better practice model (Ind2; Verra, 2021).

3.4.4 Industry and practitioner leadership strengthening

With rainfall deficiencies experienced across much of Australia for many years since the ERF commenced, practitioner participants described increasing use of adaptive management approaches to assist forest regeneration (Ind1,2,3). Learning by doing, industry is gaining knowledge and data on project performance under various climate conditions, with one organisation having up to a decade of baseline and time series data for projects over 10 million hectares (Ind1). Carbon broker participants also flagged that they are partnering with researchers to better understand future climate risks and effective responses, including landscape scale restoration approaches relevant to project portfolios.

Practitioner and research participants discussed that while the ERF's risk management mechanisms are adequate across the initiative, they are insufficient for many projects and are unlikely to mitigate combined climate variability and climate change risks this century, particularly in areas facing increasing aridity (Ind1,2; Sci2,3,6,7). The risk of losing forest cover due to climate change is now recognised by industry participants as a commercial issue. Tailored climate risk mitigation measures beyond ERF methods are being widely applied by practitioner participants, including species selection suited to future climate beyond the shorter permanence period, adjustment of the timing of establishment activities to benefit from rainfall events, and creation of internal buffers in portfolios (Ind2). Recent drought events have also challenged parts of the industry, with impacts of the widespread 2017-2020 drought in New South Wales including delays to planting and consumption of much of a company's internal buffer (Ind2). Looking ahead, participants highlighted the importance of robust approaches to climate risk management, based on quantifiable methods, science relevant to regional and property scales, and an understanding of risks that can disrupt investment streams.

More broadly, participants noted that development and adoption of the Australian carbon industry's code of conduct that seeks to enhance the market integrity, transparency and accountability of forest sinks practice, demonstrates leadership by the industry (Ind2,3; CMI, 2021a). The code aims to increase the quality of carbon abatement that is occurring in Australia, and facilitate meaningful stakeholder engagement and delivery of environmental and employment co-benefits. It has attracted signatories across key industry organisations since its launch in mid-2018 (CMI, 2021a).

3.4.5 Diverging motivations across regime

Participants from across industry, government and science portrayed the forest sinks regime as in a state of dynamic change, where actors' interests in the trade of forest offsets are diverging. Industry and land management participants recognise many farmers as having interests in measuring carbon sequestration for their farm carbon accounts, rather than for trading carbon, an approach reinforced by recent industry commitments to carbon neutrality.[2] For instance, many farmers see their property as a legacy able to support reforestation activities that deliver productivity, social license and resilience co-benefits (Ind1; Lm1; Schirmer & Bull 2014; Fleming et al. 2019), and seek services from carbon brokers to help them realise such outcomes. Simultaneously, as noted by government participants, the CFI sector has grown into a large business. Carbon brokers now manage land and projects worth hundreds of millions of dollars and are a significant industry voice in their own right (Gov1).

Industry and government participants also identified that well-resourced companies have interests in offsets to meet net zero targets and can purchase substantial areas of forest sink to meet private objectives. Shell Australia's purchase of forest sinks over 9 million hectares, for example, removes that sink from regulatory approaches that could seek to deliver wider environmental or community benefits. Many such global corporates typically engage with voluntary carbon markets and, beyond Climate Active, can access international carbon measurement standards, such as Gold Standard and Verra, which also only provide limited guidance on how best to consider future climates in projects and are not tailored to Australia's conditions (Kollmuss et al., 2008; Gold Standard, 2021; Verra, 2021). A relative weakness in compliance testing of large company voluntary offsets, including strength of mechanisms to ensure permanence, was also identified by participants (Ind2; Gov2).

Carbon broker participants highlighted that there are marked differences in the interests and science needs of rural partners and big institutions with a focus on ESG, requiring tailored frameworks for engagement, monitoring and risk management. Participants across organisational categories indicated that government leadership is now needed to level the playing field regarding climate science and data availability, and in policies to facilitate

[2] For example, the Australian red meat industry has adopted a carbon neutral by 2030 initiative, and GrainGrowers support net zero carbon emissions by 2050 for Australia.

long-term climate-adapted approaches in any up-scaling of investment (Ind1; Lm1; Sci3). In this context, strengthened regime collaboration interfaces were identified as important to address areas of incoherence in regime actors' objectives.

3.5 Discussion

This study makes visible a growing misalignment between scientists' understanding of climate change risks and current national forest sinks policy and methods in Australia. The variability of Australia's climate and the likelihood of more extreme climate events point to risks of climate change driving losses of forest carbon storage through the 21st century, which are not well reflected in policy. Also of significance is a finding that, in its inattention to changing and higher end risks, policy and methods to date could be substantially overestimating the permanence of certain ERF projects. These findings align with recent studies in Australia as noted in section 3.2.2 and in other climate-sensitive regions (e.g. Anderegg, 2021). Through concerns about the permanence of forest sinks in a changing climate expressed by experts across regime stakeholder groups, they also highlight urgency in addressing the first research question of this study – how climate change knowledge can be integrated into forest sinks policy and practice in Australia.

To inform an effective response to this research question, an improved understanding of how and why the misalignment between science and policy is growing was sought through exploring actor perspectives across the forest sinks regime. The study revealed a regime with multiple and different interfaces, and the utility of a disaggregated organisational consideration to identify how barriers and enablers to the uptake of science into policy and practice function. This approach aligns with recent studies that understand SPPIs as social processes that are outcome-focused, that a focus on the production of actionable knowledge is insufficient, and that greater attention is needed on decision-making processes and contexts (e.g. Serrao-Neumann et al., 2020; Weichselgartner & Arheimer, 2019). In turn it enables a better understanding of how the various interfaces between organisations present challenges and opportunities to how policy and practice can more effectively integrate climate change knowledge. Table 3.2 summarises the various challenges and opportunities identified by participants for the better integration of climate change science into Australia's forest sinks policy and practice. It leads to the other central finding of this study that knowledge co-production and national SPPIs for forest sinks in a changing climate are weak in Australia.

Table 3.2. Climate change challenges and opportunities for Australia's forest sinks SPPIs.

SPPI component	Challenges	Opportunities
Science	• Resourcing for forest and climate research insufficient for robust understanding of rapidly changing risks • Lack of mechanisms for knowledge synthesis and shared learning • Science uncertainty affects perceived research relevance	• Science maturity to support risk assessment and adaptive management • Growing insights from landscape sustainability science on dynamic and interlinked change • Industry science partnerships and growing experiential learning • Emerging time series sequestration datasets under variable conditions • Government interests in geospatial tools[3] and robust ACCUs
Policy (including methods, implementation incentives and wider context)	• Goals not formulated through dialogue across regime actors • Policy separation from adaptation, climate risks insufficiently recognised • Diverging sector may increase tension and community concern • Prescriptive methods exclude consideration of climate change impacts and their permanence implications • Institutional rigidity constrains innovation and limits science uptake	• Community calls for more integrated landscape management • Growing understanding of potential for significant co-benefits • Recognition that HIR projects performing poorly provides impetus for reform • Ongoing challenges with landscape degradation and community call for participation in finding solutions across scales

[3] For example, the Clean Energy Regulator's Corporate Plan 2021-25 identifies the need to significantly enhance geospatial tools and capability for faster and more accurate assessment of claims for Australian carbon credit units (ACCUs) (CER 2021b).

	• Poor coherence with wider landscape policies constrains uptake	
Industry and practitioners	• Lack of tools for industry on how to integrate future climate • Prescriptive methods limit capacity for innovation • Lack of government established data gathering and sharing provisions require industry to fill gap	• Lessons learned from adaptive management approaches such as on the value of long-range forecasting, site preparation, and for some regions First Nations insights on fire management • Recognition that collaboration facilitates learning for a more effective regime • Collaboration in code of practice enhancing accountability and quality of forest sinks
Interfaces	• Partial. Lack of formal mechanisms for engagement across regime	• Appetite across industry, land managers and researchers for greater collaboration

As outlined by the participants in this study, realising these opportunities calls for reforms to regime SPPIs that recognise the magnitude of climate change risks to forest sinks, address gaps in knowledge, and facilitate its uptake through enabling policy and collaboration. With regards, then, to the second research question as to how the SPPIs may be enhanced for forest sink permanence in a changing climate, three interlinked reforms can be identified:

1. *Provision of tools that facilitate consideration of future climate change in project planning and risk assessment*. An *initial climate risk screening tool* is needed to show the significance of climate risks to forest sequestration, including areas that could shift from predominantly forest to non-forest ecosystems under medium or high climate change scenarios this century (Ind2,3; Sci1,7). To support rapid initial screening of climate risk, the tool could be derived from forest potential mapping, a mid-range climate change scenario, and expert knowledge of forest vulnerability, and be freely available. A *regional climate change risk management diagnostic tool*

would then be used where initial screening suggests medium or high levels of risk to sequestration this century. This tool responds to a need for diagnostic capabilities on when and where management interventions can assist tree survival and hazard management, particularly for forests in areas with marginal water supply, and where climate limitations to sequestration are critical (Ind1,3; Sci2,7,8; Mitchell et al., 2014; Keenan, 2017). Many participants argued that such a tool would link climate change scenarios, likely regional impacts on forests, and growing knowledge on the effectiveness, costs and benefits of various interventions, and can be built collaboratively to inform risk management planning.

2. *National forest carbon policy framework*. Such a framework would respond to issues raised by many participants to establish a unifying long-term vision, best practice standards regarding scientific knowledge for tests of permanence, and science-policy-practice interface mechanisms that support learning, outcomes-based methods, and innovation. To address barriers to the access and translation of future-oriented climate and forest science into decision processes (e.g. Colavito, 2017; Keenan, 2017), participants argued for national policy to establish mechanisms for the two-way sharing and integrating of data and emerging knowledge (Ind1; Lm1). One option could extend partners of the Australian Climate Service initiative (ACS, 2021) to the forest sinks regime, integrating too the leading work of the states in, for example, integrated forest research and decision-support (Ind1; Sci5). Collaboratively developed, participants suggested that such a partnership could bring multiple datasets from both practitioner and research sources to enhance learning on forest performance in a changing climate, enable timely software upgrades for bioclimate parameter generation for model use, support up-to-date regional sequestration potential and risk assessment services, and transparent verification of sequestration actually achieved (Fleming et al., 2019; Ind1,2,3; Sci5,7). Further, while non-sequestration benefits were deliberately excluded from the scope of ERF vegetation projects to ensure low-cost abatement, a carbon price alone has not facilitated large carbon farming projects in agricultural regions or driven the stacking of carbon and other benefits (Fleming et al., 2019; CCA, 2020). A comprehensive consideration of co-benefits is beyond the scope of this article, but several participants indicated that a re-framing of incentives in a national framework to prioritise wider socio-economic and environmental co-

benefits could now stimulate greater landholder uptake and support climate-adapted forest sink projects and long-term landscape carbon retention, and support sink permanence (Ind1; Sci2,7; Lm1; Schirmer & Bull, 2014; Bryan et al., 2015; CCA, 2017; Nolan et al., 2018; Fleming et al., 2019; Schwartzman et al., 2021). One option could be to manage current forest projects that might lose carbon with climate change for specified climate adaptation or loss-retarding benefits, for example from the regeneration of non-tree species or maintenance of ecosystem services (Lm1; Sci7; Verkerk et al., 2020).

3. *Collaborative industry-research partnerships*. The large majority of participants indicated that policy and methods for predicting and assessing forest carbon sequestration that robustly include the effects of climate change would optimally be underpinned by collaborative partnerships that link research, learning from implementation and experimentation, and decision-support tools. Such a collaborative partnership can also address current areas of confusion identified by participants, such as between inventory and research (Ind3). An enhanced national forest modelling capability that can better reflect the spatial and temporal variability of climate feedbacks on forest processes, recovery potential, species bioclimatic range, and mortality risk, as well as management interventions, is a priority to operationalise climate change and better inform decision- making (Ind1,2,3; Sci5). Development of a loosely coupled operational model system can make better use of currently available tools, and support innovation (Ind2,3; Sci1,7). For example, existing dynamic earth system models such as the Australian Community Atmosphere Biosphere Land Exchange model (CABLE) can simulate biomass change under various climate scenarios, link to other relevant models such as to simulate fire spread, and then calibrate policy models being used for project carbon accounting (Ind2,3; Sci7). Such a system would also provide robust and tested alternatives to the currently available version of FullCAM, such as the open-source Full Lands Integration Tool (FLINT) which is configured to spatially and temporally model climate change impacts on forest carbon, and to distinguish drivers of change (Ind1,3; Roberts et al., 2022). As previously noted, critical knowledge gaps also need to be addressed including a better understanding of the hot spots of greatest potential change in forest health with climate change, how sequestration rates and regeneration potential could

quantitatively change, the impact and likelihood of multiple or compound events, the performance of various and coupled models in sequestration estimation, and the opportunities for and spatial mapping of potential co-benefits (Sci1,2,4; Lm1; Ind1,3; Fleming et al., 2019, CMI, 2021b).

Many participants pointed to Australia's experience in industry-research partnerships as important to be drawn upon in the design of institutional mechanisms to support an evidence-based approach to forest sink permanence. Australia's Rural Research and Development Corporations (RDCs), partnerships between the Australian Government and primary producers to co-invest in research and development for the benefit of industry and regional communities, have helped drive innovation and improve productivity since 1989 and could be a relevant model for forest sinks (Ind3; Lm1; Gov3; DAWE, 2021). Similarly, the Joint Venture Agroforestry Program (1993-2009), a partnership between three RDCs, collaborated with many government and research organisations to build knowledge of the environmental and productivity opportunities from agroforestry (Sci7; Powell, 2009). Support for a multi-actor climate and forest partnership would build on and scale up current industry-research links to meet knowledge needs for future policy and management, and complement the current Forest and Wood Products Australia (RDC) which attends to non-carbon market needs and value chain optimisation (Sci6,7; FWPA, 2021).

The operation of these three institutional reforms collectively is considered by participants as necessary to improve sink permanence outcomes across the regime. Multiple interfaces require multiple strategies. Adaptive management and anticipatory tools, with policy settings that facilitate their use, support robust practice in a changing climate. Collaborative research partnerships, in turn, allow for experimentation in changing conditions, and ensure updated knowledge informs tools, future management needs, and further policy development. A more engaged industry sector, working with policy framings that incentivise sinks within the context of wider land management motivations, may also engender community support and partnerships that build the credibility of forest sink offsets across scales. In concert these reforms can improve policy outcomes through increasing government and investor confidence in sink permanence, and in substantially improving the evidence base for compliance testing and ongoing policy and methods development, and negotiations at national and international scales.

Further, the climate change risks to permanence of forest carbon sinks point to the benefits of much closer integration of approaches to achieve emissions reduction and climate change adaptation. Effective adaptation foregrounds an understanding of climate change impacts over time, approaches based on wide engagement, anticipation and adaptive learning and implementation, along with an openness towards transformation (Anderegg et al., 2021; Keenan, 2017; Nolan et al., 2018). Findings from this study suggest that these characteristics are also now critical for confidence in the environmental integrity of forest sinks, and adaptation considerations need to be a central part of effective forest sinks policy and methods.

In reflection, although some of the stated views of participants may be considered somewhat speculative, participants are speaking from their fields of expertise and their views are, furthermore, consistent with recent studies that find that the future of forests in a rapidly changing climate change is uncertain, and that improvements in both policy and the underlying science, including through the provision of rigorous continental-scale forest climate risk assessments, are needed for effective forest-based mitigation initiatives (e.g. Anderegg, 2021; Anderegg et al., 2021; Anderson-Teixeira & Belair, 2021; Breshears et al., 2021). It is also arguable that the deficiencies in our capacities to comprehensively understand and project future climate require such anticipatory approaches in the absence of full knowledge.

3.6 Conclusion

Forest sinks are important in Australia's climate policy, and climate change risks to sinks need to be integrated into policies and implementation to strengthen their permanence. This article demonstrates the value of attention to coherence between climate change science, policy and practice in the national forest sinks regime, where knowledge of changing conditions remains incomplete. The weak interface identified between climate change science and national policy and parts of industry practice, including a lack of formal mechanisms that facilitate regular engagement with science, help explain the lack of future climate focus in methods and specified tools. Declining resources, reported by interviewees, and weak coordination mechanisms between forest researchers and industry have also undermined the capacities of science to influence practice. These weaknesses, in turn, point to governance reforms to normalise the ongoing uptake of knowledge that are tailored to the challenges and opportunities identified within the regime. The call for a new forest sinks research-industry partnership in this article, for example, can address deficits in engagement mechanisms and knowledge for future management described by participants.

The proposed national policy framework can also incentivise knowledge uptake to support sink permanence and help address wider land sector sustainability challenges. In a warming climate, Australia faces increased risks of forest loss and desertification, and approaches that enhance carbon retention through natural regeneration can help repair landscapes and increase their productivity and long-term climate resilience. Further research and analysis is needed to appreciate the potential of forest regeneration for both carbon and landscape repair objectives under various climate change scenarios, and to identify the governance approaches that can be effective in the context of the magnitude of the risks. While power and political issues within the forest sinks regime were not addressed in this article, further consideration of inequities and political "lock-ins" that constrain imposition of more robust expectations on specific stakeholder groups is needed for such a policy to be effective.

Finally, while the article has focused on Australia's forest sinks regime, the challenge to incorporate changing physical risks from climate change to ensure permanence in carbon offsets is a wider global problem, and there is limited readily available guidance on how best to consider future climates in forest policy or projects. While there are considerable regional and national differences in forest vulnerability to climate change, and in drivers for methods or standards reform, insights from this article regarding tools and institutional reforms to better align climate change science with forest sinks initiatives may have relevance to other countries with interests in forest sinks and facing increasing aridity and bushfire risks.

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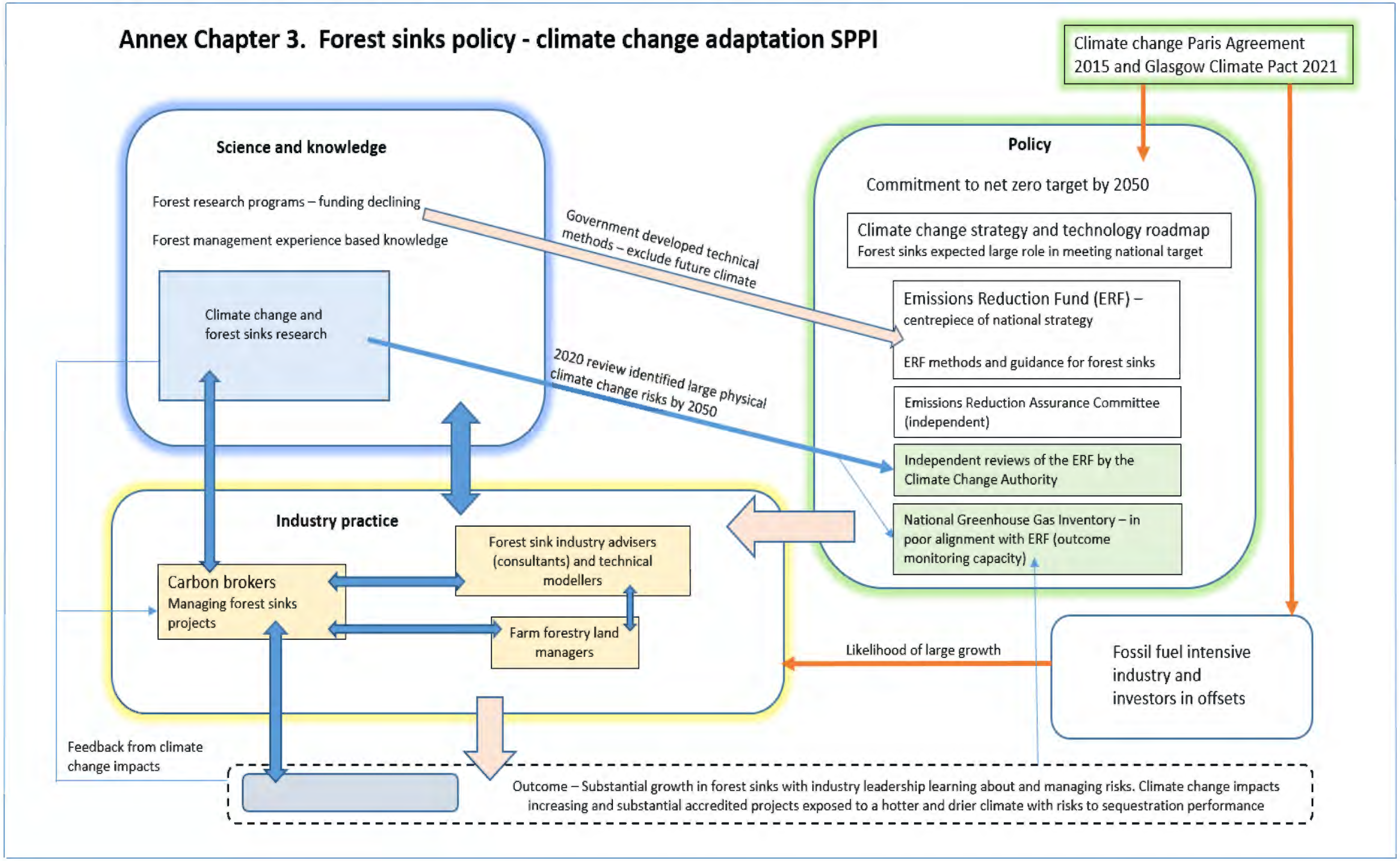
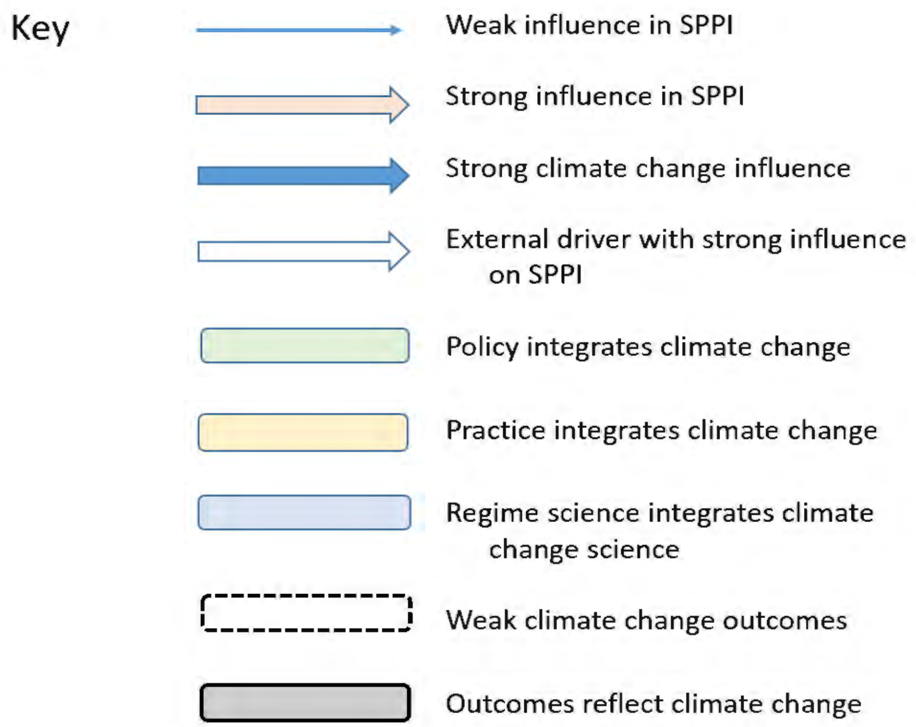


Annex Chapter 3. Forest sinks policy - climate change adaptation SPPI
Climate change Paris Agreement 2015 and Glasgow Climate Pact 2021
Science and knowledge
Forest research programs – funding declining
Forest management experience based knowledge
Climate change and forest sinks research
Government developed technical methods – exclude future climate
2020 review identified large physical climate change risks by 2050
Policy
Commitment to net zero target by 2050
Climate change strategy and technology roadmap
Forest sinks expected large role in meeting national target
Emissions Reduction Fund (ERF) – centrepiece of national strategy
ERF methods and guidance for forest sinks
Emissions Reduction Assurance Committee (independent)
Independent reviews of the ERF by the Climate Change Authority
National Greenhouse Gas Inventory – in poor alignment with ERF (outcome monitoring capacity)
Industry practice
Carbon brokers
Managing forest sinks projects
Forest sink industry advisers (consultants) and technical modellers
Farm forestry land managers
Likelihood of large growth
Fossil fuel intensive industry and investors in offsets
Feedback from climate change impacts
Outcome – Substantial growth in forest sinks with industry leadership learning about and managing risks. Climate change impacts increasing and substantial accredited projects exposed to a hotter and drier climate with risks to sequestration performance


Key
Weak influence in SPPI
Strong influence in SPPI
Strong climate change influence
External driver with strong influence on SPPI
Policy integrates climate change
Practice integrates climate change
Regime science integrates climate change science
Weak climate change outcomes
Outcomes reflect climate change

Chapter 4

Overcoming segregation problematics for environmentally accountable and transformative policy in a changing climate: The case of Australia's EPBC Act

Josephine Mummery and Jane Mummery

Abstract

The needs for environmental accountabilities and sustainability transformation are growing in Australia due to changing climate and collapsing biodiversity, but building robust environmental accountabilities and enabling sustainability transformation and human, nonhuman and ecological community resilience is proving elusive. This chapter examines Australia's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) – the Australian Government's key legislation for protecting environments of national significance – which has recently been reviewed and found to have achieved few of its stated objectives. This analysis utilises a critical environmental accountability frame to better understand how the legislation's procedures and norms have translated into ineffective practice. Three longstanding, problematic tendencies of segregation – between a) human and ecological cultures; b) science, and policy and practice; and c) sectoral scopes of policy – are identified to help explain the barriers to and challenges in enabling robust environmental accountability. Examining the EPBC Act and these problematics of segregation, the chapter outlines how relational rather than segregated understandings might build stronger pathways towards the environmental accountability and socio-environmental transformation needed for the challenges of the Anthropocene.

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4.1 Introduction

Australia provides an interesting case for exploring how environmental accountabilities and the context of a changing climate are reflected in national environmental policy and governance, and how well they support sustainable outcomes. Unlike many other developed nations, Australia is highly biodiverse, with large numbers of species and combinations of ecological processes found nowhere else (Steffen et al., 2009), and of high conservation and cultural significance. Since European colonisation of the continent, however, landscape change has been rapid and extensive, and biodiversity loss and environmental decline substantial, and climate change now poses an additional and far-reaching threat to Australia's biodiversity (Cresswell & Murphy, 2016). There is a clear need for transformed approaches to environmental management that enable the conservation and sustainability of biodiversity in a changing climate. With regard to the governance capacities relevant to the management of complex environmental problems, Australia has strong climate change and environment research and knowledge generation capabilities (in, e.g., climate science and meteorology, energy, water, agriculture, infrastructure, adaptation, disaster preparedness and response; see Commonwealth of Australia, 2019b). The large majority of this research is funded by national and state governments through publicly funded research agencies, universities, and also in partnership with industry in cooperative research centres and rural research and development corporations. Australia also possesses a stable system of government, a skilled and respected legal system, and a relatively robust Fourth Estate. Furthermore, Australia has experience in design and delivery of cross-jurisdictional approaches and partnerships for the management of broadscale environmental problems, such as water flows in the Murray-Darling Basin, loss of natural capital in agricultural regions, and emissions of synthetic greenhouse gases and ozone-depleting substances (see, e.g., Campbell et al., 2017; Mummery, 2021; Pittock & Finlayson, 2011).

Such capacities not only inform design and implementation of current environmental policy and legislation, but have the potential to enable the building of broad cross-functional support for strong environmental accountability measures. National policy and legislation are important means to achieving environmental accountability, and the effectiveness of such means, including the priority afforded the environment in policy implementation, is critical for realisation of the transformations needed for biodiversity conservation and sustainability. In this chapter we explore how well Australia's national environmental legislation, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), has tackled the challenges of climate change and biodiversity loss, and consider how strengthening its environmental accountability could better support such transformations.

After elaboration of relevant concepts from environmental accountability research, this chapter explores how well the EPBC Act and its implementation demonstrate environmental accountability in Australia, and then synthesises three problematics in its design and implementation which, we argue, have constrained the Act's effectiveness regarding environmental accountability and realisation of its goals. As will be illustrated, these problematics arise from tendencies of segregation between human and non-human cultures, between science and policy and practice, and between sectoral scopes of policy. Our proposal is that these three segregation problematics must be identified and addressed as barriers to enabling comprehensive environmental accountability in order for conservation and sustainability goals to be achieved through the implementation of policy and legislation.

4.2 Environmental accountability for biodiversity conservation in a changing climate

Despite the establishment and implementation of multiple policies for biodiversity conservation and environmental accountability, and legislation that seeks to protect matters of national environmental significance, including threatened species and communities, Australia's biodiversity is in a state of crisis. Over the last 200 years Australia has the highest rate of mammalian extinction in the world, with two mammals lost in the last decade alone (Commonwealth of Australia, 2019c). There are now more than 1,800 plant and animal species and ecological communities at risk of extinction, a number that is increasing and also likely to be an underestimate (Cresswell & Murphy, 2016). The Australian Government's most recent State of the Environment report concluded that Australia's biodiversity has declined further since 2011 with no decrease in the main pressures faced by native plants and animals, namely habitat loss and degradation, climate change, land use practices and invasive plant and animal species (Cresswell & Murphy, 2016). Scientific research now reveals that the magnitude and scale of climate change threatens to undermine efforts to conserve and sustainably manage biodiversity, with substantial losses of aquatic, marine and terrestrial biodiversity likely including in Australia's globally significant biodiversity hotspots (Steffen et al., 2009; Lindenmayer et al., 2010; Cresswell & Murphy, 2016). Climate change to date has also already impacted significantly on Australia's biodiversity, including causing extensive mortality of key marine habitat forming organisms (coral, kelp, seagrass, and mangroves), and losses of freshwater habitat and biodiversity (Pittock & Finlayson, 2011;

Babcock et al., 2019). Collectively, the impacts of climate change in Australia are projected to transcend single systems and have cascading effects through whole environments, including the ecosystem services and resources valued by humans, as well as impacting human well-being itself.

These severe challenges of climate change and environmental degradation call for responsive and anticipatory national policy to centrally position action to stem biodiversity loss and enhance environmental resilience at multiple scales. Recognition that the safe operating boundaries of the global environment are being exceeded highlights that human activities are collectively driving planetary change and that fundamental reconfigurations of the relationships between humans and the natural environment are needed for sustainability (Rockström et al., 2009; Steffen et al., 2015). Indeed, such reconfigurations have become recognised as the key to a sustainable future, meaning one which 'integrate[s] people and planet across scales, and can be defined as attaining human prosperity and social inclusion within a stable and resilient Earth system' (TWI2050, 2018, p. 5), with no further loss of natural capital. Achieving such a future in full will require intensive global partnership and engagement, bringing together governments at all levels, the private sector, civil society, the United Nations system and other actors, as well as requiring the mobilisation of all available resources. Nonetheless, sovereign states and their governments, typically having authority and responsibility for environmental governance, public good considerations, and citizen well-being, have critical roles in the framing, enabling, and sustaining of these reconfigurations.

The emerging body of environmental accountability research provides a useful conceptual base to explore how effective governance for biodiversity conservation, environmental resilience and broader ideals of sustainability can be orchestrated in a changing climate. Accountability is both a concept and a process which, through a combination of procedural and normative expectations, frames what can be considered appropriate and legitimate in political and economic fields (e.g., Stevenson & Dryzek, 2014). In practice, accountability refers to responsibility and obligation for desired performance, the traceable measurement and reporting mechanisms that facilitate public scrutiny and hold the actions of responsible actors to account, and the values that determine what is considered to be of accounting significance (Andrew, 2001). Accountability thus has an ethical, democratic or public interest intent (Orozco, 2006) which can expose inequities and inequalities, and empower people and institutions to advocate and demand that responsible actors meet agreed standards (Andrew, 2001).

A purpose of environmental accountability, then, is to enhance the accountability of all relevant actors and institutions to mitigate environmental damage and reverse the trend of environmental loss and degradation. In this way environmental accountability holds potential to help progress practices of effective environmental management and transitions towards sustainability (Bebbington, 1997; Bebbington & Unerman, 2020). However, despite this potential, environmental accountability practice can still reflect assumptions that embed narrow neoclassical economic frameworks, monetary dependence and short periodicities that suit business interests (Andrew, 2001; Lohman, 2009; Jones, 2010; Kramarz & Park, 2016, 2017). The embedding of such assumptions can over time result in wider environmental and ethical considerations being subordinated in accountability approaches, which can act as a barrier to steps to realise improved environmental outcomes and the transformations needed for sustainability. Indeed, conventional understandings and practices of environmental accountability – and the environmental policies, practices and institutions they have informed – have been recognised as having failed to facilitate adequate attention to climate change and sustainability and stem biodiversity losses globally and in Australia (see, e.g., Lindenmayer et al., 2010; Pittock & Finlayson, 2011; Saintilan et al., 2019).

The complexity and worsening state of contemporary environmental challenges in Australia and globally is increasingly leading to a questioning of traditional economic, ethical and accounting assumptions, and a search for more holistic approaches that can recognise the interdependence of organisations and the environment and help operationalise more environmentally-sensitive practice (Jones, 2010). In response, environmental accountability research seeks to extend core accounting concepts such as responsibility, the capacity of publics to hold authority to account, and transparency, to improve environmental problem-solving as well as the responsiveness of stakeholders affected by environmental problems (Kramarz & Park, 2016; Marrone et al., 2020). Through its capacity to make visible environmental deterioration, the allocation of responsibility for environmental action, and how environmental measurement standards need to align with planetary boundaries, environmental accountability research has the potential to contribute to a transformation of practices and to agenda-setting for sustainability transitions (Bebbington, 1997; Bebbington & Unerman, 2020; Marrone et al., 2020).

In particular, bridging environmental accountability approaches with insights from sustainability transformation research provides a reminder that as the Anthropocene places a stronger focus on interactions with an adaptive earth system, ways will need to be found to articulate these interactions and the responsibilities that arise from them. This framing foregrounds the need for environmental accountability to better consider dynamic biophysical thresholds, the causes and interconnectedness of environmental change, extended time frames that include future generations, and planetary boundaries to ensure that development occurs within the limits of nature (Milne, 1996; Bebbington, 2001; Gibassier & Alcouffe, 2018). These forms of connectivity within the interlinked social-environmental earth system also need to be understood as engendering complex and at times chaotic changes. These insights will in turn require new and better targeted forms of accounting (Bebbington et al., 2019), able to make clearer contributions to deliberate and adaptive steps to reduce the drivers of environmental degradation. Such steps need to reorient attention to the environmental ends sought, enable transparent examination of likely conflicts and resistances, and challenge the dominant procedural view of accountability with its corresponding subordination of ethical and sustainability components (Lohman, 2009; Kramarz & Park, 2016, 2017). We argue that new operational perspectives, ways and mechanisms are needed that connect awareness of the long-term effects of both climate change impacts and environmental decision-making to environmental accountability and management practices, and ensure resulting insights are implemented through policy and legislation. Given that such ways and mechanisms would in effect interlock the desired ends (e.g., biodiversity conservation, transformation toward sustainability) with the means of environmental accountability, their lack constrains the capacity of environmental accountability approaches to be fit for purpose in the Anthropocene. The manifest shape and repercussions of this lack are, we contend, clearly visible through consideration of the effectiveness of Australia's EPBC Act.

4.3 Examining the EPBC Act

4.3.1 Design and operation of the EPBC Act

The first comprehensive attempt to define the environmental responsibilities of the Australian Commonwealth, the EPBC Act was designed to focus Commonwealth interests on matters of national environmental significance, establish a streamlined environmental assessment and approvals process as concerns such matters, and put in place an integrated regime for biodiversity conservation and the management of important protected areas. The EPBC Act recognises nine matters of national environmental significance: world heritage properties, national heritage places, wetlands of international importance (listed under the Ramsar Convention), listed nationally threatened species and ecological communities, migratory species protected under international agreements, Commonwealth marine areas, the Great Barrier Reef Marine Park, nuclear actions (including uranium mining), and water resources (in relation to coal seam gas development and large coal mining development). The EPBC Act also encompasses actions that have a significant impact on the environment and that affect, or are taken on, Commonwealth land, or are carried out by a Commonwealth agency (even if that impact is not on one of the nine matters of national environmental significance).

In practice the Commonwealth Environment Minister has responsibilities for decision-making regarding the objectives of the Act, primarily to provide for the protection of the environment and to conserve Australian biodiversity. All land and sea (and seabed) use actions that have, or are likely to have, a significant deleterious impact on a matter of national environmental significance require an approval from this Minister. The approvals process spans decisions on whether the action should be assessed under the EPBC Act, and whether it should be approved or declined. In making these decisions, the Minister must consider both long-term and short-term economic, environmental, social and equitable considerations, assessment reports on the anticipated impacts of the action, comments from other Ministers, and the principles of ecologically sustainable development (Environment Australia, 1999). Actions that are lawful continuations of land, sea or seabed uses from before the commencement of the Act are exempt from requiring an approval (Environment Australia, 1999). Beyond approvals, the Act seeks to ensure that recovery plans are made for listed threatened species and ecological communities, and that a threat abatement plan is developed for key threatening processes to those species or ecological communities if this is considered a feasible, effective and efficient way to abate the threat (Environment Australia 1999). Of note, despite the now recognised significance of climate change for biodiversity conservation, the Act has not been amended to require assessment of impacts from an action under future climate change scenarios.

The Act reflects environmental accountability procedural concepts through its clear allocation of responsibility for the listing of nationally threatened native species and ecological communities, and for recovery and threat abatement planning. Further, such plans prepared to date have been made publicly available. Capacities for wider publics to hold decision-makers to account are also arguably supported through transparent and robust reporting, including five-yearly authoritative state of the environment reports, and ten-yearly independent reviews of the operation of the Act and the extent to which its objects have been achieved.

Analysis carried out for the 2019 Senate Inquiry into Faunal Extinction and the associated review of the Act shows substantial failings in the achievement of the Act's objects. Specifically, analysis showed that existing federal and state laws (including the EPBC Act) designed to prevent native animal species and populations from being injured, or their overall presence endangered through loss of habitat or by other threats, are weak, and poorly implemented and regulated (Australian National Audit Office, 2020; Commonwealth of Australia, 2019c). With regard to the protection of habitat for threatened species, research shows that between 2000 (when the legislation was enacted) and 2017, 7.7 million hectares of threatened species habitat was cleared or destroyed in Australia, and 1,390 (85 per cent) of terrestrial threatened species have experienced habitat loss within their range (Ward et al., 2019). Of note, despite its significance, some 74 per cent of this cleared habitat was not deemed a controlled action requiring approval to proceed (Ward et al., 2019). In addition, while the legislation provides for recovery plans, no such plans for ecosystems or habitats have yet been developed (Akhtar-Khavari & Richardson, 2020). That between 76 and 93 per cent of endemic Australian plants lack an extinction risk assessment is also impacting on the capacity to protect vulnerable and endangered species (Alfonzetti et al., 2020).

Indeed, both the interim and final report stated that despite the stated purpose of the EPBC Act, Australia has become a global leader in 'faunal extinction and decreasing biodiversity' (Commonwealth of Australia, 2019c, p. 61; also see Australian Conservation Foundation, 2020). In the words of the chair of the inquiry, Senator Janet Rice,

> The most important issue to arise from the Inquiry thus far is how totally inadequate our current Federal legislation is in terms of protecting the environment. We're dealing with the drivers of extinction. The EPBC Act is totally inadequate to deal with the situation – the problem is there's no framework for protection (as cited in Arnold, 2019).

4.3.2 The EPBC Act and environmental accountabilities

Several factors, including the long-term insufficiency of government funding for environmental management, have been identified to help explain the outcome failures of the EPBC Act, many of which point to gaps between the means and ends of environmental accountability. Not only is the Act lacking effective mechanisms to both describe or measure desired environmental outcomes, and ensure decisions are made in a way that contributes to those outcomes, but the transactional nature of the Act's operation, with its focus on individual actions and project-by-project development assessment, is particularly problematic as it fails to identify, consider or manage cumulative impacts (Samuel, 2020).

One factor which can help in understanding the Act's poor record for robust environmental accountability arises from characteristics of Australia's economic development and its traditions of political authority. Australia's export economy has traditionally relied on exploitation of natural resources through agriculture and mining which has generated governance that both facilitates this exploitation and mistrusts measures that might require change to this economy (e.g., Tangney & Howes, 2016). Thus, while the EPBC Act requires consideration of both long-term and short-term economic, environmental, social and equitable factors, in practice three quarters of these considerations – specifically economic, social and equitable – are already weighted towards the privileging of economic interests. This is because, under neoliberal ideology, social and equitable considerations are considered best achieved via sustained economic growth, and economic growth models remain geared towards the exploitation of nature (Adelman, 2018; Mundt, 1993).

As such, the EPBC Act, despite its objectives, illustrates in practice a preference to maintain vested human economic interests over enabling strong environmental accountability. This preference can be discerned in several ways. The first is that the Act is designed to not challenge land, sea or seabed use projects that were approved before the commencement of the Act – and before stronger policy recognition of the transformational needs for biodiversity conservation in the Anthropocene. Such projects include the ten regional forestry agreements (RFAs) in Victoria, Tasmania, New South Wales and Western Australia which permit continued native forest logging in areas important for the protection of threatened species (Lindenmayer & Burnett, 2021; Samuel, 2020). Agreements between state and federal governments have meant that proposals to log in such native forests are not required to be approved through the EPBC Act, even given extensive breaches of logging codes of practice and logging being demonstrably unsustainable in terms of its environmental impacts (Lindenmayer & Burnett, 2021; also see Kearney et al., 2019; Lindenmayer et al., 2020). Such weighting of economic over conservation aims is also exemplified by petroleum and other mining exploration projects not being excluded from many marine park areas despite their potential significant environmental impacts (see, e.g., Bell et al., 2014; Delany-Crowe et al., 2019).

Implementation of the EPBC Act's offset policy, established in 2012, has also, perversely, resulted in an ongoing loss and decline of habitat through privileging developer (economic) interests over environment protection (Samuel, 2020). Through offsets developers are required to compensate for unavoidable environmental impacts such as habitat loss, mostly by protecting areas of habitat similar to the area destroyed or damaged by the project (Gibbons & Lindenmayer, 2007). While the policy specifies a hierarchy of environmental impact avoidance, mitigation, and offsetting, a proponent's decision to develop a particular site has generally already been made before a referral is made under the EPBC Act, limiting real consideration of impact avoidance (Samuel, 2020). Further, offset conditions are not adequately monitored and efforts to enforce compliance are weak (Samuel, 2020). There is also no transparency of the location, quality or quantity of offsets, and in some cases development projects that have not identified suitable offsets have still been approved on condition that the company would 'look for an offset down the track' (Kilvert, 2020). Finally, offsetting schemes rarely deliver effective conservation and protection measures for existing populations of threatened species (Hosking, 2020).

Critical approaches to environmental accountability research also call for consideration of how key governance mechanisms respond to the climate change and sustainability challenges of the Anthropocene. Science has an important role in providing the evidence base for policy and governance reform to support transitions towards sustainability, and as noted in section 4.1, Australia has strong climate change and environment knowledge generation capabilities. However, while robust science exists that demonstrates the urgency that must now be given to habitat restoration and the protection of endangered species and communities, current settings in the EPBC Act do not incentivise effective ecological restoration (Lindenmayer et al., 2010; Ward et al., 2019). There is strong expertise within the Threatened Species Scientific Committee, but the terms of reference of the Committee, as prescribed in the legislation, limit the advisory capacity of members to, primarily, advise on the amendment and updating of lists of threatened species and communities, and on the development of recovery and threat abatement plans. The noted lack of mechanisms in the Act to measure environmental outcomes, including monitoring, also limits the capacity of emerging science and scientific advisers to build the case for reform of policy and practice (ANAO, 2020). Such disconnection between available scientific expertise and the measures enabled towards environmental accountability through the EPBC Act can be discerned on a number of fronts, demonstrating what can be called a weak science, policy and practice interface.

One such weakness in the ability of the EPBC Act to improve Australia's environmental accountability outcomes by engaging with robust environmental science is visible in the ongoing reticence of governments to recognise and address habitat loss, notably from agricultural and other development, as a threat to biodiversity conservation. For instance, the Australian Government's Species Profiles and Threats Database which stores information on Australian plant and animal species listed under the EPBC Act, has historically listed 'invasive species and disease' as the most prevalent of a set of key threats impacting on nationally threatened Australian fauna and flora (Allek et al., 2018; Kearney et al., 2019). That is, it does not identify habitat loss, fragmentation, and degradation as threats (Ward et al., 2021), despite clear evidence of their negative impacts on biodiversity conservation. Indeed, habitat loss through land clearing has been identified as having contributed to a similar number of extinctions in Australia (62 species) as introduced animals such as feral cats (64) (Ritchie et al., 2021). The vegetation communities that underpin habitat of species of national environmental significance, which extend across landscapes managed often for intensive or extensive agricultural purposes, also generally receive no federal protection under the EPBC Act until they have already been extensively cleared and identified as being under significant threat (Tulloch et al., 2016). Further to this, climate change is not explicitly recognised as a threat in the legislation, despite the existence of strong scientific evidence of a large and increasing threat as indicated in section 4.2.

It is also increasingly apparent that sectoral policy scopes generate and reinforce hard barriers between, for instance, protected areas under the EPBC Act and off-reserve conservation management. Off-reserve conservation refers to conservation practices carried out on private land or on Crown land potentially subject to production forestry or agriculture or other practices. Much suitable habitat for many species of national environmental significance is found off-reserve, and such conservation practices can be very important for the recovery of species and ecological communities, particularly in a changing climate where the spatial distribution of suitable habitat can shift. Of concern, there are almost no examples in Australia where off-reserve conservation initiatives have been robustly integrated with protected area management to underpin conservation outcomes across tenures (Lindenmayer et al., 2010). Efforts to date can be characterised as fragmented and not in alignment with the scale of the problems. Multiple programs have aimed to encourage ecological restoration across Australian landscapes and numerous niche examples of best practice have emerged, but a lack of incentives and inadequate resourcing, failures in integration and incessant restructuring, among other factors, have limited restoration outcomes to particular districts or properties and they risk not being maintained into the future (Campbell et al., 2017). Restoration program goals have rarely been enabled by sufficient resources, and Wintle and colleagues (2019), for example, find that for threatened species recovery efforts to be successful, an approximately 20-fold increase in funding from that currently allocated will be required. Challenges here are further exacerbated by expectations that private landholders have rights to exploit natural resources for economic benefit, and a clear reluctance from the agriculture sector to comply effectively with EPBC referral requirements despite dominating national land clearing activities (Evans, 2016; Ward et al., 2019; ANAO, 2020).

Not only has the EPBC Act been proven ineffective with reference to its own environmental conservation aims – the ends and means disconnection referred to earlier – but robust environmental accountability clearly also requires coherence between the policy intent and implementation of the EPBC Act and wider policies at multiple scales. There are, however, additional gaps in the alignment of the Act with *Australia's Strategy for Nature 2019-2030*, which identifies the importance of adaptive management and the address of climate change but perhaps unsurprisingly lacks compliance obligations (Commonwealth of Australia, 2019a). Weak integration between the EPBC legislation and management plans to guide practice has also been detrimental to the conservation of migratory species and their habitat (Miller et al., 2018). Similarly, Australia's commitments under the Convention on Biological Diversity, including targets to enhance biodiversity conservation off-reserve, are not currently facilitated by the Act. Collectively, the EPBC Act with its reluctance to constrain economic development, a weak science, policy and practice interface, and poor coherence with wider environmental policy, establishes barriers to the achievement of sustainability goals and effective environmental accountability in a changing climate. It is thus unsurprising that the EPBC Act has delivered 'managed decline, not sustainable maintenance or recovery […] Stabilisation of decline or a net improvement in the state of the environment cannot be achieved under the current system' (Samuel, 2020, p. 44). Analysing and understanding the basis for these failures is the focus of the next sections.

4.4 Three problematics

It is in the context of these gaps between the design (ends) and implementation (means) of the EPBC Act that we discern three problematics of segregation that we consider need to be addressed for the achievement of effective environmental conservation and accountability. Segregating, or keeping one thing separate from another, is a longstanding, widely employed, even perhaps ingrained, model of human thinking that enables the summarising and management of complexity (Lakoff, 1990). The problem is that segregation processes can also entail oversimplification through amplifying the importance of both similarities and differences among items. This can occlude not only complexity, but the presence of spectrums and processes and the possibility of other models for the organisation of different items and the giving of value. An over-reliance on segregation can thus lead to treating the members of a category as if they were more alike than they are; amplifying differences between categories and members of different categories; discriminating, favouring certain categories over others; and fossilising, treating identified categories as if they were static. In the context of the implementation of the EPBC Act, segregation processes have likely contributed to an under-valuation of nationally significant species and ecosystems, a narrow recognition of threats, and a constrained approach to recovery planning that requires substantial off-reserve conservation action.

Segregation concepts and processes are also relevant to the analysis of governance and policy as both tend to be produced and carried out through often deeply siloed organisations with different departments or areas operating with varying forms of 'tunnel vision' as if they were segregated from each other (Rosenbloom et al., 2010, p. 33). Of note, the silo is the principal organisational form for governments in many countries including Australia (e.g., Scott & Gong. 2021). While the hierarchical and vertically-coordinated characteristics of siloed organisations can deliver goods and services efficiently and develop relevant expertise for that delivery, such models also contain weaknesses. A tendency for tunnel vision or inward-looking perspectives that narrowly conceive goals to align with organisational silo aims and boundaries can result in problematic failures of horizontal communication and coordination and an inability to resolve jurisdictional disputes with other departments or organisations (Tett, 2015). Deeply siloed organisations may have difficulties, then, in taking responsibility for and robustly making inroads into cross-functional and systemic problems – such as those posed by the impacts of climate change and environmental deterioration. They can also struggle in effectively collaborating with the breadth of industry and community actors needed for solution identification and implementation. These are problems of a tendency toward segregation.

The following three subsections identify and explore three problematics in segregation which we consider occlude the ability of environmental policies such as the EPBC Act to effectively improve Australia's environmental accountability and facilitate sustainability transformations. As we illustrate, these problematics arise around the tendency to segregate human from non-human interests and to value the former over the latter (problematic 1), to segregate between different forms of knowledge and to devalue (certain forms of) scientific knowledge within the policy arena (problematic 2), and to leave unchallenged the segregation between sectoral scopes of policy (problematic 3). As we outline below, each of these has differentially limited the EPBC Act with regards to its capacity when implemented to facilitate robust environmental accountability.

4.4.1 Between human and ecological cultures

A first problematic of segregation that has proven particularly important with regards to the desired ends of the EPBC Act arises with the longstanding effort to segregate human from ecological cultures, as well as the value model of anthropocentrism which typically inhabits such segregation. Referring to human centredness and, typically, an assumption of human superiority, anthropocentrism finds it normal that only human interests could count in any significant way. From this viewpoint, nonhuman nature is seen as radically separate from humans and as of lesser (or no) importance other than as potential human resources (Barua, 2019; Burns, 2014; Kopnina et al., 2018). This is the view nonhuman nature has only instrumental value, in for instance resource extraction or amenity. Anthropocentric practices thus take nature to be a free input able to be exploited in the pursuit of economic growth allowing economic transactions to only focus on extraction and product development costs (Mundt, 1993). These ideas have undergirded projects of modernism, capitalism and colonialism as well as contemporary neoliberal economic and political systems (Adelman, 2018). Such systems have normalised the idea that the 'destruction of natural systems and domination and extinction of other animals' is an inevitable, if regrettable, result of human development (Boyd et al., 2015, p. ix).

Although awareness is certainly growing regarding the importance of collapsing such segregation between human and ecological cultures for improving environmental accountabilities, biodiversity conservation and sustainability transformation, the legacy of anthropocentrism and its inherent reliance on a model of segregation remains embedded in such policies as the EPBC Act. This legacy also underwrites the consistent inability of those administering the EPBC Act to close the loopholes that continue to grant exemptions for practices that deliver short-term economic benefits to humans while further endangering multiple threatened species and ecological communities.

4.4.2 Between science, and policy and practice

The second problematic arises from the disjunct between robust scientific knowledge regarding safe planetary operating boundaries and the requirements for restoring degraded ecological communities, and the forms of knowledge and understanding which drive much policy and practice. In recent decades scientific knowledge has become very important in informing environmental policy-making, including through clarification of the nature and causes of environmental problems (van Enst et al., 2014; Dunn et al., 2018). However, policy is also generated from and reflects the values underpinning the contemporary political and economic system. In Australia, the characteristics of an anthropocentric neoliberal ideology strongly influence public policy (Baldwin et al., 2019; Miller & Orchard, 2014), with these characteristics used to justify the absence of strong policies on the conservation of biodiversity and nature, as well as to downplay research insights where they challenge narrow economic interests. Furthermore, policy and practice also tend to evolve iteratively from successful past approaches. This generates a tendency for path dependency in valuing historic experience and lessons and advice based on that experience, even when changes in external conditions and new scientific research findings suggest new approaches may be better suited to future conditions (Barnett et al., 2015). Practice from such policy can thus become deeply embedded within a regime, reinforced through continual regime interaction processes, supported by powerful vested interests, and actively resist change. In this way policy and practice can privilege knowledge and understanding gained from positive reinforcement from alignment with predominant economic values, and from experience in this context. These factors together can mean that policy settings may remain complacent in the face of conventional assumptions and economic development pathways (Tangney & Howes, 2016), and act as a barrier to the uptake of new findings.

The nature of the science striving to clarify the severe challenges of climate change and environmental degradation in the Anthropocene also presents particular challenges to policy and practice. Climate change science, for example, is predominantly future-oriented, and derived from models with levels of irreducible uncertainty that demand different approaches to assessment and value than those derived from policy or practice regime experience. The long-time horizons of climate change and ecological recovery further contrast with policy decision-making approaches that fit within electoral timeframes or seek a return on investment of around 5–7 years. Given high short-term climate variability it is also difficult to identify causal impacts of climate change within business-relevant temporal scales (Linnenluecke et al., 2015). In addition, the call from the science community to transform human economic activities and behaviours has led to vested interests contesting the science itself and adding to community confusion on needed action (Pérez-González, 2020). The complexity of the science in combination with these factors means that many policies and practices continue to be developed and employed with little or no regard for knowledge of such complex long-term problems as collapses in biodiversity or climate change (Hewitt et al., 2017). Such practices can hobble attempts to enable transformation, as can be discerned in gaps in the alignment of the EPBC Act's biodiversity conservation objectives and procedures. Such gaps persist even though both the Act and investment in climate systems and resilient landscapes science through the National Environmental Science Program are managed within one government department.

4.4.3 Between sectoral scopes of policy

The third problematic arises from typical approaches to environment policy development within distinct and siloed government institutions. As noted, narrowly defined scopes of policy can result in conflict and incompatibility with other policy domains, and ultimate failure in implementation to achieve the objectives sought. The already mentioned tensions between biodiversity conservation objectives and logging practices in areas covered by RFAs, or in agricultural regions with biodiversity values where land clearing rates remain high, exemplify this. Similarly, while Commonwealth marine areas are supposedly protected by the EPBC Act, the over-exploitation of fish stocks in many marine regions, and declining populations of numerous commercial fish species, again reveals a disconnection between different sectoral policy scopes, as well as the tendency toward path dependency that continues to allow a privileging of economic interests over conservation in Australian ocean fishing policies (Delany-Crowe et al., 2019). Thus current policies in these, among other, areas further embed the distinction between human and ecological cultures, and illustrate an ongoing failure of policy to adequately consider the wider implications of natural resource extraction for the conservation of ecological communities and long-term resource sustainability in a changing climate. Sources of knowledge such as on climate change, developed externally to sectoral policy development processes, also face challenges in recognition and incorporation in sectoral decision systems.

4.5 Steps towards overcoming problematics for environmental accountability

The operation of the three problematics – the segregations between human and nonhuman interests, between different forms of knowledge, and between sectoral scopes of policy – has effectively embedded a culture of unaccountability with regard to achieving biodiversity conservation in a changing climate. This culture is clearly illustrated through the continued failures in achieving the EPBC Act's primary objectives, specifically the protection of the environment and the conservation of biodiversity. This chapter has revealed that the policy and institutional settings of the EPBC Act have led to an avoidance of consideration of systemic issues, persistent privileging of short-term economic interests over environmental protection objectives, as well as characteristics of path dependency, including from weak accountability practice in its implementation. As we have shown these have contributed to a more depauperate biodiversity, and will further reduce resilience, and increase damage and restoration costs. These problematics hinder attempts to contest narrow and short-term economic assumptions and values and deliver the environmental protection and restoration goals needed in the Anthropocene. We argue that for environmental accountability and associated policies to be effective and transformative in the face of Australia's changing climate and collapsing biodiversity, these problematics need to be identified and investigated for their capacity to act as barriers to environmental sustainability and climate change adaptation in the design and implementation of policy and legislation.

A further reform focus is the need for mechanisms that better relate accountability procedures with environmental objectives and required outcomes that are more tightly linked to global environmental change. Several environmental accounting capacities have the potential for development to contribute relevant insights in the Anthropocene, including more comprehensively designed and implemented full cost accounting whereby externality increases could indicate future system shifts, natural capital accounting able to identify systemic impacts and environmental limits, and collective or wider sectoral accounts that can reveal interactive information obscured at the single project or transaction scale (e.g., Bebbington et al., 2019). Reforms to the EPBC Act, notably to enable listing of climate sensitive species, to address weaknesses in the offsets policy, and for inclusion of critical climate habitats (such as refuges and important corridors) as a matter of national environmental significance (e.g., Clews, 2012), can also better align accountability means and ends. Effective implementation of such reforms also calls for critical consideration of these three segregation problematics. This would enable the development of a science, policy and practice interface able to go beyond simple linear – and sectoral – forms of information provision with wider knowledge and actor engagement, linking national with planetary frames, and dismantling the anthropocentric segregation between human and ecological cultures. This more broadly relational interface has the potential to encourage more robust accountability and transformative measures that better align with the scale of the challenges faced. In the case of the EPBC Act, broadening the role of the Threatened Species Scientific Committee to enable deliberation regarding accountability for matters of national environmental significance in the Anthropocene, would be a useful first step.

Insights from this analysis also contribute to wider considerations of whether incremental change can contribute to transformation. While a topic of active debate, an increasing number of scholars are finding that incremental steps alone are insufficient to address the challenges of climate change, and that transformational change requires new governance strategies or interventions (Pelling et al., 2015; Termeer et al., 2017). We would suggest that given the ongoing segregation between science, and policy and practice, and the consequent embedding of governance processes within tendencies toward path dependency and anthropocentrism, that incremental change processes are more likely to allow, perhaps unintentionally, the continuation of current environmentally damaging pathways. Ultimately, mechanisms that can address the problematics identified earlier, make visible narrow underlying assumptions and privileges, and facilitate wider societal engagement on desirable goals and purposes have some potential for reform of rules, values and governance arrangements for transformative change. For instance, exposing the dependence of Australia’s export economy, historically and currently, on the exploitation of natural resources (e.g., Tangney & Howes, 2016), highlights the cultural privileging of resource development including at the expense of the environment. Such privileging will require reconsideration and address for the enabling of transformational change. While disagreements can be expected, an approach that allows for the problematics to be explored and debated, and for exploration of alternative scenarios, has capacity to build community support and drive innovative solutions to help decouple biodiversity loss from enviro-economic decisions.

In total, this chapter highlights a profound challenge for the progress of environmental transformations needed in the Anthropocene. The design and implementation of policy is a critical enabler of environmental transformations; other drivers of transformational change such as from innovative and inclusive governance, social movements, or the upscaling of successful niche initiatives, have proven less effective to date in achieving broadscale conservation outcomes in Australia (e.g., Campbell et al., 2017; Díaz et al., 2019). The wider and deeper analysis in this chapter of the need for transformational change in policy and practice – with such change found to be dependent on addressing the three problematics identified above – provides insight into how to realise the reforms called for in the recent Samuel review.

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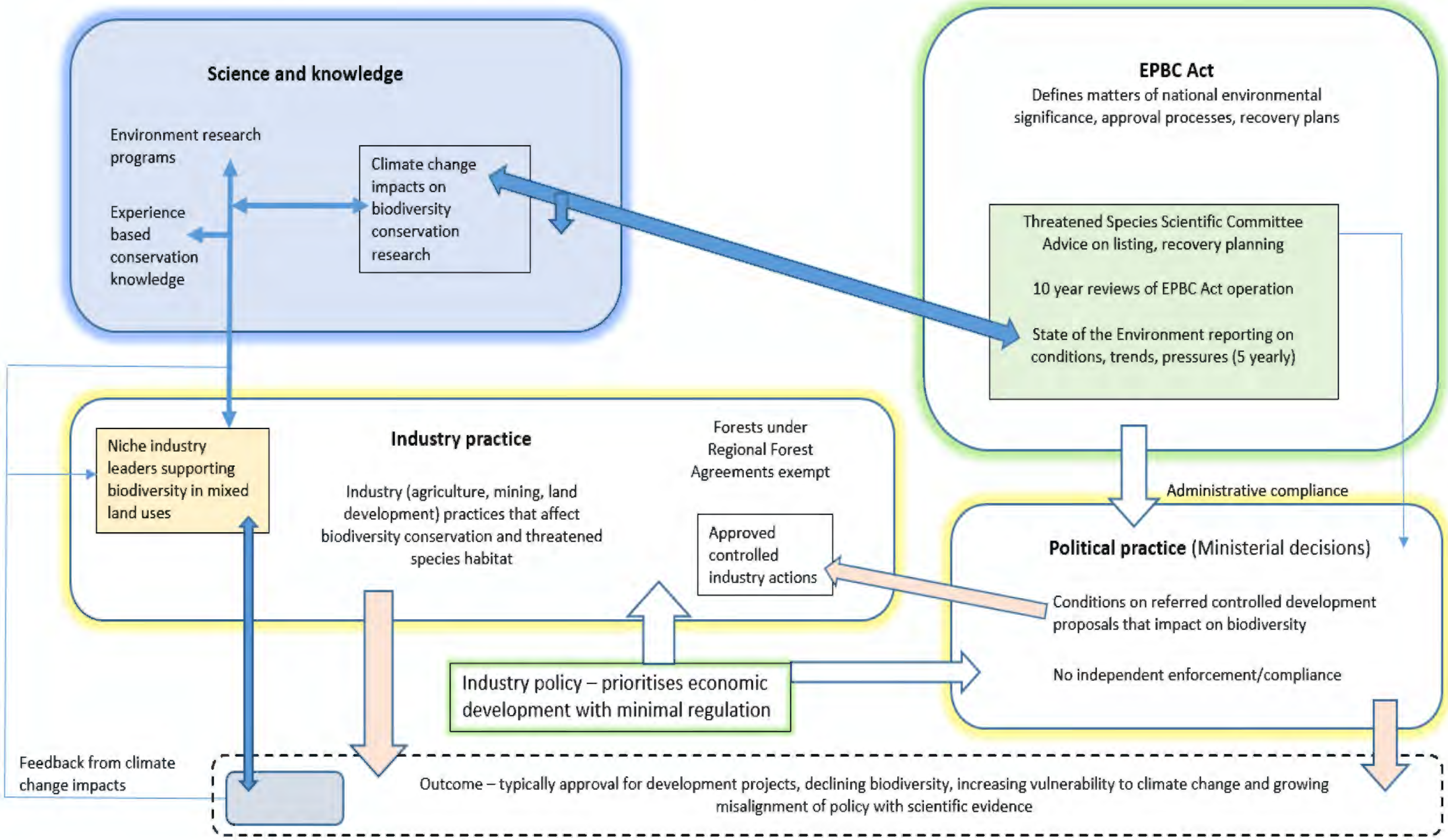
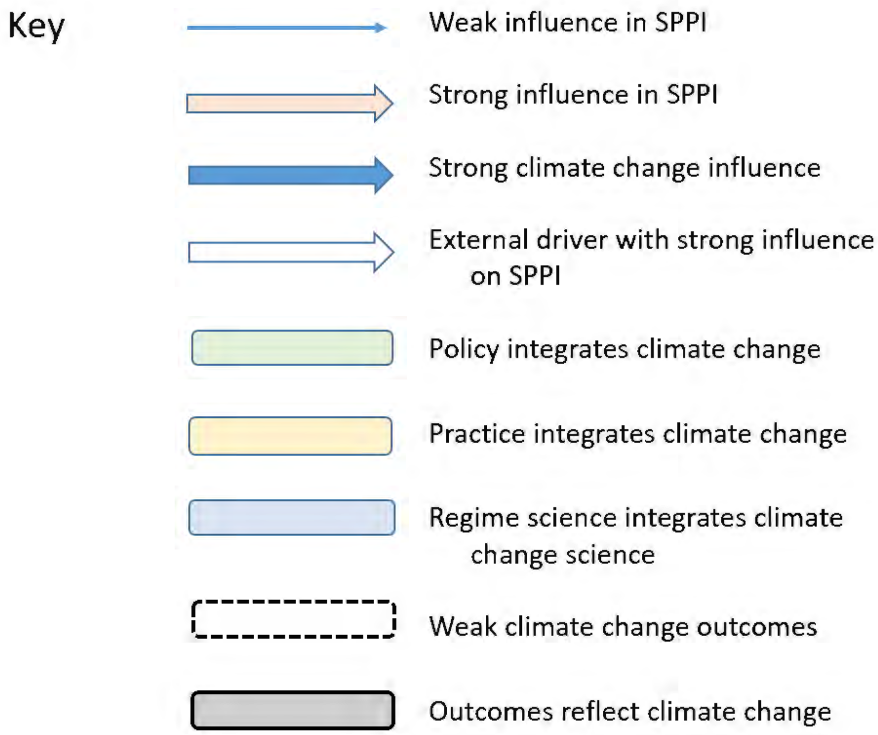
Annex Chapter 4. EPBC Act – climate change SPPI (biodiversity conservation)




Key
Weak influence in SPPI
Strong influence in SPPI
Strong climate change influence
External driver with strong influence on SPPI
Policy integrates climate change
Practice integrates climate change
Regime science integrates climate change science
Weak climate change outcomes
Outcomes reflect climate change

PART 2

SCIENCE-POLICY-PRACTICE INTERFACES FOR CLIMATE CHANGE TRANSITIONS

Chapter 5

Science-policy-practice interfaces for city climate change transitions: A case study of Canberra, Australia

Abstract

Science indicates that cities are central to society's capacity to avoid catastrophic and irreversible climate change, that rapid transitions to climate wise practices are needed, and that transition steps will face implementation challenges. Lessons learned from reform experience can build understanding of the knowledge, policy and practices required for further transitions. This paper identifies lessons learned from renewable energy and resilience reforms in the city of Canberra, Australia. It finds that attention to science-policy-practice interfaces contributes important insights for the design of planned transitions and for integrative and implementation-focused reforms needed to overcome local barriers.

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5.1 Introduction

Climate change science provides compelling evidence for transitioning to low-carbon, resilient and sustainable cities and urban areas, and there is growing urgency for their progress (Hölscher et al., 2019; Sachs et al., 2019). Cities account for 75 per cent of the world's final energy use, and deep cuts in carbon dioxide emissions are required to avoid dangerous climate change (Alberti, 2017). This will involve as a first step rapid transitions to net zero emissions by mid-century, supported by a decoupling of urban development from an increasing carbon footprint (Bai et al., 2018; Goubran, 2019). The warming climate of recent decades, causing increasing damage from extreme weather events, simultaneously highlights the need for practices that build resilience and reduce risk exposure. With cities typically built under assumptions of climate stationarity, growing urban populations call for anticipatory development of these practices (Jiang & O'Neill, 2017). Science can help design anticipatory transitions, for example, through articulating plausible futures, analysing how policy settings contribute to solutions, and supporting learning across decision-making communities (Kowarsch et al., 2016). A priority now is identifying knowledge-based pathways to support the realisation of climate change city transitions.

Science-policy-practice interfaces (SPPIs) can leverage such pathways, as they focus on the processes and institutions that determine how knowledge is perceived, reflected in policy, and acted on in practice (van Enst et al., 2017). For the purposes of this article, SPPIs are understood to be multi-dimensional social processes that facilitate dialogue and learning between knowledge producers, users and other stakeholders, and knowledge application with the potential for problem-solving (Turnheim et al., 2020; Solecki et al., 2021). This understanding extends conventional notions of the 'science–policy interface' that assume knowledge production and the decision-making that utilises knowledge are independent from one another, to include purposeful knowledge use (Muñoz-Erickson et al., 2017). In the context of this article, then, SPPIs allow for assessing how well climate policy and practice for low carbon and resilient cities align with the magnitude and dimensions of projected change identified by science (Moss et al., 2019).

This article explores the climate change SPPIs of the city of Canberra, Australia, as a case study. The Australian Capital Territory (ACT), where Canberra is located, has transitioned to 100 per cent renewable energy in advance of other Australian jurisdictions, and put in place initial reforms to build resilience to water security and bushfire risks. Significant challenges remain, however, in sectoral emissions reductions and vulnerabilities to climate risks. This raises two questions. What role did SPPIs play in enabling the reforms or transitions? And, are there lessons learned from the steps taken that can help with further climate change reforms? This article first describes how SPPIs can contribute to understanding city climate change transitions, and then explores these questions in the context of Canberra's climate change priorities. The key strengths and weaknesses of Canberra's climate change SPPI components are identified in this exploration, to clarify the factors that can obstruct or mobilise support for shared visions of low-carbon and resilient pathways, and facilitate practice reform to implement such pathways.

Through this focus, the article seeks to contribute to areas in the transitions literature that need greater attention, notably how SPPIs can inform governance of uncertain and disruptive reforms, and how SPPIs as learning processes can help bridge implementation gaps between urban transition goals and actions realised (Turnheim et al., 2020; Solecki et al., 2021). Several studies have called for further research into how SPPIs for urban climate change pathways are formed, inform decision-making, and enable practice reform (Bai et al., 2019; Bansard et al., 2019).

The structure of the article is as follows. Section 5.2 draws on relevant literature to describe the role of SPPIs for climate change transitions. Section 5.3 outlines the methods and data sources drawn upon in this paper. Section 5.4 provides context for the case study on the climate change SPPI for Canberra, Australia. Section 5.5 then outlines the case study results, identifying lessons learned from reforms to date to reduce the carbon intensity of the city's energy supply and build resilience in a changing climate, and section 5.6 identifies major reform themes for Canberra's SPPI to support further climate change transitions.

5.2 The role of SPPIs for climate change city transitions

Connections between science, policy and practice are critical for steps toward low-carbon and climate resilient cities. Urban climate change challenges are multi-faceted and require utilisation of multiple knowledges and capacities to design and implement feasible pathways and resolve constraints to the uptake of climate change practices (Bai et al., 2019). The cross-domain nature of SPPIs can facilitate shared visions and understandings of the structural, institutional and behavioural changes needed over time horizons, and their likely benefits, costs, feasibility, and trade-offs (Bansard et al., 2019; Sachs et al., 2019). With the narrowing window of opportunity to avoid damaging climate change, deeper collaborations across science, policy making, and practice are needed to co-create and implement effective transition pathways (Alberti, 2017; Bai et al., 2018).

Science is important in responses to the urban challenges from climate change. In describing the nature and consequences of climate change, as well as understanding of the drivers and activities that generate greenhouse gases, science is central to framing the urgency and scale of city transitions (Fünfgeld, 2010). Urban scientists provide knowledge for the implementation of practice transitions, including through critical assessment of the success of policies and interventions, research that involves experimentation in practice or behaviour change, and in co-development with stakeholders feasible pathways towards resilient futures (Loorbach et al., 2015; Kivimaa et al., 2017; Rodriguez et al., 2018). There is a large body of literature that identifies the role of research in urban adaptation and mitigation strategies, such as to achieve nature-based solutions (e.g., Frantzeskaki et al., 2018) and in transitions to low carbon economies (e.g., Newton, 2014). Urban science is also critical for understanding interactions between climate change and the multifaceted urban system (Solecki et al., 2021). Further, through knowledge co-production science can build capacity in wider communities for the interpretation and use of scientific information (Bansard et al., 2019). This understanding of science, with a focus on problem solving, integration of multiple disciplinary approaches, and participation of non-academic actors, aligns with the tradition of transdisciplinary research (Stock & Burton, 2011). Science can thus input to all stages of urban climate change policy, from agenda setting, policy formulation, and implementation and evaluation, to ensure that transitions draw on the best knowledge available.

Despite its centrality, science does not always translate readily into city climate change policy or practice, which may instead rely on experiential or more informal sources of knowledge (de Wilde & Coley, 2012; Hurlimann et al., 2018). Science uptake is challenged by the long-term nature of climate change information that misaligns with many decision specifications or horizons, such as for building construction (Moss et al., 2019). There are also knowledge gaps on how projected impacts will affect city practice-systems, and on how best to design, initiate and implement pathways for low-carbon and resilience transitions (Bai et al., 2018; Weichselgartner & Arheimer, 2019). Further, the use of new knowledge can be constrained by path dependent governance and dominant institutions that resist change, reflected for example in urban designs that continue to embed car dependence (Low & Astle, 2009). Policies tend to also lag behind research findings on the importance of more integrated and stakeholder-driven approaches to urban system reforms (e.g., Hensley et al., 2014). Such challenges to science uptake can help explain the relative deficit in adaptation implementation (e.g., Preston et al., 2011)

Recognition of the need for innovation to align pathways to the magnitude of climate challenges, as well as to address knowledge gaps, supports calls for science to have a stronger role in urban policy and practice (McPhearson et al., 2016; Bai et al., 2018). It also raises a key question. How can SPPIs be designed and function to bring new learning to the practice reforms needed? Answering this requires research (Rodriguez et al., 2018; Wolfram et al., 2019) and empirical explorations of how practice integrates and is reformed by knowledge. Practice within SPPIs can be conceptualised as the operationalisation of knowledge and policies in applied initiatives, decision-systems and routines. Practice determines the actual carbon intensity and resilience of a city, and how initiatives are implemented. Policies, including strategies and regulation, are key to the framing of practices as they can strongly influence how cities are designed, developed, and operated, including how science is prioritised (e.g., Shapiro, 2016). Progressive policy makers can facilitate research that demonstrates the feasibility of practice change for climate outcomes (Wise et al., 2014; Kivimaa et al., 2017).

5.3 Method

A case study method is used to explore how lessons learned from the renewable energy transition and resilience measures undertaken in Canberra can inform further climate change reforms. The focus is on understanding the science, policy and practice perspectives and interfaces from actual experience to date, to guide a forward-looking reform agenda (Yin, 2003). Characteristics of the ACT make an informative context for this case study, including limited revenue sources and cross-border dependencies (such as for water resources and disaster risk management) within a federated system, access to robust science, and exposure to a hotter, drier and more fire-prone climate.

Data sources for the case study come from documents and expert interviews. Following the literature review to clarify how SPPIs can contribute to climate change transitions in cities, government documents and data from semi-structured interviews informed a thematic analysis on lessons learned from reforms to date and emerging future priorities. Government documents included key policies, strategies, legislation and review reports, and those drawn on are identified and cited in sections 5.4, 5.5 and 5.6 of this article.

Semi-structured interviews (n=17) were undertaken with experts from government agencies and advisory committees (n=6), private sector planners and developers (n=5), researchers (n=3), and urban water and electricity utilities (n=3). The primary criterion for interviewee selection was experience and expertise in the climate change transitions and reforms undertaken in the ACT. Interviews were conducted by telephone, zoom conferencing, or in person between October 2016 and March 2021. Interview information in the paper is categorised by organisational type, notably government (Gov), planners and developers (Pld), research (Res), and utilities (Ut), and quotations from interviews are used to illustrate key concepts and points in the following style (Gov2 or Pld4).

5.4 Case study context

Canberra, the inland capital city of Australia is in a small jurisdiction (the ACT, 2358 km2) with a climate that since the 1970s has become warmer and drier (BoM, n.d.). These conditions increased risks for more severe bushfires, which in 2003 destroyed some 300 properties and in the 2019–20 summer exposed people to prolonged hazardous levels of smoke air pollutants, including inside their homes (Hughes & Steffen, 2014; Hughes et al., 2020; Vardoulakis et al., 2020). The ACT has access to robust climate change science, and science-based priorities for Canberra span reductions in greenhouse gas emissions, and action to prepare for and reduce the risks from increased heatwaves, drought, bushfires, and storm events (CSIRO & BoM, 2015; Fouche & Crawford, 2015; ACT Government, 2019a).

The ACT Government has developed a range of policies that respond to climate change science, growing international action and community concerns. Importantly, greenhouse gas emissions reduction (net zero by 2045) and renewable energy targets are established in legislation, along with an advisory Climate Change Council to connect expert and community views with government policy (ACT Government, 2010). The target for achieving net 100 per cent renewable energy was met in 2019, slightly ahead of schedule. The Territory Plan includes codes that promote planning for bushfire risk and water sensitive urban design, and Government strategies have targets for a carbon neutral waste sector by 2025, 30 per cent urban tree canopy cover and 30 per cent surface permeability by 2045, and for newly leased government fleet passenger vehicles to be zero-emission from 2020–21 (ACT Government, 2008, 2009, 2011, 2018, 2019a, 2019b). Government measures to facilitate business uptake of innovation for climate change include support for a Renewables Innovation Hub and a Demonstration Housing Project (ACT Government, 2019a; ACT

Renewables Hub, n.d.). Key ACT capacities relevant to strong climate policy settings are ‘the population and its preferences – a predominantly urban population with high average incomes and progressive attitudes’ (Res3), and Canberra itself, home of the national government, and science experts and research institutions.

5.5 Towards climate change transitions in Canberra – lessons from approaches to date

Drawing from interviews with government officials, researchers, and planning and development practitioners, and key practitioner and scholarly documents, several key enablers for and barriers to climate change transitions in Canberra can be identified. These are that: extreme weather experience triggered reforms; leadership and policy entrepreneurship were key to the energy transition; interface institutions were influential; a significant unmet practice demand for science continues; and policy siloes and path dependencies inhibit knowledge uptake. This section addresses each of these findings and then identifies strengths and weaknesses in Canberra’s SPPI.

5.5.1 Extreme weather experience triggered reforms

Interviewees agreed that climate change exacerbated weather extremes affecting the ACT in the early 2000s led to the integration of new climate knowledge into select policy and investment decisions for a more resilient city. Response to the catastrophic 2003 bushfires, which commenced in NSW, spanned science, policy and practice to restructure emergency services. Research delivered new insights in high country fire weather and future projections of high fire risk days were incorporated into new bushfire risk assessments (ACT Government, 2014). New partnerships for improved fire management were established, community programs commenced to build preparedness, and cross-jurisdictional fire-fighting measures with NSW resourced, including provision for aircraft and heavy plant for fire suppression. Policy changes were driven by new emergency legislation in 2004 that required strategic bushfire management planning and whole-of-government planning mechanisms for periods of high fire danger (ACT Government, 2014).

Major water security projects for the city were triggered by the Millennium Drought, the worst drought on local climatic records, involving capital works and longer-term risk focused practices (Ut2, 3). New modelling incorporating potential combined climate change and bushfire impacts on ACT catchments found that additional water storage was needed sooner than previously expected, and that existing storage capacity would be inadequate in periods of future drought (ESDD, 2012). Importantly, future climate change scenarios were considered, and on the basis of prudent planning for water security, ACTEW (the then agency responsible for water supply) adopted the 'worst-case' scenario in its long-term water supply planning (ESDD, 2012). The investment in water infrastructure for the city was significant and responded to experience from recent extreme events and future pressures. Very large increases in capacity were enabled, including an enlarged Cotter Dam (from 4 GL to 78 GL), the main water supply for Canberra, purchase of an additional 11 GL of high security water from Tantangara Dam in NSW, and improved treatment capability at the Googong and Mt Stromlo Water Treatment Plants to enhance extraction options. Of note, 'the risk magnitude, while uncertain, supported building redundancy in capacity' (Ut2, 3; ESDD 2012).

In responding to specific catastrophic events, these reforms took forward-looking perspectives and transformed practice for longer term community resilience. Considering climate change was, nevertheless, difficult. While found to potentially have the largest impact on ACT water supply, for example, climate change science advice involved wide ranges and uncertainties (ESDD, 2012). Further, the extremes experienced were not predicted, including then unknown fire-driven tornado weather, and dam inflow levels below the worst estimates projected 30 years in the future. The SPPI in these examples was critical in enabling consideration of climate change science in policy, and increasing risks of extreme weather emphasises the need for ongoing interfaces between future-focused climate science and policy and practice for community resilience.

5.5.2 Energy transition driven by leadership and policy entrepreneurship

From 2008–2016, the ACT Government led a policy transition to achieve 100 per cent renewable energy, a significant outcome in a small jurisdiction with constrained generation capacity and a reliance on a national power grid which supplied 80 per cent of its energy from fossil fuels. Respondents agreed that the transition was driven by a small group of policy entrepreneurs comprising elected officials, government policy makers and expert advisors that shared a vision for reducing the carbon-intensity of Canberra's energy supply, a preparedness to innovate for locally effective solutions, and a willingness for staged experimentation and learning by doing. The ACT was the first jurisdiction in Australia to achieve 100 per cent net renewable energy in 2019, notably through contracted agreement with renewable energy providers located in other jurisdictions.

SPPIs were instrumental to this transition, particularly in framing the transition pathway, and in building Government support for the proposed approach, including by recognising longer-term cost benefits (Gov2). It was apparent early in the process that commonly used Government grant funding processes would not be adequate to realise the outcomes sought, and that a new policy approach would be needed (Gov2). The reverse auction mechanism used was then untested in Australia; it required a new rationale for Government action in the market, new risk management approaches, detailed pathways development, and regulatory and practice reforms to overcome implementation barriers (Gov2). Expert advice helped to ensure that the auction design was incremental and scalable, which built political license for the reforms and resistance to opposition from a national political party (Gov2; Res3). Importantly, the political backing for the transition was at a very senior level, 'the Minister was very engaged, he understood the issues and risks, knew what he wanted and demanded it' (Gov3). This seniority positioned the transition as a whole-of-government priority, and overcame challenges from siloed agencies, skill gaps in the public sector, and short-term budgetary horizons (Gov2, 3). Policy leadership is clearly an influential driver in SPPIs and this case demonstrates how deficiencies in other parts of the interface such as initial knowledge gaps can be overcome. Of note, lessons learned from the reverse auction in the ACT informed uptake of the mechanism in the larger State of Victoria (Gov2).

5.5.3 Interface institutions are important

Boundary or interface institutions have capacities to bridge gaps between science, policy and practice (Kowarsch et al., 2016), and Canberra has the advantage of housing national institutions with world-class research expertise and being small enough to bring key actors and communities together (Gov3; Res1, 3). Principal among the ACT's climate change interface institutions is the Climate Change Council, established by the 2010 legislation to have science, sectors, and policy membership and advise the responsible Minister on reducing greenhouse gas emissions, building resilience, and adapting to climate change (ACT Government, 2010). The advice of the Council was central to the Government adopting in 2018 ambitious and staged targets to reduce greenhouse gas emissions to net zero by 2045 (ACT Government, n.d.). More broadly, the 'Council's role is very positive – a steady presence that builds confidence for more ambitious and innovative policy options, and provides a check point for the Minister' (Res3). The ACT Government's Bushfire Council also connects science with practitioners for advice on bushfire preparedness, and the Government Architect and Chief Engineer bring practitioner expertise to policy and programs. Most respondents noted the value of these expert advisory capacities in a small government.

Collaboration between researchers and non-academic actors is also needed to identify locally suitable low carbon and resilient solutions (Mendizabal et al., 2017; Webb et al., 2018). Canberra Urban and Regional Futures (CURF), a collaborative network hosted by the University of Canberra, operated in partnership with the ACT Government from 2013 to 2018. CURF undertook studies with government support that built the evidence base for low carbon and resilience strategies, and hosted annual forums that connected government, business, and community participants in dialogues on progressing local sustainability (Res1; Gov6). The 2017 Forum, for example, entitled *Working towards a carbon neutral society: Canberra and the region*, enhanced community enthusiasm for proactive emission reduction targets and measures (Res1).

Interface institutions in the SPPI can thus operate in multiple ways to address knowledge gaps, and build trust and understanding between researchers, policy makers and practitioners on climate change reform agendas, as well as facilitate wider support for them.

5.5.4 Unmet practice demand for knowledge

ACT private sector planning and development practitioner respondents called for greater science engagement and evidence-based guidance to build preparedness in Canberra for a changing climate with more frequent weather extremes (Pld1, 2, 3, 4). While requirements for existing energy efficiency measures are clear and accessible, perverse outcomes of high energy efficiency ratings for occupant health are becoming apparent and there is little understanding of effective approaches to manage these trade-offs in practitioner networks (Hatvani-Kovacs et al., 2018a; Pld1). The next steps in reducing the carbon-intensity of the city, such as from embodied energy in buildings or from transport systems, are complex and require tailored knowledge and policy incentives (Pld5; Low & Astle, 2009; Dixit, 2017). Recent policy development on urban trees also requires guidance on what the urban heat island effect and 30 per cent tree cover targets mean for a development site, the best ways to achieve a desired micro-climate, and how to optimise design for tree canopy, water and built infrastructure on that site (Pld1, 2, 4). There is interest in the new Green Star tool[1] on resilience and its capacity to deliver insights on how to measure resilience interventions (Pld4).

There are also lags between the generation of relevant knowledge and its uptake in policy and practice. Research to better understand the risks of more intense extreme rainfall events is relevant to the ACT's stormwater network as many urban sites back on to canals, but is not yet integrated into development practice (Bates et al., 2015; CSIRO & BoM, 2015; NARCliM, n.d.; Pld1). At present stormwater modelling for developments in the ACT is done on a project-by-project basis – 'this is suboptimal and an overarching policy is needed that reflects ARRH[2] recommendations regarding sensitivity testing for more intense events, along with remodelled local 100 year flood-lines' (Pld1). Lessons learned from development of the ACT Water Sensitive Urban Design General Code include that 'reform is staged and takes time' (Pld2). For this code research from the 1990s supported new tools, and then modelling and a policy framework, and gaps still remain in monitoring and evaluation, and in the comprehensive incorporation of climate change risks (Gov5). New knowledge-based decadal pathways for other transition agendas will be needed, including clear steps on how science can progressively be integrated into practice specifications. A focus on practice can thus highlight both the importance of long-term SPPIs for reform acceptance and adoption, and identify specific weaknesses or gaps that need to be addressed for science uptake.

5.5.5 Policy siloes and path dependencies inhibit knowledge uptake

Multiple disconnects can be identified in the ACT between climate change science and city policies and practices that need attention for climate change transitions. Despite the availability of climate change projections, resilience is still a novel policy concept and there is a lack of integration of resilience objectives in building regulation and development planning. Existing buildings are excluded from buildings regulation, for example, which is problematic as around one-third of Canberrans live in housing poorly suited to heatwaves of the current climate (Schirmer & Yabsley, 2018). National buildings regulation does not explicitly address climate change, and the ACT is 'being held back by a national process that is slow, unresponsive, does not prioritise liveability, and does not align with territory

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[1] Green Star is Australia's largest voluntary and independently certified sustainability rating system for buildings, fitouts and communities, developed by the Green Building Council of Australia.
[2] The Australian Rainfall and Runoff Handbook (ARRH), developed by Engineers Australia, is a guideline for flood estimation in construction that has been updated to consider the implications of a changing climate.

emission reduction targets' (Gov2). 'Climate change is also not mentioned in the ACT's current planning and development legislation, or Territory Plan (2007), which will increasingly challenge adaptation', although there is commitment now for a review of that Plan (Gov1; ACT Government, 2020). The result is that highly energy efficient new developments occur in areas at risk of bushfire or embed car dependence (Pld1; Gov6). That the ACT's Emergency Services Commissioner and the Bushfire Council, both key interface institutions, have no role in constraining developments in high-risk areas is one explanatory factor identified by several interviewees (Gov1, 4, 6).

Path dependence is emerging in research on cities to help explain why climate change knowledge is not being more widely reflected in practice. Technical and institutional path dependence have been identified as key in explaining why roads dominate transport planning and significantly influence land use planning in Australian cities, and why low-density suburbs proliferate that constrain active travel options (Low & Astle, 2009; Bunker, 2012; Hensley et al., 2014). In this context, Canberra is a sprawling low-density city with high levels of car dependence; in 2016 for example some 91 per cent of Canberrans relied on private transport to get to work, with most journeys considerably less than 15 kilometres (Loader, 2019). Planning requirements reinforce this car dependence, with end-of-trip facilities for active travel subordinated and car parking required in developments, even those close to public transport networks (Gov3; Pld1, 2, 3). Beyond transport, the ACT Government's dependence on land release for revenue, and goals of cost and time minimisation in development also suggest path dependencies in the patterns of urban development and building types. 'Building companies have plan types they preferentially use, reinforcing a market that is not aligning with greener urbanism' (Pld4). Further, commonly used building types embed air conditioning use which can decrease the uptake of other adaptation techniques and contribute further to the urban heat island effect (Hatvani-Kovacs et al., 2018b).

Conventional approaches to cost benefit analysis (CBA) are also reinforced by cost saving government and industry goals, and a path dependent focus on factors that can be readily monetised. This results in development decisions with short-term cost and benefit horizons, with co-benefits and the longer term environmental and social dividends from stronger climate practice poorly considered (Pld1, 4). At the same time, leading practitioners have demonstrated innovation and viability in green developments, with the Campbell 5 urban renewal project, for example, converting contaminated land into green space and streets, and re-using water to deliver a net improvement in water security from the precinct (Pld4). Lessons have also been learned on the value of wider CBA approaches from major projects in the ACT. 'Traditional economic analysis would not have supported construction of the city's light rail – wider economic and climate wise benefits needed consideration' (Gov6; ACT Auditor-General, 2016), 'the enlarged Cotter Dam took longer timeframes in benefits assessment than standard CBA' (Pld4), and an 'co-benefits were important in the case for government investment in renewable energy' (Gov2). However, wider application of such approaches is hampered by knowledge gaps in valuing the co-benefits of climate change measures, and a Treasury priority for cost minimisation (Gov3).

5.5.6 Strengths and weaknesses of Canberra's climate change SPPI

Having discussed these lessons learned, there are emerging points that can be made about the SPPI in Canberra for facilitating climate change city transitions. Table 5.1 summarises the strengths and weaknesses of Canberra's climate change SPPI, drawing on interview data and document analysis. Those that are particularly important in enabling robust interfaces are identified with a star (*).

Table 5.1. Strengths and weaknesses in Canberra's SPPI relevant to climate wise transitions.

SPPI component	Strengths	Weaknesses
Science	• Strong climate change and built environment research capacity and skill • Science membership of the ACT Climate Council* • Demonstrated research experience in contributing to renewable energy transition*	• Siloed resilience science for the city • Lack of mechanism to connect resilience science with practitioners* • Lack of evidence base for resilience pathway options
Policy	• Growing understanding that political leadership for renewable energy and sustainability can pay dividends. Provides confidence for further reforms • Robust sectoral strategies on emissions reduction and urban forest	• Dependence on land release for revenue can de-emphasise climate change objectives for reduced urban sprawl and car dependence • Gaps in city policy for existing buildings, vulnerable groups, embodied energy, and linkages between disaster risk reduction and urban development*

	• Legislated targets for energy sector transition • Capacity and expertise of Climate Council and interface institutions* • Lessons from wider CBA approaches in major climate wise investments could be more broadly applied*	• Skill gaps in public sector regarding strategic resilience and transformation policy • Risk and vulnerability assessment not undertaken regularly to inform policy* • Limited resources constrain expert roles (Chief Engineer, Design Review Panel, ACT Government Architect) addressing cross-cutting issues*
Practice	• Growing experience in understanding city coping capacity to extreme events • Leading practitioners demonstrating that addressing climate change can be cost-effective • Recent tools from Engineers Australia (ARRH) and Green Star on resilience build capacity* • Uptake of energy efficiency and renewable energy measures in housing	• Accredited professional climate change training not required* • Short term horizons in construction decisions exclude risks over building life • Assumptions that building for resilience adds significant cost • Site-scale focus can lead to suboptimal neighbourhood canopy cover and active travel outcomes • Dependence on air conditioning for occupant comfort • Emphasis on operational risk management overlooks longer term increasing risk profiles

5.6 SPPI reform for effective climate wise transitions

Climate change SPPIs in Canberra have contributed strongly to realised transitions and reforms, but their partial and fragmented nature requires attention for further transitions to be achieved. Significant climate change science capacities are accessible, but their use is relatively limited with policy agencies tending to engage with researchers in an ad hoc manner. Advisory councils provide robust evidence-based advice to particular ministers, but there is an absence of formal climate change knowledge sharing across government and little translated knowledge available to development industry and planning professionals. In the absence of strong policy entrepreneurs, the current weaknesses of the SPPI will likely disadvantage effective next steps in complex agendas such as urban resilience and reductions in embodied energy and carbon-intensity of the transport and waste systems beyond those directly managed by government. Without reform, risks will increase to assets and people from climate change impacts, and policy settings may prove ineffective in achieving deeper emissions cuts and adaptation goals. Three key themes emerge that can strengthen Canberra's SPPI for climate wise transitions: governance for integration, science partnerships for implementation, and stronger interface institutions.

5.6.1 Governance for integration

The intersection of low carbon and resilience imperatives from climate change science with the multi-dimensional nature of cities highlights the need for governance that can facilitate the integration of knowledge in policies and operational practices, and whole-of-system strategies. Consistent with traditional siloed governance of built environment practices, sectoral strategies have been developed that aim to reduce greenhouse gas emissions across Canberra, provide water security for the medium-term, and ameliorate risks from the urban heat island effect through an enhanced urban forest (ACT Government, 2009, 2019a, 2019b). Next steps in transitions to a low carbon and resilient city, however, will require governance that can address gaps and bridge disconnects, notably between planning and building codes, building energy efficiency and health, and current practices and the magnitude of likely climate risks (Shapiro, 2016; Dixit, 2017; Schirmer & Yabsley, 2018). Heatwaves are projected to become more frequent and intense, and integrated strategies are needed to span building design, public health and community services, and urban planning, and not contribute further to the urban heat island effect (Hatvani-Kovacs et al., 2018b). Similarly, reducing the city's embodied energy will require new approaches to managing construction waste across the SPPI, including incentives for buildings and materials reuse, and an emissions inventory approach that can properly quantify and track performance (Fouche & Crawford, 2015). As one planning practitioner put it 'the whole system is not broken – but integration needs a lot more attention' (Pld1).

Governance attention to the integration of science knowledge can also enhance the capacities of decision-makers and practitioners to progress low carbon and resilience reforms. For example, provision of regularly updated climate change exacerbated hazard zones in the ACT Territory Plan enables urban professionals to readily appraise changing risk profiles and the effectiveness of risk reduction planning and construction measures, and enhances anticipatory capacities. The systematic collection of feedback information within SPPIs can also build adaptive governance capacities from learning about what is and isn't working.

Research participants indicated that 'current problems in implementation, where known risks are not adequately being addressed in development, need to be more clearly identified and learnt from', including where 'dominant cost minimisation objectives need to be challenged' (Gov5; Res2).

5.6.2 Science collaboration and partnerships for implementation

Science for climate transitions in Canberra is fragmented and inadequately linked to practice. Climate change brings systemic, unprecedented and damaging risks, and decision-making needs to be future-focused, draw on climate-change projections relevant to asset life, and supported by regularly updated knowledge. While the ACT has good projections information, most 'science tailored to the built environment is commissioned, one-off and project focused. It cannot be readily built upon or updated' (Gov3). With strong research and outreach capacities, the ACT is arguably well positioned to establish collaborative approaches for the synthesis and sharing of knowledge regarding the design and implementation of climate transition pathways. Such collaborative partnerships were recognised in the 2018 Cities and Climate Change Science Conference, sponsored by the Intergovernmental Panel on Climate Change and other international organisations, as being able to drive tailored and actionable knowledge for climate change solutions in cities, particularly where science is evolving and uncertain (Solecki et al., 2021).

Critically, there is a need for shared understanding of changing climate risks, city exposure profiles, and the risk mitigation potential of current measures across ACT government, private sector planning and development professionals, and the wider community. Regular and transdisciplinary risk assessment processes, that draw on multiple sources of evidence from science, policy and practice, are needed to build this shared understanding and inform identification of required interventions over time. Co-production of the risk assessments will strengthen implementation capacities to reduce vulnerabilities, such as from continued developments in known historic fire paths, and existing housing that is unable to provide occupant comfort in heatwaves (Gov4, 6; Pld1; Moss et al., 2019).

Practitioner challenges in interpreting and using climate change science for implementation also need to be addressed. Integrated guidance is needed to build capacity to deliver to policy goals on carbon neutrality, urban forest micro-climates, and well-being; practitioners are uncertain what these terms mean and how they can be realised at the scale of a development site (Gov1; Pld4). Leading practitioners in the ACT are also interested in collaborative partnerships that can exceed targets and reduce embodied energy, but grapple in an absence of policy leadership and guidance (Pld5). Such interests are discouraged by inventory methods which exclude carbon intensive materials for construction not sourced from the ACT (Pld5). Professional development and accreditation across such issues, updated regularly, could help align the skills of practitioner groups with the implementation challenges of climate transitions (e.g., Hopkirk, 2020).

5.6.3 Strengthened interface institutions

As noted, the ACT has the building-blocks for research-action networks to inform the design and implementation of robust transition pathways. Such networks need active community and researcher participation, which can help make transparent and challenge the path dependence of influential urban regime actors (e.g., Hensley et al., 2014). Respondents agreed that strengthened existing interface institutions could bridge research, government, professional, industry and community interests. The Climate Council, with its cross-disciplinary membership, has capacities to lead connectivity across government interfaces, and needs a mandate to undertake forward-looking analysis with the Bushfire Council, Chief Engineer, Government Architect, professional groups and the wider community. Similarly, the Bushfire Council and Emergency Services Commissioner roles could be strengthened to provide longer term strategic advice, and to inform decision-making on sites for city development, including to the Strategic and Emergency Management Senior Officials Group, 'which is influential in bringing the heads of all agencies together' (Gov4, 5). At present, 'advisory bodies are set up and managed differently by Directorates – this increases the difficulty in getting advice on complex cross-government issues' (Gov3). Collaborative networks such as CURF can also help link constituencies through research and dialogue on steps, stakeholder roles and co-benefits of climate change action, and engagement to explore the community's appetite for reforms (Flannery & Gilmour, 2018; Res1).

Finally, greater attention is needed to facilitate industry leadership in such interfaces. Energy policy and research have been strengths in Canberra's climate change SPPI, and there is now an opportunity to challenge industry to help remove barriers to the uptake and implementation of net zero practices. Demonstration housing projects, for example, can become living laboratories in partnership with research and industry, to build and scale-up the learned experience for reform implementation.

These themes are clearly interlinked. Strengthened interface institutions will help identify where governance is required to connect siloes, and where practitioners need knowledge or guidance to implement policy. Research to support implementation will also identify where policy interventions are successful, and where barriers exist, and inform pathway considerations of the interface institutions. Further progressing climate change transitions requires sustained research and collaboration, the cost of which, informed by the cost-benefit of disaster preparedness measures in Australia (Deloitte Access Economics, 2013), will likely be modest relative to the cross-sectoral and ongoing benefits of a low-carbon and resilient city. In addition to an effective SPPI, this article finds that progressing transitions will also require, for example, policy leadership to address implementation barriers and facilitate more ambitious reforms. In this way SPPIs can be understood as a necessary but not sufficient enabler of transitions for adaptation or mitigation.

5.7 Conclusion

Cities are crucial to the achievement of climate change goals, and science indicates that transitions to low carbon and resilient cities must occur by mid-century if we are to avoid catastrophic climate change. With many cities built prior to significant concerns about carbon emissions and climate change, and with urbanisation increasing, a shared understanding of how transitions can be enabled and implemented is needed. This paper identified lessons from steps taken by a medium-sized city, Canberra, with resource constraints and path dependencies, towards a low carbon and resilient future. 'An important lesson is that even small jurisdictions can innovate' and influence other larger jurisdictions (Gov2; Res3). Lessons learned also contribute insights on how further challenges can be tackled, including which capacities and governance approaches proved effective for Canberra's location, and context. Factors that can trigger transitions, notably extreme weather impacts, policy entrepreneurship, and partnerships to overcome implementation barriers were also revealed. These triggers align well with those described in recent urban transition literature, including political authority and leadership, learning from natural disasters, and collaboration between stakeholders and scientists for the upscaling of innovation (e.g., Mendizabal et al., 2018; Webb et al., 2018; Hölscher et al., 2019).

The article highlights how SPPIs contribute to a more nuanced understanding of how climate wise reforms and transitions can be realised. Attention to SPPI components reveals where strengths and capacities exist for reforms, how interface mechanisms connect knowledge with policy and practice, and where interventions are needed to address weaknesses or obstacles. Canberra needs now to overcome siloed governance and practice, and strengthen its interface institutions. Such governance reforms, in conjunction with knowledge collaborations for problem solving, could be relevant to other medium-sized and resource-constrained cities exploring how to overcome implementation barriers to climate change action (Bai et al.; 2019; Moss et al., 2019). Building on these findings, further research could explore in more detail the dynamics of the collaborations between policy, science and practitioners to tease out factors that underpin social learning and support adoption of more transformative action. Finally, triggers of change are important to initiate transitions, but can be disruptive, and further research could usefully explore how such triggers can support anticipatory perspectives and sustain momentum.

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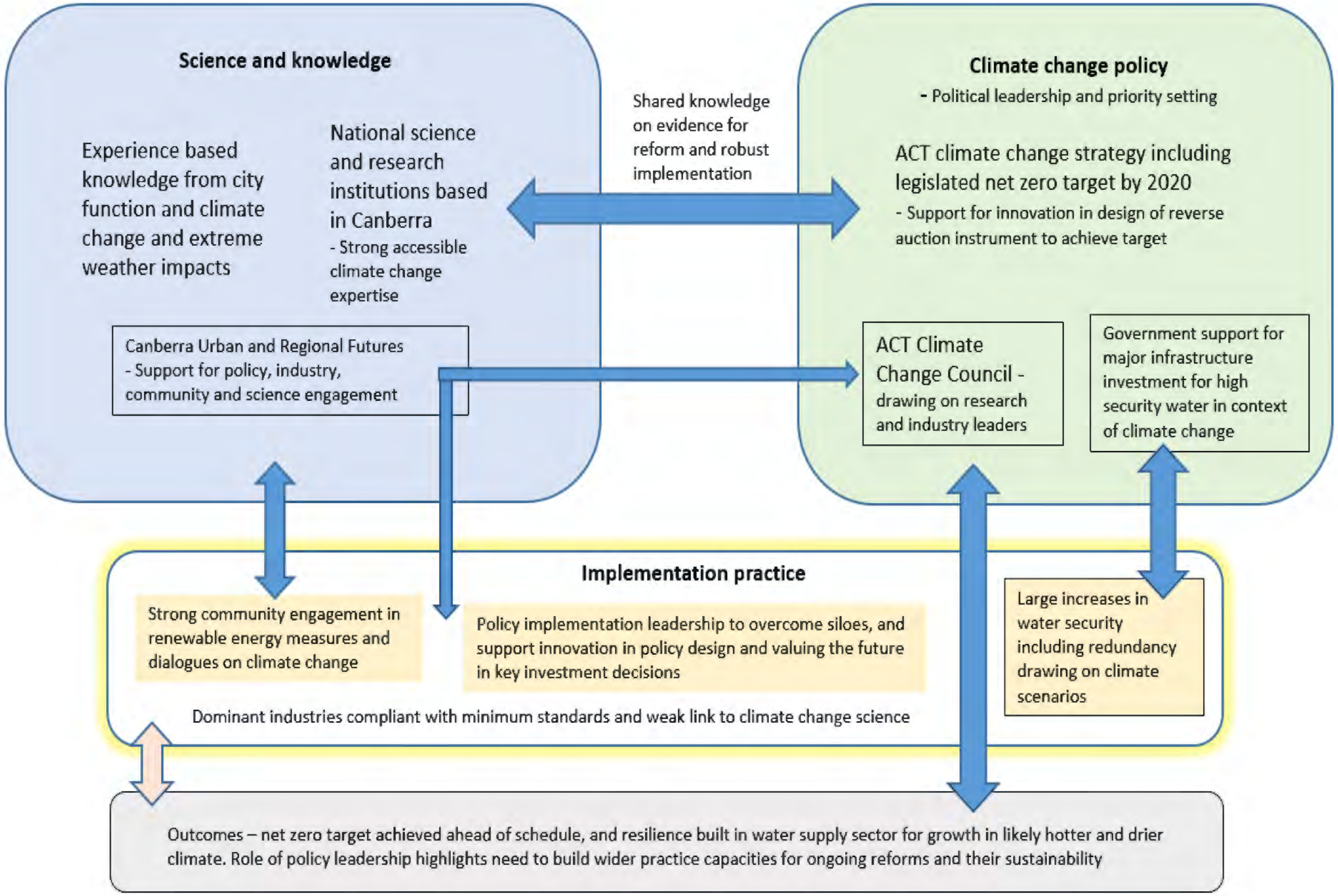
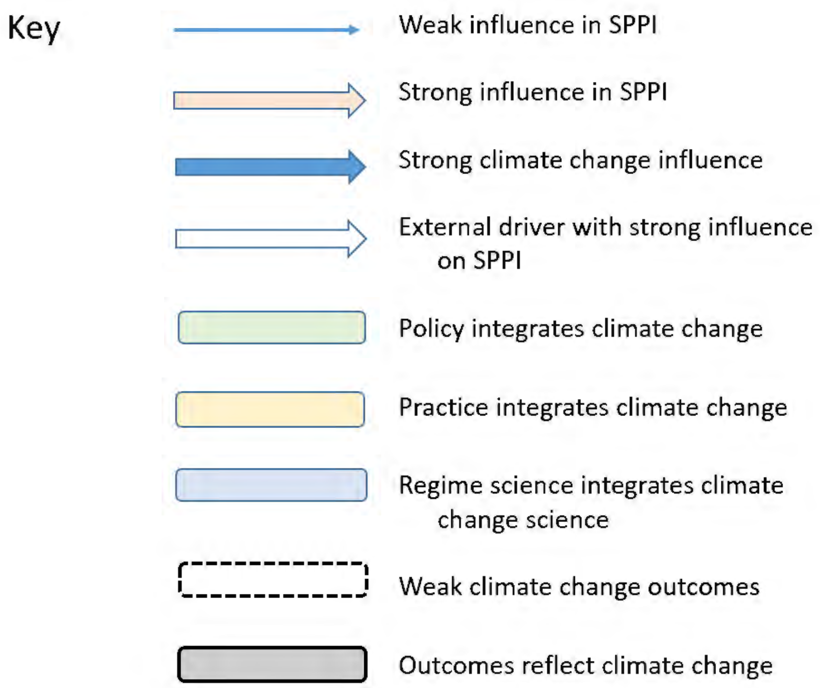
Annex Chapter 5. City of Canberra - climate change SPPI (renewable energy transition snapshot)




Key
Weak influence in SPPI
Strong influence in SPPI
Strong climate change influence
External driver with strong influence on SPPI
Policy integrates climate change
Practice integrates climate change
Regime science integrates climate change science
Weak climate change outcomes
Outcomes reflect climate change

Chapter 6

Attributes of effective national partnerships for environmental challenges – managing ozone-depleting and synthetic greenhouse gases in Australia

Abstract

The magnitude and consequences of current global environmental challenges require partnerships across sectors and scales. Accordingly, there is a need to learn from partnerships that have been effective. This article analyses a successful national partnership that is contributing to implementation of the Montreal Protocol. It uses a case study methodology that draws on expert views from industry, government, and science, and contributes to the literature on partnerships in several ways. First, it highlights the relevance of insights from science-practice interfaces, and on institutions that can work across scales, for partnerships where knowledge is incomplete, and the challenges are dynamic. Second, it identifies five attributes of the successful multi-stakeholder partnership for Montreal Protocol sectors in Australia. While the wider applicability of these attributes needs testing, they are proposed for consideration by researchers and practitioners in partnerships where environmental challenges demand new knowledge and technologies, and systemic industrial practice change across scales.

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6.1 Introduction

The complexity of current environmental challenges – typically embedded in societal development or industrial production practices – has led to a proliferation of partnerships that draw on multiple capacities to enhance the sustainability of such practices. It is increasingly recognised now that transformational practice change will be required to stem environmental degradation and address challenges to sustainability (e.g., Sachs et al., 2019), and that multi-stakeholder partnerships (MSPs) can be an inclusive vehicle for the identification and implementation of transformational pathways. A finding of concern, then, is that there are relatively few cases of successful partnerships that resolved a socio-environmental problem with global dimensions (e.g., Pattberg & Widerberg, 2016). Further, scientific research indicates worsening conditions for many transnational environmental problems in fields where multiple partnerships exist (e.g., Steffen et al., 2018; Broman et al., 2017). As tipping points towards irreversible degradation from current environmental trends come closer, there is growing urgency to learn from examples of success to date, understand their attributes and how they were realised, and consider whether they have broader applicability. This paper aims to enhance understanding of the attributes of successful partnerships by exploring a national partnership that contributes to the effective implementation of the Montreal Protocol on Substances that Deplete the Ozone Layer (the Montreal Protocol).

The effectiveness of partnerships that deliver reductions in ozone depleting substances under the Montreal Protocol stand in contrast to many environmental partnerships that do not fully achieve their objectives (e.g., Horan, 2019). Multiple studies, particularly at the global scale, have documented achievements of the Montreal Protocol; these span halted production of key ozone depleting substances (ODS), observed healing of the earth's protective ozone layer, and measured ODS levels in the atmosphere generally in line with the Protocol's phase-out schedule (Engel & Rigby, 2018; Gonzalez et al., 2015). Identified enablers for these achievements include the creation of partnerships that reconciled business interests and public benefits, global pursuit of science and the organisation and mobilisation of expertise to translate technical knowledge into implementable solutions, and governance that transcended traditional national interests of autonomy (Andersen et al., 2018; Canan & Reichman, 2002). Few of these studies, however, explore in detail how the interdependencies between national and transnational partnerships can contribute to effectiveness (Pattberg & Widerberg, 2016; Horan, 2019). This needs rectification as activity at a national scale, supported by locally resonant and globally robust knowledge, is essential to achievement of goals and targets in international agreements (e.g., Höhne et al., 2017).

This paper explores the MSP in Australia that enabled the effective national control and management of ODS and synthetic greenhouse gases (SGG),[1] namely the key players, drivers and enablers, and, in particular, their responses to the science-defined challenge role of the science-policy interface. The aim is to tease out the attributes of the successful partnership from this analysis, to understand how the implementation of systemic reform occurred. This aim aligns with the priority now afforded means of implementation, including partnerships and new governance frameworks, for realising transformations for sustainable development (Horan, 2019).

National partnership in this paper is defined as the voluntary collaboration between within-country non-governmental and governmental actors, each with national-scale interests in the address of complex problems. This definition draws on definitions of MSPs from the sustainable development literature, but differs from other MSPs in the scale of its focus and in having an open challenge-focused function, rather than a more typical focus on either knowledge sharing, service provision, or standard setting (Beisheim & Simon, 2016). Australia provides a useful case study on the topic of implementation of the Montreal Protocol due to the strength of its science and industry partnership and preparedness for leadership in this field, including in engagement with national government and in global forums.

The paper draws on scholarly and practitioner literature, combined with semi-structured interviews with scientists, industry representatives and government officials, to address the research question: what are the attributes of the science-practice partnership that underpinned the effective management of ODS and SGG in Australia? The main contributions of this paper are to deliver new insights on how national-scale partnerships can help implement an international agreement, particularly regarding the role of science policy interfaces and transnational links in such national partnerships. In addition, the paper contributes by identifying success attributes of a national partnership that may be important for dealing with today's challenges. Lessons from this case can also contribute to the wider ozone and climate change response literature.

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[1] There are links between ODS and SGG. SGG include hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), alternatives to the ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), that are also potent greenhouse gases with global warming potentials thousands of times greater than carbon dioxide. Most ODS including CFCs, HCFCs and halons also have very high global warming potentials.

The structure of the article is as follows. Section 6.2 summarises relevant literature for the article, including on the characteristics of successful partnerships. Section 6.3 outlines methods and data sources drawn upon in this paper. Section 6.4 introduces the case study on the management of ODS and SGG in Australia, including an historical overview of key developments, as well as presenting findings relevant to the research question. Section 6.5 then explores the wider implications of the findings, notably on the alignment of this partnership with governance features relevant to solving the complex problems of the Anthropocene. It concludes with a consideration of areas where further research is needed.

6.2 Partnerships for complex environmental challenges

MSPs are an increasingly used organisational strategy to address complex environmental problems. Solutions to such problems are beyond the reach of any single organisation and require the involvement of multiple actors with diverse skills and capacities (e.g., financial, technical, policy, market-based) (MacDonald et al., 2019). The appeal of partnerships is derived from their perceived mutual benefits, where the complementary knowledge fields and capacities of partners can promote shared understanding, integrated solutions suited to complex problems, and management and resolution of conflict (Margarum & Robinson, 2015). Transnationally, partnership proponents argue that coalitions between governments, business and civil society can help address global governance deficits in participation, deliberation and implementation, and increase the legitimacy and effectiveness of multilateral policies (Pattberg & Widerberg, 2016; Bäckstrand, 2010). Partnerships thus have capacities that can facilitate reforms, with Horan (2019) arguing that partnerships are uniquely equipped to harness the means of implementation for transformation, such as through mobilisation of knowledge and resources to realise system-wide change.

Case literature on partnerships for environmental or sustainability objectives has proliferated in recent decades across all scales (Ostrom, 2006). While the outcomes of such partnerships are diverse, the literature points to disconnects between the ideals of the partnership concept and its practice, with many partnerships achieving less than anticipated (Worley & Mirvis, 2013; Pattberg & Widerberg, 2016). This has spurred research into the factors that inhibit effective partnerships and into the conditions for their success. Partnerships are usually asymmetric, be they between governments and communities, funders and recipients, or governments and regulated industries, and capacity or power imbalances can result in an uneven distribution of burdens and benefits (Coaffee & Coulson, 2005). The complexity of sustainability issues highlights challenges for partnerships requiring long-term coordination, resourcing, and balancing of diverse short- and longer-term interests (Margerum & Robinson, 2015). Partnerships involving policy and practice reform are also vulnerable to changes in policy settings and political champions with changes in government leadership. Along with effective goal-setting and management processes, the literature on partnerships suggests that equality of partners, trusted inter-organisational relationships, incentives to take action, and systems that facilitate learning are all characteristics of more successful partnerships (MacDonald et al., 2019; Pattberg & Widerberg, 2016; Margerum & Robinson, 2015).

Attention to the response capacities of partnerships to address dynamic and large-scale socio-environmental challenges raises three areas that merit greater consideration. The first relates to the importance of links between national and transnational scales in partnerships (Andonova, 2014; Mol, 2007). National governments are instrumental in the implementation of global instruments; supporting research to understand environmental challenges; and framing societal values and incentivising communities and industries to act (Mummery & Mummery, 2019; Jordan, 1998). National governments thus have important roles in achieving environmental outcomes beyond their territorial borders, and in addressing normative concerns, such as legitimacy, accountability, and fairness, domestically and in wider engagement (Pattberg & Widerberg, 2015). Cross-scale MSPs that aim to drive sustainability transformations also recognise the importance of national contextualisation and tailoring for successful implementation (e.g., van Hille et al., 2020).

The second area that could benefit from greater attention is the role of science and emerging knowledge in partnerships. Large-scale socio-environmental problems are typically knowledge-intensive and not comprehensively understood, yet science organisations are rarely identified as central actors in partnerships. This is despite awareness that science has called for enhanced responses in multiple fields, developed knowledge of sustainable solutions, and demonstrated that practice and societal transitions are necessary and feasible (Broman et al., 2017). Research insights on science-practice interfaces can thus contribute to partnerships literature, including on the qualities of decision-relevant science (credibility, relevance and legitimacy attributes, capacity for translation to inform action, and iterativity), and the value of long-term collaboration between knowledge producers and users for problem-solving and knowledge dissemination and uptake in practice (Linnenluecke et al., 2015; Kirchhoff et al., 2013). Further, barriers to knowledge uptake such as weak mechanisms that institutionalise knowledge in management and regulatory standards, or an absence of guidance to enable its use, need to be addressed in partnerships (Dilling & Lemos, 2013; Iyalohme et al., 2013).

Third, the complexity of current socio-environmental challenges demands greater consideration of the governance features of partnerships. It is clear that many existing systems, practices and processes need reform for sustainability, and there is a growing call for scholarship into a more dynamic institutionalism, and into understanding effective transdisciplinary and empirical co-development approaches (Dryzek & Pickering, 2018; Sabel & Victor, 2017; Hoffman & Jennings, 2015; Lövbrand et al., 2015). The characterisation of four imperatives for national governance in the Anthropocene by Mummery and Mummery (2019) provides a useful framework to analyse the capacities of partnerships at this scale to contribute to reform agendas. The imperatives, with minor modifications, are (i) recognition of the primacy of the global environment; (ii) transdisciplinary knowledge generation; (iii) anticipatory and reflexive institutions; and (iv) learning from and supporting experimentation. Collectively, they recognise that action is needed on many complex socio-environment challenges while knowledge remains incomplete, that emphasis is needed on learning and innovation for problem-solving, and that a revaluation of the environment relative to other outcomes will be required for global sustainability objectives to be achieved. The alignment of the imperatives with the attributes of this case study is considered further in sections 6.4 and 6.5.

Regarding the case subject of this paper, there is a considerable literature on the Montreal Protocol where determinants of global achievements align with characteristics of successful partnerships such as coalitions that can address deficits in implementation, and systems that draw on complementary expertise to find effective solutions and facilitate their uptake (e.g., Andersen et al., 2018; Canan & Reichman, 2002). With ozone depletion a global issue it is perhaps unsurprising that there is less literature on national implementation of the Montreal Protocol; one case from the United Kingdom finds that national policy networks, including actor connections to decision making and strong multi-level interactions, were important for implementation pathways (Jordan, 1998). While the importance of a cross-sectoral commitment in Australia to implement the Montreal Protocol has been noted (e.g., Rae, 2012), a detailed exploration of the attributes of that partnership has not previously been undertaken.

6.3 Method

The methodology is based on a case study of partnership between industry, science and government for the control of ODS and SGG in Australia that delivered effective outcomes and at times world-leading approaches. The focus is on how and why the partnership enabled proactive reforms that delivered tangible environmental results and changed industry practices. Australia has characteristics that provide an instructive context for this case study, including a globally strong science capacity, a federal system of government where most implementation responsibility rests with state governments and national coordination is generally contingent on efficiencies, and a relatively small ODS and SGG management sector where peak industry bodies and regulators know each other. Australia was also one of the world's largest per capita users of CFCs and halons prior to the Montreal Protocol (Rae, 2012).

The data sources for the case study are from semi-structured interviews and key practitioner and academic documents. Interviewees are expert and leaders in the field, selected for their capacities to contribute insights and reflections relevant to the research question, from peak industry bodies, research organisations and state and national governments that comprised members of the national partnership. Ten people were interviewed which aligns with the relative smallness of the field in partner organisations in Australia. Interview data is categorised based on whether interviewees were from industry (ind), research (res), and government (gov) in the following style (Ind1, Ind2, Res1, Res2, Gov1, Gov2).

Documents to support the analysis include industry reports and communication magazines, and government strategies, legislation, annual reports, and progress reports regarding treaty implementation, identified through web searches and interviews. The documents are identified and cited in sections 6.4 and 6.5 of this paper. An inductive thematic analysis was then undertaken across both interview and documentary data to identify attributes of the effective partnerships in this case. Finally, the alignment of the attributes was then considered against the four imperatives for governance in the Anthropocene identified in section 6.2, in order to better understand their success in the context of institutional requirements to address large-scale and multifaceted socio-environmental problems.

6.4 Managing ODS and SGG in Australia – case study

The core Australian partnership that is the subject of this case study comprises the Australian Government department responsible for the environment, the Commonwealth Scientific and Industrial Research Organization (CSIRO) (Australia's leading publicly funded research organisation), and industry associations spanning Montreal Protocol industries. Evidenced by growing engagement and information sharing, the voluntary partnership can be considered functioning by around 1980, with core partners having structured links to the key ODS actors in Australia, notably state governments, industry end-user sectors and NGOs. Across all core partners the following decades saw a dramatic transformation in approach and capacity. The refrigerants industry[2] for example, transformed from a dispersed and poorly regulated sector, with inconsistent practices and limited compliance mechanisms for gas disposal, to an industry with strong links to government and science organisations, and effective regulation, that is achieving substantial environmental outcomes (DAWE, 2019; Navigant, 2016).

While it is not possible to cover all aspects of Australia's national partnership for ODS and SGG management in this paper, section 6.4.1 provides a broadly sequential overview of the key initiatives from each of the partner organisations. These are summarised in Table 6.1, along with their timelines and partnership functions. Section 6.4.2 then describes the attributes of the successful partnership that emerge from the analysis.

Table 6.1. Key steps in national partnership, functions realised, and timelines.

Key step	Timeline	Partnership functions
Establishment and maintenance of high-quality monitoring and research capability	From mid 1970s	• Information sharing – domestically and internationally • Problem identification • Resource commitments (linking science and industry institutions)
Public frameworks for chemical notification, assessment, and import control	Late 1970s	• Transnational dialogue and learning • Agenda and standard setting • Industry deployment/control experience
Experimentation in end-use controls (sub-national level)	1980s	• Experimentation and innovation • Enhanced community support
Formation of peak industry body	1985	• Coherence building across industry sectors

[2] The industry is economically significant, directly employing 300,000 people and with total expenditure in 2016 equivalent to 2.3 per cent of Australia's GDP (Brodribb & McCann, 2018).

		• Problem identification and industry agenda setting
Ratification of the Montreal Protocol, and subsequent implementation National interjurisdictional and industry consultation forums	1989 +	• Target setting for consumption phase-down • Transnational industry-research problem solving and capacity building • Technology advance coalitions • Policy development and standard setting • Information sharing across scales
Refrigerant Reclaim Australia Industry accreditation and licensing	1993	• Technology advances (reprocessing and destruction) • Industry capacity building
National regulation of import, export, licensing and end-use controls	2004	• Policy coherence across state jurisdictions and industry • Target based regulation that allows for innovation

6.4.1 Australia's approach to ODS and SGG management – key steps in an effective partnership

The science community in Australia sought early to understand change in the stratospheric ozone layer. Responding to a landmark paper in the highly-regarded journal *Nature* in 1974 that linked CFCs (chlorofluorocarbons) to destruction of the ozone layer, CSIRO scientists (Paul Fraser and Graeme Pearman) organised purpose-built instrumentation and, with the newly founded remote and pristine Cape Grim research site in Tasmania, commenced high quality atmospheric monitoring in 1976. The CSIRO atmospheric research activities constitute arguably the most comprehensive non-carbon dioxide greenhouse gas measurement program in the world (Fraser et al., 2018), and by the late 1970s Cape Grim researchers had delivered major new insights into the understanding of trace gas transport, for example between the Northern and Southern Hemispheres, and Fraser was invited to join a new international Atmospheric Lifetime Experiment that linked atmospheric research with industry CFC data and confirmed the threat to stratospheric ozone (Fraser et al., 2018). Industry interest in the research was high, with the first three years funded by the US refrigerant manufacturers, followed by funding support from the NASA Mission to Planet Earth and the Australian fluorocarbon industry (critical to release matching funding from CSIRO) (Res1).

Robust science which confirmed long CFC atmospheric lifetimes and increasing concentrations, along with concerns of growing danger to human health, agricultural production, and natural ecosystems, was critical in the negotiation of the Montreal Protocol in 1987. The 1985 discovery of the Antarctic ozone hole by scientists brought urgency to the negotiations and shifted positions of powerful groups opposed to rapid reduction (Maxwell & Briscoe, 1997). The success of the Montreal Protocol has been well documented (e.g., Canan et al., 2015; Gonzalez et al., 2015), with identified enabling factors including mechanisms for collaboration between scientific and technological bodies which supported swift reliable assessments and innovation diffusion (Canan et al., 2015). Further, the Protocol's requirement for periodic re-evaluation based on new knowledge highlights the value of technical expertise and a scientific culture for effective implementation (Canan & Reichman, 2002).

Governments in Australia were also positioned well to respond to emerging knowledge of the risks of CFCs and other ODS by the late 1970s. The approach taken in building frameworks to manage environmentally hazardous chemicals such as PCBs[3] meant that Australia, by around 1977, had in place: a national scheme for the notification, assessment and control of hazardous chemicals; an inter-jurisdictional National Advisory Committee on Chemicals (NACC); an Industry Liaison Sub-Committee; and experience in phasing out the importation of hazardous chemicals with negotiated industry agreement (Gov5). Partnership with the OECD's Special Programme on the Control of Chemicals (established in 1978), then very influential in transnational dialogue and learning, enabled Australia to benefit from leading practices regarding notification approaches, laboratory standards for testing, and mutual acceptance of testing data (Gov5).

A range of measures by state and territory governments to manage end-use and disposal of ODS followed a detailed assessment of CFCs by the NACC (around 1980). Not surprisingly there were inconsistencies in state government approaches to licensing, certification, training, and compliance, including the specified gases covered (Gov2). Some state measures were leading practice, such as the Victorian Government's management of halons which included establishment in 1990 of a Halon Essential Uses Panel with industry to phase-out gas use apart from very limited uses where no safe alternative existed. Other initiatives, however, highlighted the need for further reform, such as one jurisdiction's 'late

[3] Polychlorinated biphenyls are highly toxic compounds previously used widely in such applications as electrical equipment and hydraulic fluids.

1980s regulation requiring return of gas cylinders – too big a burden for the one functioning company in the state capable of receiving them' (Ind1). Community sentiment at the time was for strong government action, bolstered by concerns about the 1985 Antarctic ozone hole and the effective national 'Slip, Slop, Slap'[4] campaign initiated by the Victorian Cancer Council. In response the National Strategy for Ozone Protection 1989, following Australia's ratification of the Montreal Protocol, set a national target of 95 per cent phase-out in CFC and halon consumption by 1995 (when the Montreal Protocol advocated a 50 per cent reduction in consumption of CFCs by the year 2000) (DEH, 2001).

Growing industry concerns about inconsistent state regulation, environmental risks, and a lack of clarity in directions of policy development led to the formation of the Association of Fluorocarbon Consumers and Manufacturers (AFCAM) as a peak industry body in 1985. AFCAM brought the industry together and enabled more coherent advocacy and strategy development. While import control measures were in place for ODS through national legislation, industry leaders were becoming aware of a policy and systems failure in Australia regarding end-use processes for recovered refrigerant. Wholesalers' branches and distribution centres were becoming warehouses for used and contaminated refrigerant for which there was no ultimate destination, and capacities for recovery and emissions prevention were lacking (Ind3). In response, industry established Refrigerant Reclaim Australia (RRA) in 1993 as a sector-wide approach to cradle-to-grave management of refrigerants that previously would have been vented to the atmosphere. RRA drove development and application of new reprocessing and destruction technologies, with the cost-burden shared across the sector. 'RRA built significant industry capacity at a time when there was no idea what to do with used refrigerants, when parts of the industry opposed reform. A focus on research and engagement with CSIRO, and incentives for recovery, aided the capacity build' (Ind2). The effective and efficient chemical stewardship demonstrated by RRA has been recognised internationally as leading practice through for example US EPA awards in 1995 and 2006 for leadership and technical achievements in protecting the earth's climate, and a 2007 UNEP Montreal Protocol Implementers Award for extraordinary contributions to global efforts to protect the ozone layer.

[4] 'Slip, Slop, Slap' stood for 'Slip on protective clothing, slop on sunscreen and slap on a hat' and was the message in a mass-media campaign that produced huge behavioural change (Gov5) and reduced the incidence of skin cancer.

Industry leadership did not stop with a world-first recovery scheme. The industry recognised that the new practices would require accreditation and upskilling in the sector, and with support from the government, established the National Refrigeration and Air Conditioning Council (NRAC) to trial a voluntary certification scheme for businesses and technicians. The scheme is now regulated, with the Australian Refrigeration Council (renamed from the NRAC) managing the licensing, accreditation and training of technicians and businesses. Simultaneously, industry negotiated with government on the phase-out of HCFCs under the Montreal Protocol, and advised a feasible and accelerated schedule with Australia only taking up half of its initial consumption allowance under the Protocol (Ross, 2010).

Community concerns about ozone reignited after detection of the then largest-on-record Antarctic ozone hole in 2000 (around three and a half times the size of Australia), which emphasised that the problem was far from fixed (NASA, 2000). In 2004 the Australian Government drew on its constitutionally afforded external affairs power and 'took over' regulation of the sector. The amended Ozone Protection and Synthetic Greenhouse Gas Management Act 2004 spanned the import, export and manufacturing licensing, and end-use controls on purchase, handling, and disposal of both ODS and SGG, as well as the phase-down of ODS consumption. The legislation was ambitious in establishing a nationally consistent approach for industries to comprehensively manage gases under the Montreal Protocol and minimise preventable emissions. Its development also involved resolution of some complex problems. An enhanced legislative scope to require licenses for import of ODS and SGG in pre-charged equipment highlighted the need to remove disposable canisters from the domestic market as 'they were small and too easy to dispose of poorly' (Ind3). An innovative solution, negotiated by industry with government, involved a licence condition on importers to manage ODS and SGG at the end of their life and participate in an approved product stewardship scheme (i.e. RRA). Implementation of this condition resulted ultimately in greater company ownership of recyclable cylinders and leakage control (Ind1, 3). Overall, industry viewed the nationalisation of end-use regulation as efficient and well-designed, being largely self-funding and incentivising industry engagement and compliance, where 'commercial signals aligned with environmental directions' (Ind1).

Trust between industry and the government declined at the time when political commitment was strongest for market-based approaches to reduce greenhouse gas emissions. The strength of the government's 2007 drive to develop a carbon price mechanism with uniform application meant that successful practices in reducing emissions based on constraining the useable amount were at risk of being dismantled, even when measurable declines in atmospheric concentrations could be demonstrated (Ind3; Rossi, 2018). A particular concern to industry was that a carbon price of AUD$23/tonne would lead to a 400–900 per cent increase in the price of refrigerants at import, with even greater price impacts on consumers, compared to up to 10 per cent for most other industry sectors (RA, 2013). This disconnect between industry and parts of the national government was further manifest in government's 'lack of interest in industry proposals for HFC phase down in 2007 – it took many years and leadership from other countries (such as Canada and Mexico) for Australia to follow' (Ind1).

Overall, the approach taken by industry, science and government in Australia resulted in significant environmental outcomes with progress in phasing-out CFCs and HCFCs ahead of the Montreal Protocol schedule (DAWE, 2019; Dunse et al., 2018). Importantly, reductions were informed by Cape Grim data, which show for example that Australian CFC emissions declined by about 5 per cent per year from 2005 to 2011 (Fraser et al., 2013). The success of Australia's approach has been recognised in an international comparative study of national systems to manage environmentally damaging refrigerants, where Australia received the highest overall rankings with regard to effectiveness, cost/burden on industry, and stakeholder engagement (Navigant, 2016). Australian leaders from industry, the science community, and government have been internationally recognised for their contributions to implementation of the Montreal Protocol (Rae, 2012).

6.4.2 Attributes of the successful national partnership

The case history in section 6.4.1 shows that partner initiatives combined to form a cohesive governance approach to the implementation of ODS and SGG in Australia. National legislation aligns with both Montreal Protocol and UNFCCC treaty requirements and comprehensively guides action to limit, manage and dispose of ODS and SGG; industry primarily drives implementation mechanisms with a continued focus on the opportunities from improved practice; and the science community monitors the environmental outcomes that inform national policy and link to international experimentation. Table 6.1 summarises the complementary partnership functions that enable and reinforce the new governance framework and industry practice. From interviews with partnership leaders and consideration of key practitioner, government, and science partner documents, several attributes of successful partnerships emerged from this national case. These are: longstanding trust and equality-based relationships; active networking across scales and sectors; a drive to innovate; an integral role for science; and deliberative and proactive leaders. This section now elaborates on each of these attributes.

6.4.2.1 Longstanding trust and equality-based relationships

The tenure of key people across partner organisations through the development and implementation of the Montreal Protocol, coupled with the relatively small size of the sector in Australia, underpinned deep, longstanding and trust-based relationships between partners. 'Since 1998, for more than 20 years, four people have managed the relevant team in the Australian Government and the key industry body AFCAM – this central relationship is stable and collegiate; everyone knows each other well' (Gov4). In industry, the roles and knowledge of Alan Woodhouse, were critical for building a reformed, coherent sector. Since 1982, Woodhouse's roles included CEO of the Australian Refrigeration Council (ARC), chairman of the Australian Refrigeration Wholesalers Association (ARWA), chairman of the Association of Fluorocarbon Consumers and Manufacturers (AFCAM), chairman of Refrigerant Reclaim Australia (RRA), and inaugural CEO of Australian Refrigerants Council (ARC). Steve Anderson, long-term former CEO of AFCAM and Refrigerants Australia, 'worked closely with Alan and was very effective in building trust and partnerships between industry and government' (Ind3).

The science team in CSIRO was also very stable, with Fraser involved from establishment of the measurement program in 1975. Fraser is highly respected by industry and was sought and retained as a science adviser to the Aerosol Association of Australia (1977–84), and then the Association of Fluorocarbon Consumers and Manufacturers (1985–95). 'Paul is a great science communicator – he provides factual, practical and evidence-based messages, which are clear and straightforward' (Gov2). The length and quality of the relationship between industry and science 'led to industry and companies having a reasonable level of scientific literacy, which was critical to the building of trust and support for phase-downs' (Ind3).

Importantly for trust building and for open relationships prepared to identify and address problems, this partnership stressed equality in inter-organisational relationships over time. Partners recognised mutual dependence and complementary roles. 'Industry accepted the science and recognised the need to reduce atmospheric concentrations to show solutions were working – which took away much of the angst of the need for reform' (Ind1). 'Government needed industry support and industry solutions to actually solve problems; and industry needed sensible policy settings to plan their future' (Ind1; Gov4). Equality was also manifest in the dialogues between partners, 'where information from all players was put on the table and assessed by all on its merits' (Ind3). One solution that emerged from such a dialogue was government agreement to a licence condition that importers must be a member of an approved product stewardship scheme; 'without it the industry-led recovery scheme would not have been viable' (Ind1).

6.4.2.2 Active networking across scales and sectors

The strength of the national partnership and its capacity to achieve outcomes was also supported by strong and active links between partners, international organisations, and initiatives at state government level. Internationally, the culture of the annual Earth Technologies Forum,[5] which brought together industry and government from around the world, was influential. As described by Canan and Reichman (2002), the Forum was where participants explored new directions and committed to action, debated viability of emerging technologies, and strengthened relationships – in other words, a place where integrated governance could progress. Australian partners participated in the Forums and continued the conversations and networking to build common ground domestically. More formally, Australian contributions to international processes were valued; 'Australia was always represented on the Executive Committee or a Technical Committee of the Protocol' (Gov2). Australian science also has strong international links, including through core roles in key international programs (Atmospheric Lifetime Experiment, Global Atmospheric Gases Experiment, Advanced Global Atmospheric Gases Experiment), and in Fraser or other CSIRO researchers being a 'lead or contributing author in every global scientific assessment on ozone depletion, and Cape Grim data involved in around half of all charts showing gas concentration change over time in these assessments' (Res1).

Active networking within Australia also meant that national governance reform could ensure the uptake of best practice. The 'Victorian state government, for example, had established good halon management processes, and had concerns about losing fire

[5] The Earth Technology Forums were annual conferences and trade shows in Washington D.C. on ozone and climate protection technology and policy, sponsored by the United States government, trade and industry organisations and NGOs.

suppressant capacity with national legislation' (Gov2). However, the solution of a Halon Bank for essential uses (such as aircraft and defence, where evacuation cannot occur in a fire) developed by Victoria was recognised as successful, and the approach was integrated into the Montreal Protocol and adopted nationally.

6.4.2.3. Innovation for practice reform

Innovation was a consistent feature of this science-industry-government partnership. Ready solutions were frequently not at hand, and partners' experience and trust-based relationships created a culture that supported experimentation, learning, and openness to reform. 'With the establishment of RRA, industry innovated to solve problems in absence of government regulation' (Ind3). Its *cradle to grave* scope positioned industry to take charge of the breadth of reform ultimately required, including development of new and effective technologies for emissions prevention and recovery. Examples include new processes developed by AGAS, a large importer of refrigerants into Australia, to vacuum R-22 gas (an HCFC no longer in production in developed countries) out of pipes and enable its resale, and by Nordiko Quarantine Systems to economically recover residual methyl bromide from its allowed use in fumigating shipping containers (Ind1). The innovative partnership between industry and government to regulate certification programs for technicians and businesses, while not overwhelmingly embraced initially, also led to a more united and professional sector through NRAC and then the ARC. Government support, particularly in the licensing of importers, was important in part-funding the trialling of the scheme and providing policy backing for its implementation. From the Victorian state government, Ian Porter contributed internationally to research and technologies on alternatives to methyl bromide, and drove practice change across Australia (Gov3).

Similarly, the CSIRO commitment to measure atmospheric gases preceded the availability of suitable commercial instruments, and significant ongoing innovation was involved in the development of the Cape Grim site to become the globally significant facility it now is. The Australian experience thus reinforces the finding of Sabel and Victor (2017) that the global effectiveness of the Montreal Protocol arose significantly from innovation at the science-practice interface, and not intrinsically from the top-down global imposition of control targets.

6.4.2.4 The integral role of science

As the case study revealed, the atmospheric science was trusted and central to the partnership in bridging government and industry interests. The science demonstrated the unsustainability of failure to constrain emissions of ODS, and critically linked to wider processes of industry and government. Internationally the Montreal Protocol's Technical and Economic Assessment Panel linked scientists with technology developers to focus on finding alternative solutions. Such integration enabled effective responses to address unexpected atmospheric concentrations of ODS or SGG, such as following the detection of HFC-23 and trifluoromethyl sulphur pentafluoride (CF3SF5, the second most potent SGG yet identified in the atmosphere) at Cape Grim, both of which were then rapidly controlled by relevant companies and governments (Res1; Fraser et al., 2013).

Recognition of the value of science also led to Fraser participating in meetings of the Ozone Protection Consultative Committee, established under the inter-jurisdictional Australian and New Zealand Environment and Conservation Council. The common science briefings to industry and government officials were critical, 'there was misinformation at that time, like damage to the ozone layer was caused by volcanoes, and Paul could correct the errors and enable industry, governments and scientists to respond with one voice to the nay-sayers' (Gov1).

6.4.2.5 Deliberative and proactive leaders

Leadership by influential individuals and organisations is a widely recognised feature of effective partnerships (e.g., Pattberg & Widerberg, 2016). In this case Australia enjoyed an extraordinary conjunction of deliberative and proactive leadership across partner organisations, underpinned by trusting relationships. 'Outstanding leaders in industry organisations, Alan Woodhouse and Steve Anderson, engaged with science and shared information and translated between industry and government to negotiate effective solutions' (Ind3). 'Steve had a vision of the future, he helped industry define the best future for them, and he got things done' (Gov3). In negotiating with government early in the Montreal Protocol, Woodhouse found himself in the unusual position of arguing that Australia only take up 50 per cent of its allowance of HCFCs (Ross, 2010, p. 25). Importantly, such a proactive approach continued as industry leaders brought coherence and empowerment to the sector during a period of major reform which included working through periods of conflict and opposition. 'The early narrative of industry was that stopping emissions was practically impossible' (Ind2). Parts of industry opposed gas phase-out, recovery proposals were just seen as extra work, and there was criticism of the nationalising of licensing, accreditation and training as it involved ceasing fragmented state programs to which businesses had become accustomed (Ind2; CCN, 2003).

Similarly, the foresight and outreach of individual scientists, notably Fraser and Pearman, grew Australian science in a new area to gain industry support and funding, and to establish one of the world's premier atmospheric observatories (recognised in the Global Atmosphere Watch program of the World Meteorological Organization). 'The achievement comes down to individuals and their personalities – and Paul Fraser was the right person' (Gov2). Leadership by public servants was also apparent. Brian Robinson and Harry Blutstein, Victorian state government, progressed halon phase-out ahead of equivalent national measures – 'courage was needed as risks existed and many businesses needed to find ways to reform practices' (Gov1). Nationally, Ian Carruthers was far-sighted in proposing and establishing robust national mechanisms for hazardous chemical assessment and control, which provided the building blocks for managing CFCs. More recently proactive leadership occurred in the 2004 legislation design to incorporate SGG, draw on effective state initiatives, and ensure industry has space to innovate, and by Pat McInerney in co-facilitating negotiations on the 2016 Kigali Amendment to phase down HFCs. If fully implemented the Amendment will avoid up to 0.4°C of global warming this century, and substantively contribute to Paris Agreement goals while continuing to protect the ozone layer (UN Environment, 2019).

6.5 Discussion and conclusions

This paper has contributed new insights on the role of national-scale partnerships in helping to implement an international agreement to address a global environmental challenge, particularly on the importance of effective science policy interfaces and transnational information and technology linkages in such partnerships. The case study has identified the key attributes of a national partnership, where longstanding trust-based relationships, equality among partners, active networking across scales and sectors, and a focus by proactive leaders on science and innovation for practice change enabled a diffuse problem, lacking in comprehensive solutions and with initial divergent stakeholder interests, to be successfully addressed. While some overlap is evident with the findings of previous research on conditions of MSP success, particularly regarding the importance of leadership and trust (e.g., Fraser & Kunz, 2018; Beisheim & Simon, 2016; Pattberg & Widerberg, 2016), differences are also apparent. The focus of many MSPs on specific tasks seeking short-term results, and in areas where partnership capacities may be constrained (Beisheim & Simon, 2016), may explain the emphasis on normal life cycle processes, resources and institutional capacities in success conditions. The attributes identified in this case, such as innovation, science integration, and deliberation for problem resolution, are collectively novel and they emerge from a long term partnership focus on solution-finding and practice reform. They align more closely with characteristics of partnerships needed for sustainability transformations (Horan, 2019).

The focus on a national scale but globally oriented MSP, contributes to a relative deficiency in the literature but is salient as national actions are critically important to most transnational initiatives that address sustainability challenges. While the international goals of the Montreal Protocol, including nationally allocated targets, were important for framing and incentivising the task in this case, the steps to meet and exceed those targets, to bring into wide practice less damaging alternatives, and reduce unintended emissions, depended primarily on innovation between industry, science, and government at the national scale.

Of note, the national MSP considered in this paper extended institutional structures and relationships. New and influential coordination mechanisms were established within industry, between industry and science, and by national actors in approaches for developing transnational partnerships. In contrast to the operation of many MSPs, these institutional relationships can be described as loosely coupled, where flexibility and clear responsibilities enabled partner organisations to progress independent and complementary action aligned with the shared aspiration.

Reasons for the success of this partnership also need consideration in the context of the finding, noted in section 6.2, that many partnerships fail to fully realise their anticipated outcomes. A strength of this partnership comes from the complementarity and recognised essentiality of partner roles and an absence of significant power imbalances. The national scale of interest of each partner, reflected in the definition of national partnership in section 6.1, then acted to reinforce a shared alignment of aspiration and focus on solution finding. There was also a sufficiency of resourcing and capacity within each partner organisation, with the establishment of the new coordinated peak industry body affording greater collective capacity to the previously smaller, and more fragmented industry sectors that use ODS. The emergence of coordinated industry capacity within the agreed aspiration of sector reform to dramatically reduce ODS use, also likely minimised risks of undue business influence on policy making that have reduced the success of other MSPs (Beisheim & Simon, 2016). Further, bipartisan political support for an effective Australian response to the Montreal Protocol enabled long-term networking and policy development that was proactive, coherent, and additive (Ind3).

This case study highlights two areas where further research on partnerships is warranted. First, much of the literature on partnerships for sustainability understates the need for continuously improving knowledge, and the value of re-positioning science from an input variable to a central actor. Many sustainability challenges are characterised by incomplete knowledge, the need for expert interpretation of interrelationships that may not be readily perceptible, for a systems perspective, and for evidence that facilitates learning and explores the future, including of potential interventions (e.g., Kowarsch et al., 2016). In this partnership, science acted as the honest broker, and enabled industry and government to understand the urgency to act, consequences of inadequate action, as well as evidence that can demonstrate whether solutions are working. Lessons from linking differentiated and complementary capacities in this case, and emergent learning and innovation, can inform approaches to replace linear models of science provision that are not proving effective (e.g., Chiaromonte, 2006). However, the potential for science integration as a core partner in more networked approaches to national environmental problems may face challenges in Australia as the concentration of power in the government of the day can constrain more participatory structures (Lalor & Hickey, 2014; Stewart, 2004). Further analysis on whether this is the case for other environmental challenges and how active engagement of knowledge producers can be facilitated would contribute to better understanding of this potential constraint.

Second, consideration of governance characteristics that can respond to the dynamic nature of sustainability challenges can add relevant dimensions to partnership studies. For example, while some scholars of partnerships have found formal institutionalisation and process management to be indicators of effectiveness (e.g., Liese & Beisheim, 2011), an over-emphasis on these factors may limit opportunities for experimentation. In contrast, this case demonstrates that a looser networked and flexible approach can support innovation, solution finding and tailored practice reform, particularly when coupled with committed and influential leaders. Achieving the national control and phase-down of ODS and SGG maintained the primacy of the global environmental goals in the Montreal Protocol across governance scales in the strategies and operations of national business, government and science partners over time. In large measure, this goal embedding and its translation to national contexts without dilution of ambition was enabled by the anticipatory and reflexive stance taken by the partnership. The preparedness of the Australian peak industry body (AFCAM and then RA) to seek and act on emerging science knowledge, and to negotiate with government for settings that incentivise innovation and allow for self-determination in practice reform, exemplifies an anticipatory institution. The outcomes of this case also align with emergent thinking on science needed in the Anthropocene, including for integration of research and practice to find solutions to real-world problems (e.g., Hummel et al., 2017). Individual leaders also demonstrated critical reflexivity in challenging early dominant narratives, for example on the difficulty of reducing emissions from in-country sources (Ind1, 3). Recognition of the importance of leadership and relationships from this case adds to the scope of the imperatives for national governance in the Anthropocene identified in section 6.2.

Finally, these attributes could be useful to other environmental challenges with national and global dimensions in identifying where interventions may be needed to enhance the capacity for success. The binding nature of the Montreal Protocol provided impetus for the identification of alternatives to ODS and their global uptake, and it is thus reasonable to expect limitations on the transferability of lessons from this case to voluntary agreements. However, the innovation and exceedance of national targets in this case suggest factors beyond top-down requirements were also critical. The strength of the core and applied science-industry partnership is likely important, as it maintained a sense of urgency for action in an environment that enabled solution finding and deployment. Further, the attributes identified here, in combination, supported a reframing of industrial practice norms, development of tailored technological solutions, and systemic uptake of reformed practices; outcomes relevant to partnerships for transformation. Such attributes could inform design of approaches to other environmental problems where new knowledge, technological innovation and systemic uptake of reformed industrial practices are required.

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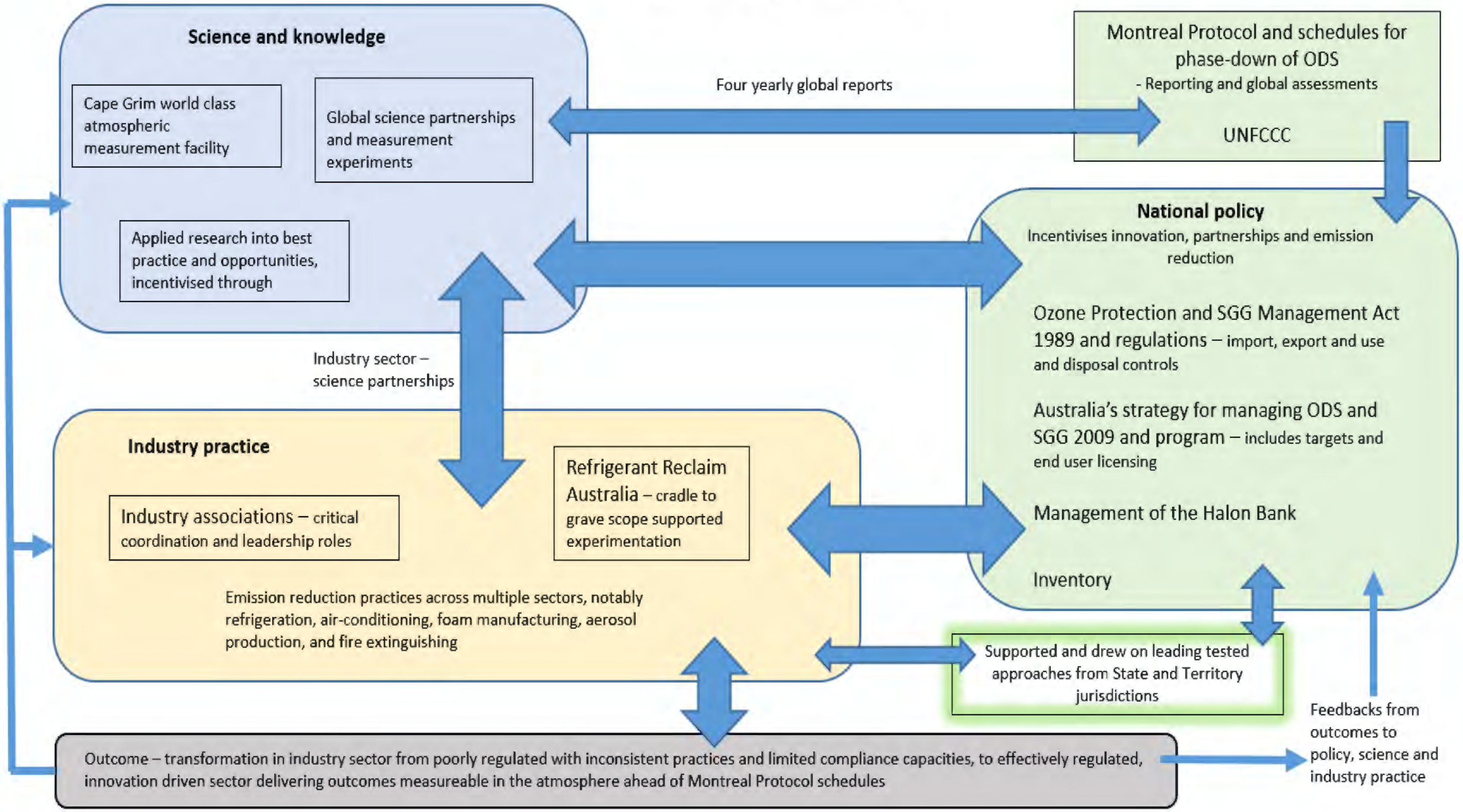
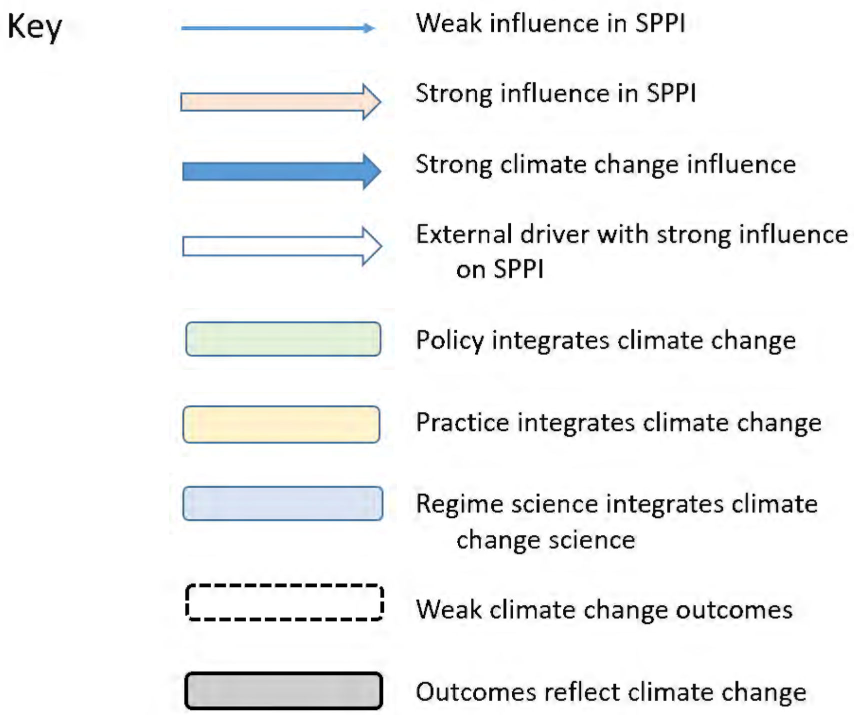
Annex Chapter 6. Ozone-depleting substance (ODS) and synthetic greenhouse gas (SGG) management SPPI




Key
Weak influence in SPPI
Strong influence in SPPI
Strong climate change influence
External driver with strong influence on SPPI
Policy integrates climate change
Practice integrates climate change
Regime science integrates climate change science
Weak climate change outcomes
Outcomes reflect climate change

Chapter 7
Discussion and conclusion

7.1 Introduction

This study has had two goals: first, to develop a critical understanding of SPPIs in Australia relevant to achieving climate change outcomes, and second, to use this understanding to develop practical and targeted recommendations for improving the operation of SPPIs for progress of policy reforms and transitions for long-term societal benefit. With climate change research often divorced from policy development and decision-making processes, there is a crucial need for greater understanding of how actionable knowledge can support change towards climate-smart societies. As described in Chapter 1, there are gaps in the scholarly literature on a) how policy and practice can apply climate change science to better understand the challenges and adequacy of current and alternative approaches; b) what actionable knowledge means for policy and practice; and c) how climate change SPPIs can help contribute to transitions. The case studies in this thesis (Chapters 2 to 6) respond to these gaps through exploring SPPIs within key policy regimes. From critical analysis of regimes with effective SPPIs, and of national policies that fail to address growing vulnerabilities and the path-dependencies embedding increasing risks in a changing climate, this thesis reveals new insights on barriers to climate change action and identifies tailored reforms to facilitate the integration of climate change and climate change science in policy implementation. In this chapter, I re-engage the research questions that have underpinned this thesis by outlining findings from analysis of the case studies. These include a new characterisation of effective SPPIs for responding to climate change (section 7.2), consideration of the implications of the findings for current conceptual and theoretical debates regarding SPPIs and more widely (section 7.3), and the identification of future research directions (section 7.4).

7.2 Addressing the research questions

The research questions developed to address the goals of this study (see section 1.4.2), are:

> How can science-policy-practice interfaces (SPPIs) facilitate climate change policy reforms and transitions in Australia?
>
> (i) How can climate change-relevant SPPIs be conceptualised?

(ii) What are the lessons learned to date from SPPIs for climate change policy reforms and transitions?

(iii) What are the characteristics of effective climate-relevant SPPIs that support achievement of climate change adaptation and mitigation outcomes?

This section takes a cross-case perspective to summarise findings from the case studies on the operation of SPPIs in Australian policy regimes. Identifying important insights into how climate change-relevant SPPIs can be conceptualised, section 7.2.1 addresses sub-question (i). Section 7.2.2, addressing sub-question (iii), explicitly examines the effectiveness of the SPPIs for climate change adaptation and mitigation, including through providing explanation for observed deficits and strengths. Addressing sub-question (ii) and the overarching research question, section 7.2.3 summarises key lessons learned from the analysis with a focus on the capacities of SPPIs to facilitate the realisation of policy reforms and transitions.

7.2.1 Insights on the conceptualisation of SPPIs for climate change in Australia

The objects of SPPI research in this thesis are framed by an articulation of the functional scope and purpose of the concept. Social interfaces can be understood as a 'critical point of intersection between different life-worlds, social fields or levels of social organization, where social discontinuities based upon discrepancies in values, interests, knowledges and power, are most likely to be located' (Long, 2001, p. 243). Interfaces draw attention to the relatedness of many institutions, perspectives and experiences, including their interdependencies, and to how they can influence social structures and practices and, in turn, enhance their alignment to support and enable societal change. Thus, the objects of SPPI research in this thesis span the key institutions and perspectives from science, policy, practice, and their interdependencies and interactions. In addition, recognising that the *raison d'être* of SPPIs is to improve the handling of problems (see Chapter 1, section 1.2.2), the outcomes from these interactions must also be considered a relevant object of SPPI research.

This framing of research objects, supported by the case study analyses in Chapters 2 to 6, calls for a new definition of SPPIs. As noted in the Introduction to this thesis, SPIs are conventionally understood as social processes that span the interactions between scientists and actors in the policy process, and allow for the joint production of knowledge for improved decision-making. For this thesis, however, recognising the importance of knowledge and learning in real-world contexts for effective responses to socio-ecological challenges like climate change, SPPIs are more robustly defined as the multiple social processes that span the interactions between scientists and policy and practice actors, and enable the co-production of knowledge and/or approaches that illuminate pathways to desired societal outcomes. By this definition, and applied to climate change, robust SPPIs have strong multi-directional interfaces between science, policy, and practice actors that enable the shared development of goals, knowledges and approaches to inform and support adaptation and mitigation action. The dimensions and implications of this new articulation of SPPIs will be elaborated throughout this and forthcoming sections.

The case studies in this thesis (outlined in Chapters 2 to 6) have identified and mapped a range of interactions between policy and science, and between science and industry and other practitioners. Figure 7.1, in turn, summarises the key institutional elements and processes of each case relevant to the development and use of climate change knowledge, and indicates the prioritisation given to achieving climate change adaptation and mitigation objectives. The strength of specific interfaces in Figure 7.1 is indicated by the width of arrows connecting SPPI components in one-directional, or two-way processes, and by the extent of coloured infill in the boxes representing science, policy, practices, and outcomes. A wide arrow indicates a strong influence, which when orange, means a non-climate influence. A fully coloured box indicates a greater attention to, and the existence of processes and capacities to understand and address, relevant climate change issues than a partially coloured box.

Overall, the policy cases concerning housing, forest sinks and environmental protection reveal a lack of strong climate change interfaces that openly engage with all key constituent organisations to build shared understanding on how to resolve the societal problem (see Figure 7.1 (a), (b) and (c)). Policy instruments that are highly prescriptive and typically draw on industry-embedded knowledge, as well as historic climate data, are the dominant frame for practice concerning building regulation and forest sinks. Mechanisms for climate change science to inform policy in these cases tend to be weaker, more *ad hoc*, and characterised by less effective one-way linear transfers of knowledge when sought, for example, in scheduled review processes. Critically, the provision of climate change science in these cases tends to not be fully integrated across the policy domain and, further, is not then enabled by policy to transfer strongly to practice. Further detail on the SPPIs for these cases can be found in the Annexes to Chapters 2, 3, 4, 5 and 6.

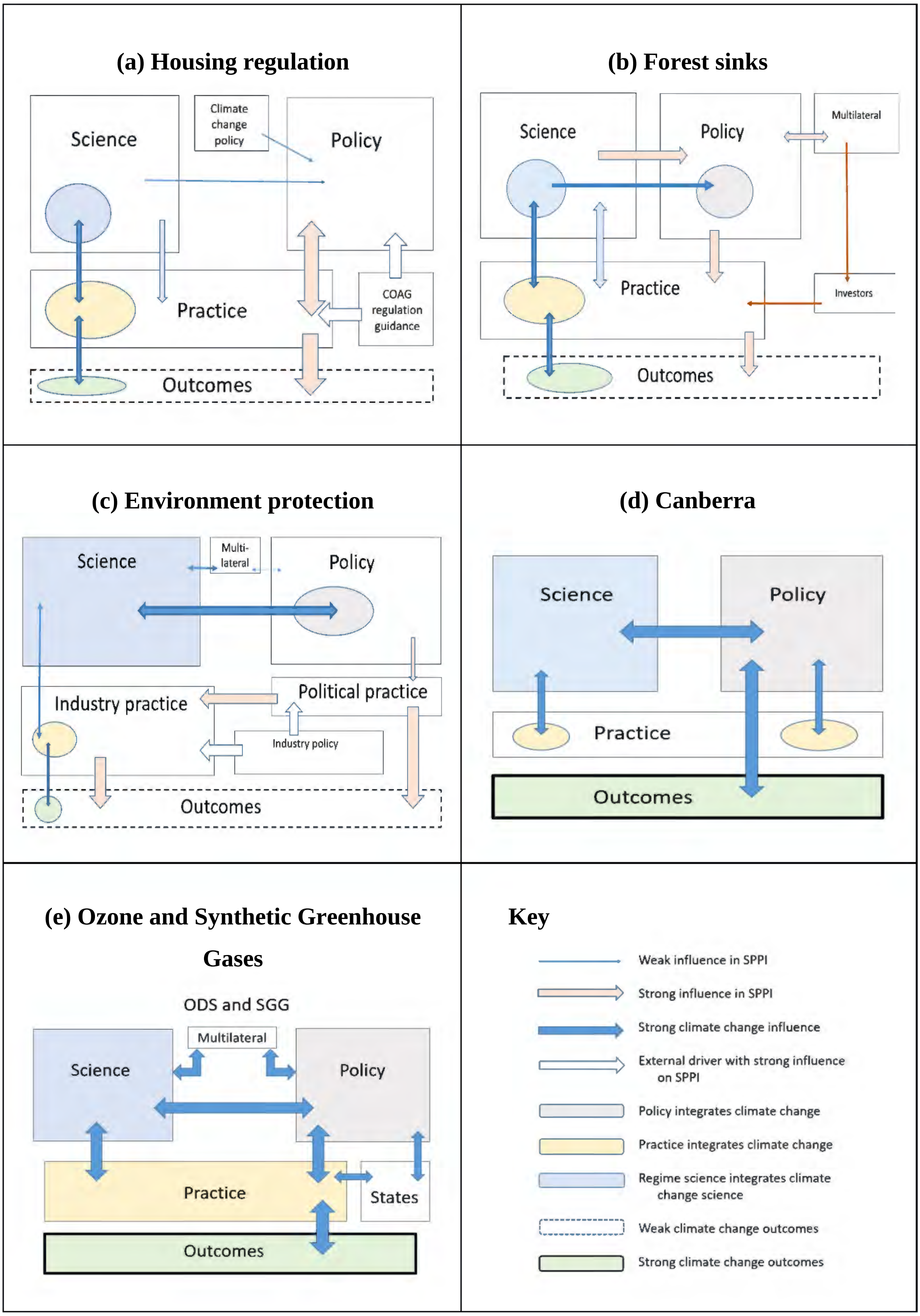


Figure 7.1. Major climate change SPPI components and influences in case studies.

At the same time, housing and forest carbon broker industry leaders are learning from experience in a changing climate, recognise increasing risks from climate change and are establishing partnerships with researchers to inform more resilient and climate-adapted practice. There have been calls from these industry leaders for policy reforms to respond more strongly to climate change science (e.g., ASBEC, 2018), but at present there are only weak and occasional interfaces that enable such calls to influence policy and the wider SPPI.

Similarly, environmental protection legislation involves a partial integration of climate change science, but there are constraints on the capacities of otherwise well-performing scientific advisory bodies to contribute to decision-making and wider policy reform in this area (see Figure 7.1 (c)). As a public good matter with decision-making by a government minister, practice in this case is highly politicised, and a trend of the subordination of environmental and climate change objectives to the maintenance of industry and development interests is apparent (see, e.g., Chapter 4, section 4.3). Major reviews of the legislation, for example, whose reports reflect substantive scientific evidence and spell out recommendations for reform, have been largely not adopted by recent conservative governments (Craik, 2019; Samuel, 2020).[1] There is also a lack of coherence between a very substantial body of science that calls for urgent action to stem the loss of biodiversity in a changing climate (e.g., Cresswell & Murphy, 2016), the EPBC Act itself, and related policy measures that both lack mechanisms and fail to support implementation approaches. This lack of coherence has hobbled conservation action across most environments and habitats of importance for significant ecosystems and species.

Framed by knowledge of the magnitude and pervasive challenges of climate change impacts, these case studies draw out some of the inadequacies of the design, scope and implementation of key policies in Australia. For example, the current EPBC Act implementation approach is demonstrably insufficient to protect threatened and endangered species in a changing climate (see Chapter 4, section 4.3), and current building standards in Australia fail to robustly draw on emerging climate change and impacts science to facilitate housing that prioritises occupant health and wellbeing into the future (see Chapter 2, section 2.5).

In contrast, in the successful transition cases on ozone-depleting and synthetic greenhouse gases (ODS and SGG), and climate change transitions in the city of Canberra,

[1] The Labor Government elected in May 2022 has flagged it will respond properly to the Samuel review and progress reforms to better protect the environment.

climate change science is afforded priority and strongly linked to policy and practice (see Figure 7.1 (d) and (e)). As detailed in Chapters 5 and 6, effective engagement interfaces between key organisations across these regimes span both formally established committees and informal networks, and involve multi-directional interactions. These support the sharing of knowledge, the building of trust, and the lifting of ambition and shared commitment for ambitious goals and problem-solving. In both cases also, top-down policy leadership and community support are important, particularly for goals or targets, which, without excessive prescription, allow for innovation and experimentation in both policy and industry practice. In these cases, there is clear coherence between the findings of climate change science for substantive action to reduce greenhouse gas emissions, and the outcomes of policy regime implementation.

Importantly, in achieving the outcomes in the successful transition cases there were also differentiated and complementary roles and actions taken by the key actors and institutions, each of which drew on their relative strengths. For example, as described in the ODS and SGG case study (Chapter 6, Section 6.4), an innovative partnership between government and industry included a government licence condition on importers for end-of-life management of ODS and SGG that, in turn, enabled industry innovation in recycling and leakage control.

Collectively, these insights along with the case studies outlined in Chapters 2 to 6 provide a body of evidence to support the new approach proposed in this thesis to understanding the characteristics and operation of SPPIs in policy regimes. These insights also identify and foreground a range of the key requirements for and elements of such an approach. Specifically, it should be noted that the definition and conceptualisation of SPPIs developed in this thesis differ from previous conceptualisations in three main ways. First, as was outlined in Chapter 1, most SPPI research has focused predominantly on individual institutional interfaces relevant to science provision, and has described interactive and co-production processes as enabling alignment with end-user needs. In contrast, this study is developed from the recognition that understanding how climate change science can influence particular adaptation and mitigation outcomes involves consideration of multiple structures and interlinkages between science, policy, and practice, and that these must be comprehensively considered for a robust shared understanding of the nature of problems and solutions to emerge.

Exploring SPPIs within a policy regime – understood as comprising multiple inter-related institutions and reinforcing certain social norms – has proved highly productive in this study, but is uncommon in the literature. The breadth of regimes provides a span appropriate to identify pathways where science can influence social behaviours and practices, and, for example, support adaptation outcomes. In addition, attention to regime operation can identify where additional interfaces may be required to enable the consideration of new risk knowledge that may be externally produced to the institutions that need to lead in progressing action. Importantly, in this way, the actual policy settings and practice drivers for knowledge and science use can be identified, including whether they enable or inhibit integration of climate change science, which is typically developed independently.

Second, this new definition and conceptualisation brings the concept of SPPI back to its functional purpose which is, in particular, to improve environmental management. This focus explicitly positions desired outcomes as an object of SPPI research and, further, identifies which institutions and interfaces across science, policy and practice might facilitate or hinder the achievement of those outcomes.[2] Insights from such analysis are of growing importance as there is urgency now in society heeding the message from climate change science for rapid and tangible action towards low-carbon and climate-adapted futures.

Third, in exploring how science is actually used, this thesis draws attention to the role and influence of embedded knowledge in policy and practice systems, a factor that has rarely been robustly considered in SPI research. Several of the case studies of key national policies important for climate change adaptation and societal decarbonisation included in this thesis – see, for instance, Chapters 2, 3 and 4 – found that policies that are prescriptive of knowledge to be used, and practices that are reliant on deeply embedded knowledge based on historic climate, are major barriers to the uptake of climate change science. For example, there is considerable embedded knowledge in the construction industry, including deeply embedded supply chains, that preferences practices based on experience that deliver to minimum cost and compliance objectives, and can also be described as path dependent (see Chapter 6, section 6.5). Table 7.1 describes some of the additional research foci and opportunities that emerge from the wider conceptualisation of SPPIs developed in this thesis.

[2] While this research considers outcomes as they relate to the purpose of SPPIs, it is recognised that other factors can influence outcomes and there is not a deterministic relationship.

Table 7.1. Research areas enabled by typical and reconceptualised SPPIs.

Typical SPPI conceptualisation	**Research areas enabled**
Single interface institution (e.g., boundary organisation, knowledge broker, multi-lateral research synthesis partnership)	• Qualities of effective science provision • Qualities of interface institutions, including operation and outcomes • Insights from interactive and knowledge co-generation processes
Re-conceptualised SPPIs in this thesis	**Additional research areas enabled**
Multiple institutional and knowledge span across science, policy and practice and interdependencies - Wider span of inter-relationships - Recognition of more than one type of knowledge Focus on desired outcomes and extent enabled and/or achieved	• Drivers and effectiveness of knowledge uptake and use in linked policy and practice system or regime • Exploration of barriers to knowledge uptake within policy and practice, and tailored identification of where and nature of reforms required • The importance of scale for SPPI analyses to understand implementation approaches from specific institutions, policies, to wider regimes • Operation and effectiveness of SPPIs with regard to problem solving, policy implementation success or achievement of outcomes • Evaluation of effectiveness of SPPIs with regard to societal goals

7.2.2 Lessons learned: Effectiveness of selected Australian SPPIs for climate change

Many contemporary scholars are calling for radical, rapid and systematic changes, informed by science, to avoid dangerous climate change, reduce the vulnerability of communities to projected impacts, and enable long-term resilience and sustainability (see, e.g., Steffen et al., 2018; Lawrence et al., 2022). In this context, the concept of *effectiveness* becomes central to investigations of policies and reforms for climate change, as isolated, narrowly sectoral or historically-based approaches alone will be insufficient to address the multifaceted causes of increasing emissions and climate-related vulnerabilities. This insufficiency is clearly illustrated through several of the case studies outlined in this thesis (see, e.g., Chapters 2, 3, and 4). For the purposes of this thesis, policy effectiveness has been understood to comprise instrumental and capacity elements, where *instrumentality* addresses the substantive ability and the feasibility of the policy to solve the problem, and *capacity* relates to the technical know-how of relevant agencies and how they employ coordination and management mechanisms for policy design and implementation (Howlett, 2018; Bali et al., 2019).

A concept important for both instrumentality and capacity in designing for policy effectiveness in addressing future-oriented and long-term problems such as climate change adaptation is *anticipation*, meaning foreseeing the future and preparing for it (Bali et al., 2019; Muiderman et al., 2020). Studies on the attributes of climate change policy effectiveness have identified that outcomes relevant to reduced emissions, and/or risk and vulnerability, are key, as well as capacities relevant to addressing multiple impacts and trade-offs, achievement of co-benefits, and responses to changing temporal risks and evidence gaps (e.g., Chausson et al., 2020; Singh et al., 2021). Ultimately, effectiveness in this context requires a normative test of the extent to which policies or interfaces consider and tangibly contribute to climate change adaptation and mitigation.

The case studies in this thesis, combined with insights from the new definition and conceptualisation of the SPPIs in section 7.2.1, provide rich and varied information on the effectiveness of policy regimes for climate change outcomes. Building regulation (Chapter 2), forest carbon (Chapter 3) and environment protection (Chapter 4), are all policy areas of national importance for climate change resilience outcomes. However, as illustrated in these chapters, relevant policies in these sectors have rather been designed to deliver other objectives, including safety and cost-effectiveness, protection of matters of national environmental significance in the context of ecologically sustainable development, and net emissions reduction. A lack of interface mechanisms that deliver climate science to policy specifications and build implementation capacities suited to a changing climate have meant that, despite reviews identifying the growing relevance of climate information (Roxburgh et al., 2020; Samuel, 2020; CSIRO & BoM, 2015), climate change resilience outcomes are not being realised. As these chapters have illustrated, these policies are clearly ineffective with regard to anticipating and managing a substantial risk area, resulting in long-term outcomes in a changed climate being uncertain, and an increasing likelihood for maladaptation.

In contrast, the niche industry areas of housing and forest carbon that deliver outputs in recognition of future climate, and the cases of Canberra city (Chapter 5) and ozone depleting substances and synthetic greenhouse gases (ODS and SGG) (Chapter 6), demonstrate leadership that exceeds required practice and involves iterative links or partnerships with the science community. In these cases, as these chapters have shown, science and robust SPPIs are valued and influential in reform processes. Formally established interfaces, spanning advisors, committees, and practices of engagement, prioritise access to up-to-date knowledge and its use within policy regimes. Importantly, such prioritisation contributes to growing practice capacities and partnership establishment that supports the testing of new implementation approaches and anticipatory learning. The successful ODS and SGG case, in particular, saw the development of an SPPI that operates as an ongoing multi-directional partnership, with long-term commitment and iteration to share knowledge and problem-solve, and spans research, industry and technology actors with a culture that drives innovation and finds solutions. In the Canberra city case, strong leadership and trusted relationships with research advisers underpin an interface partnership that delivers on its policy reform goals. The ODS and SGG and Canberra case interfaces are further supported by a clear government demand for knowledge and engagement that strengthened the influence of the SPPI. Examples of key lessons learned from the Australian SPPI case studies, and their implications for effectiveness, are described in Table 7.2.

Table 7.2. Lessons learned and implications for effectiveness.

Examples of lessons learned	**Implications for effectiveness**
Long-term formal and informal interfaces and SPPI institutions are important for transitions (ODS and SGG case study in Chapter 6)	• Long-term and stable interfaces enable trusted partnerships between agencies and actors to be built over time • Duration of partnership aligns with timeframes to resolve complex environmental problems • Sustained commitment, experimentation and leadership needed to overcome barriers from vested interests and short-term decision-making
Flexible policy can provide room for industry and practitioner problem-solving (Chapter 6)	• Supports innovation across interacting sectors and stakeholders directly relevant to the challenges they were facing • Enhances capacities for the technical design of solutions, their employment and lessons learned
Dominant policy leadership can solve problems rapidly (Canberra city, Chapter 5)	• Policy settings central in climate change transitions can progress change quickly • Strong leadership can bridge siloes, find new solutions and gain support of other decision-makers • Policy-only approaches can overlook wider capacity building needed for further reforms and progress of transitions • Risks to sustainability of outcomes following leadership changes
Prescriptive policy processes based on historic climate data embed increasing risks (e.g., forest biomass estimation models specified in	• Constrains capacity for learning across regime • Fails to anticipate increasing climate risk • Shifts burden of responsibility for understanding and managing pervasive risks to multiple practitioners

methods for Australia's Emission Reduction Fund, Chapter 3)	• SPPIs need critical review capacities to identify and debate policy settings that clash with climate change science
Lack of alignment between climate change science and experience-based knowledge used in decision-making where powerful actors and embedded processes subordinate climate science (Chapter 2 regarding housing)	• Potential for conflict and increasing unmanaged risk • Span of SPPI operation needs to allow for recognise multiple knowledge systems • SPPIs need critical review capacities to identify and address dependence on historic climate in decision-systems where exposure is increasing, and debate how operational processes can be open to the uptake of climate science
Poor coherence apparent between science that identifies systemic impacts and calls for urgent integrated action, and implementation approaches that decrease policy fit-for-purpose (e.g., decision processes for threatened species protection, Chapter 4)	• Incapacity of narrowly framed and implemented policy to achieve societal goals • SPPI focus on outcomes can bring into consideration areas where policies conflict in implementation, or where unintended outcomes are reinforced through influence of interlinked policies or actors in regime
Deeply embedded underpinning requirements for particular approaches to understanding the costs and benefits of reform can be path-dependent (e.g., cost-benefit analysis and housing reform, Chapter 2)	• Constrains capacities to anticipate increasing risks • SPPIs need capacity for critical scrutiny of underlying drivers of particular practice • SPPIs can create spaces for recognition of ways to value health, well-being, resilience, and biodiversity conservation in a changing climate
Weak policy in areas where risk increases are being experienced can lead to niche industry innovation (e.g., Chapter 3)	• Coordination mechanisms important to capture lessons learned • Mechanisms for learning and up-scaling successful niche innovation important in SPPIs
Uncertainty in science of future climate precludes robust consideration of implications	• Science translation and bridging to experience-based knowledge needed in SPPI • Collaboration on use of tools that can incorporate uncertainty

Analysis of the case studies identifies twelve characteristics of effective SPPIs that can facilitate climate change outcomes (see Table 7.3). These characteristics reflect both instrumental and capacity elements of policy effectiveness, anticipate future climates, and have relevance to the attributes of partnerships needed to address long-term, temporally changing, complex environmental problems. Collectively these characteristics of effectiveness, when realised, enable a robust SPPI as defined in section 7.2.1. Beyond the cases investigated in this thesis, the characteristics can be regarded as provisional hypotheses for further exploration and contextualisation.

Table 7.3. Twelve characteristics of effective SPPIs for responding to climate change.

SPPI component	Characteristics of effective SPPIs for responding to climate change
Science and knowledge	1. Co-production of actionable knowledge that anticipates futures and draws on wide disciplinary and inter-disciplinary insights 2. Iterative exchanges of knowledge to understand challenges and explore solution pathways with SPPI and wider stakeholders 3. Explicit attention to how climate change science can relate to and be compatible with technical policy specifications and embedded practice knowledge 4. Climate change science that is translated for policy and practice, and builds capacities for use
Policy and practice	5. Policy and practice that integrate and afford priority to coherence with future climate change, including with the magnitude and directions of reform needed 6. Genuine openness to critical scrutiny of existing policy by science and practice interests, and to different perceptions and priorities 7. Attention to clarifying science needs, enabling technical capacities for science uptake and use, and to measuring impact of use 8. Enabling mechanisms for experimentation, capacity building, mainstreaming and alignment of interlinked policies for coherent climate change responses
Overall interfaces	9. Representation of key science, policy, practice interests and expertise and affected communities, with all involved in subsequent decision-making 10. Multi-directional processes that facilitate deliberation, reflexivity, learning, and capacity building relevant to achieving outcomes and societal transitions 11. Purposeful attention to facilitating shared spaces for innovation 12. Durability that aligns with problem-solving horizons

This thesis contributes to the relatively under-researched multi-institutional SPPI effectiveness literature, with application to climate change adaptation and mitigation. Importantly, this thesis has found that effective SPPIs that embrace consideration of the outcomes from knowledge use recognise the purposeful nature of climate change science and the mutual inter-dependence of science, policy and practice. In this way, this research corroborates and extends recent case findings (see, e.g., Carter, 2013; Görg et al., 2016) on how science and policy need to be understood as coherent and co-constitutive. The characteristics of effectiveness identified and examined in this thesis also highlight important enabling and orchestrating conditions, where interfaces can help support transition steps through critical scrutiny of current systems, and in building a shared understanding and capacity for reforms that better align with future needs. These characteristics significantly expand on the understanding of effectiveness in conventional SPPI literature where effectiveness arises from the saliency, legitimacy and credibility of knowledge produced (e.g., Wyborn et al., 2019). Identifying these characteristics provides useful guidance for evaluative purposes as well as facilitating dialogue and reflexive spaces that can enhance the effectiveness of interfaces.

7.2.3 How can SPPIs facilitate policy reforms and climate change transitions in Australia?

Insights from this re-conceptualisation of SPPIs, and associated exploration of factors characterising their effectiveness, raise questions on how climate change SPPIs can act as agents of reform, including how they can go beyond delivery of actionable knowledge to learning, empowerment and transformative action by non-science actors. While science alone is clearly an insufficient driver of change, from a synthesis of the insights from the case studies of this thesis, three functional capacities of how SPPIs can act as agents of reform can be distinguished.

(i). Effective SPPIs underpin effective climate change policies. As the case studies in this thesis make clear, policy settings have a major role in enabling or constraining adaptation and de-carbonisation outcomes in a changing climate. Scientific knowledge of climate change is complex and spans social, economic, and environmental impacts and dimensions over varying geographical and temporal scales which can challenge existing policy settings (see, e.g., Chapter 1, section 1.3, Chapter 2, section 2.5, and Chapter 3, section 3.2). Navigating this complexity requires a robust scientific evidence-base to ensure that interventions are well-tailored to the problem, that new relevant knowledge can be readily considered and incorporated, that performance is measured and understood, including lessons learned from successful or unsuccessful outcomes (see Chapter 6, section 6.4). Effective climate change policy also needs to enable and incentivise effective implementation approaches, involving wider practitioners and stakeholders, to realise the outcomes sought. In this way there is a clear three-way interaction – between knowledge producers, the policy designers that draw on that knowledge, and the policy implementers that translate and use the policy design in real-world contexts – that underpins policy effectiveness. There is urgency now to establish robust SPPIs as defined in this thesis for the national policies that are important in adaptation, resilience and decarbonisation in Australia.

(ii). SPPIs are critical for adapting policies in a changing climate. As described in Chapter 1, an effective response to climate change will require substantial reform and transformation within many sectors, industries, policies and across many behaviours. Even should the Paris Agreement aspirational targets be met,[3] the global climate will continue to change for many hundreds of years and challenge decision-systems that continue to assume a stationary climate. It is critical now that policy settings in exposed and vulnerable sectors are adaptive and nimble, that obstacles to adaptiveness are rapidly removed, and that successful niche innovations are supported into policy and practice and up-scaled.

As revealed through the case studies in Chapters 2, 3 and 4, analysis of the operation of SPPIs in real-world policy regimes bring unique insights to understanding the barriers to adaptive policy. These case studies, illustrative of where weak interfaces and implementation outcomes neither reflect calls by climate change science for urgent action and reform, nor recognise increasing risk, point to the need for deeper and more critical consideration as to why the science is subordinated. This thesis identifies four key factors that help explain the limited uptake of climate change science in key national climate policies:

- *Policy or regulatory prescriptiveness* on what knowledge should be used in implementation and how knowledge relevance is assessed. Such prescriptiveness, evident in methods for forest carbon sinks and in substantial parts of the national housing standards, while initially perhaps intended to support comprehensive implementation (see sections 2.5 and 3.4), can become problematic where relevant areas of science are rapidly evolving, such as regarding a changing climate.
- *Disconnect between climate change science and the knowledge systems driving practice*. Much future-oriented climate change science does not readily connect with the more experiential knowledge base of industry policy, particularly when the latter is supported by powerful economic actors, is path-dependent and resources are needed

[3] The Paris Agreement includes goals to hold the increase in global average temperature to well below 2°C above pre-industrial levels, and to pursue efforts towards a 1.5°C temperature limit. Current nationally determined contributions to this global effort do not yet align with the effort required to meet the 2°C goal, and there is a substantial gap between projected emissions and a pathway towards the 1.5°C goal (Climate Action Tracker 2021).

for science tailoring and translation. Niche industry leaders in the housing and forest sinks cases (see Chapter 2, section 2.5, and Chapter 3, section 3.4) are demonstrating that bridging knowledge sources is feasible and can support adaptation and mitigation action, and are calling for further tailored research.

- *Underlying priority-setting frameworks that prioritise the status quo*. As was made evident in Chapters 2 and 4 (see sections 2.5 and 4.3 in particular), existing frameworks can reflect persistent and prevailing neo-liberal political, ideological and cultural goals or preferences for cost-minimisation and industrial development. Such goals may not be explicitly identified in policy or regulation, but their influence can constrain prioritisation of investment in climate change outcomes.
- *Implementation approaches driven by short-termism.* Also, as illustrated in Chapter 2 (see section 2.5), many decision processes have implicit short time horizons, and traditional and ubiquitous approaches to valuing costs and benefits, for example, largely fail to factor in longer-term benefits and climate change risks.

These four factors add another dimension to understanding the barriers to climate change adaptation. Although several previous studies have enumerated institutional and policy barriers to adaptation (e.g., Oberlack, 2017), this thesis exposes critical insights into the influence of multi-institutional path-dependencies, and into underlying characteristics of practitioner knowledge and the drivers of practice that constrain the uptake of externally-produced climate change knowledge. In particular, consideration of how real-world national policies such as for housing can deliver to climate change adaptation reveals that barriers cannot be considered as only extraneous factors that can be addressed, for example, through the provision of resources or information. Several of the key barriers identified in this research are central elements or processes of policies, and addressing them will require major reform processes involving change to influential institutions that benefit from current arrangements. Such barriers are likely to be pervasive, as many policies and institutions in vulnerable sectors were developed under assumptions of a stationary climate, are well established, and operate within systems having embedded knowledge and self-reinforcing practices. The requirement for a quantified and certain net benefit from application of specific cost-benefit analysis (CBA) methods to allow amendment to building standards, for example, has been found in practice to exclude consideration of uncertain future benefits for resilience objectives (see Chapter 3, section 3.5.2). Use of alternate methods that recognise and value uncertain future benefits will be challenging to implement, as CBA approaches for regulatory reform have been agreed to by national ministerial-level councils, guidance has been developed and approved by central economic departments, and practitioners and subordinate decision-makers are well versed in the accepted practice.

These insights into barriers to science uptake can, nonetheless, guide tailored reforms for adaptive policies. Reforms, to be effective, need to be strongly informed by the nature of barriers and an understanding of how the barriers interact with other SPPI components to affect outcomes achieved (see e.g., Chapter 2, section 2.6, and Chapter 3, section 3.5). For example, despite weak policy for forest sinks in Australia with regard to climate change adaptation, there are niche solutions emerging from practitioners who are learning from project management through drought, heatwaves and floods (Chapter 3, section 3.4). Thus, reforms that can require consideration of long-term climate change resilience, and at the same time remove prescriptive impediments to innovation and incentivise adaptive capacity in ways that deliver to and support regional land-management objectives, could meet both policy and community goals (Chapter 3, section 3.5).

Another important theme emerging from the case studies is that innovation and experimentation are essential to address complex adaptation and de-carbonisation challenges. Effective SPPIs provide a fertile space for innovation and problem-solving through the bridging of science, policy and practice sources of expertise and capacities. The enabling of experimentation from such spaces is essential to widen consideration of how policies can be adapted to achieve desired climate change goals. Case studies in Chapters 2, 3 and 6 reveal the capacity of industry-research partnerships to establish robust SPPIs and find solutions at niche and wider scales, even in the absence of progressive policy from government. The sharing of understanding of the benefits and opportunities from niche climate action across a wider regime, can build readiness for up-scaling when enabling conditions emerge.

(iii). SPPIs can help reshape policy debates. Finally, and of importance in supporting wider and ongoing transitions towards climate-smart societies, robust SPPIs, as defined in this thesis, can help reshape policy debates away from a narrow neo-liberal paradigm towards more expansive, holistic and evidence-based approaches to climate policy responses. Through their inclusion of multiple and diverse voices in dialogues on desirable futures in a changing climate, robust SPPIs can help build anticipatory capacities and blend future-oriented perspectives with embedded, prescribed or experiential knowledge, and hence reduce the occurrence of conflicting perspectives on preferred pathways. Such SPPIs can transparently foreground and bring to debate assumptions and evidence around the costs and benefits of policy reform over time, encourage learning relevant to policy and practice, and help avoid the subordination of externally-developed climate science that may challenge current policy settings. Robust SPPIs can also help mitigate some of the risks of climate change policy debates being dominated by misinformation and biased media reporting of research.

Overall, it is clear that the capacities of SPPIs to help drive policy reforms and transitions, rely in reasonable measure on government action. Governments have roles in coordinating, enabling and incentivising the uptake of successful niche activities to realise climate change outcomes through SPPIs, as well as in being accountable for outcomes from policy implementation. This aligns with the imperatives identified by Mummery and Mummery (2019) for governance in the Anthropocene, including on climate change, to give primacy to the global environment, support transdisciplinary research and anticipatory and reflexive institutions, and facilitate learning from experimentation. Accountability is important for the mainstreaming of climate change science in policy implementation, and in enabling such institutions and learning, through its attention to transparency in reporting and on holding responsible actors to account. Cases in this thesis (e.g., Chapters 2 and 4) reveal that robust SPPIs can help align dimensions of accountability with the wider societal goals of preparedness and protection of vulnerable communities and environments in a changing climate. In this context, SPPIs can be effective mechanisms to support environmental accountability through their linkage of information on emerging risk with knowledge on the contextual performance and adequacy of policy settings and practices, and through their capacity to facilitate shared learning across policy-makers, practitioners and other stakeholders from the insights generated from such linkages (e.g., Chapter 4).

In addition, governments have important roles in enabling coherence across the mix of interdependent policies for successful climate change reforms (section 7.2.2). Effective protection of species of national significance in Australia, for example, requires approaches that span protected areas, other public lands, and private property in landscapes managed for agriculture and grazing, and that incentivise conservation outcomes that are well beyond the scope of current environmental protection legislation (see, e.g., Chapter 4). Similarly, as detailed in Chapter 2, the legacy of a focus on minimum building standards, up-front cost minimisation, and at best *ad hoc* and constrained engagement with the science community (input only), accompanied by rising costs of disasters and insurance and increasing vulnerability, point to the need for wider integrated coherent approaches to policy mixes for housing and infrastructure. Such reform will likely only be achieved through the development and implementation of complementary housing, planning, disaster management and insurance policy approaches and settings, and from a shared understanding of the changing risks and the feasibility of improved practice from niche innovation. It is clear that the pervasive nature of climate change challenges requires that multiple policies across more than one sector, implemented by a range of actors, work effectively in concert. Such a coherent integration of policies that aligns with the systemic implications of climate change is itself facilitated and supported by the establishment and operation of robust SPPIs.

7.3 Conceptual and theoretical contributions and implications of the research

The insights regarding robust SPPIs and their potential to overcome barriers to knowledge uptake and to the design and implementation of adaptive knowledge-based solutions described in section 7.2, also contribute to wider contemporary conceptual and theoretical debates on change governance, policy implementation, and climate change adaptation. This section examines how robust SPPIs can advance understanding in these fields, and then appraises the scholarly contributions of this thesis.

As highlighted in section 7.2.1, an original contribution of this thesis is its new definition and conceptualisation of SPPIs, which, importantly, draw attention to capacities that can better align with the multi-faceted nature of environmental problems. More specifically, the re-conceptualisation of SPPIs in this thesis as spanning multiple institutions and knowledge systems responds to a recognised weakness in SPI research, notably a deficient consideration and understanding of end-user needs of science (e.g., Hoffman et al., 2019). Figure 7.2 illustrates the difference in emphasis and span of conventional understandings of SPPIs in schematics (a) and (b) (see Chapter 1, section 1.2), which are widely used, relative to the re-conceptualisation developed in this thesis encapsulated in schematic (c). Through the multiple interfaces depicted in shading, Figure 7.2 (c) foregrounds more than one pathway for science to influence policy, and that in the context of dynamic environmental problems further insights can be gained from separate consideration of policy and practice, and from the inclusion of how practices are affecting outcomes. These interfaces highlight the utility of robust SPPIs as a framework for exploring the wider research questions described in Table 7.1.

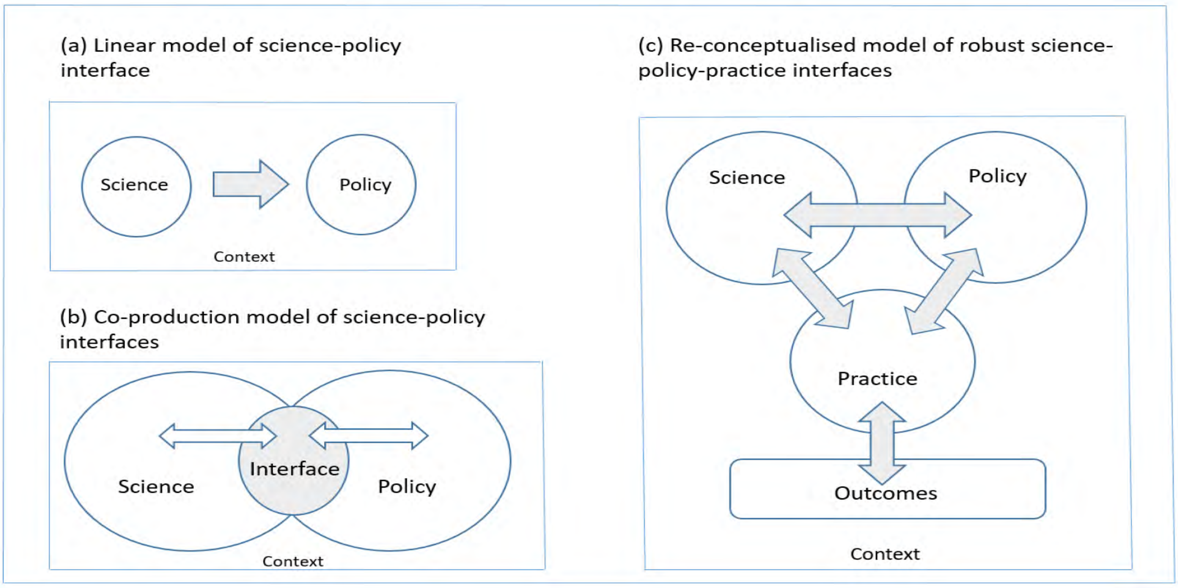


Figure 7.2. Science-policy interface models.

Further, the application of this new SPPI definition and framing to specific policy implementation processes and regimes as explored throughout this thesis, generates a more robust understanding of knowledge generation and uptake processes. The case studies show that SPPIs can act as mechanisms that facilitate experimentation within wider transitions, and in this way can build shared knowledge of the nature of successful interventions (see e.g., Chapter 3, section 3.4 and Chapter 6, section 6.4). Further, the operation of robust SPPIs as conceptualised in this thesis can significantly enhance capacities to identify direct and underpinning obstacles to knowledge uptake, including how such obstacles to uptake can be reinforced across several SPPI components, and thus how reforms need to be tailored and inter-operable to overcome identified challenges in knowledge use.

Insights from this thesis also have relevance and implications for theory regarding change governance. Scholarship on governance has become an important means for analysing and supporting tangible ways to enable transitions towards resilience and sustainability in a changing climate (e.g., Hölscher et al., 2019). The findings of this thesis, underpinned by empirical insights derived from the case studies, contribute to a conceptual frame that can strengthen conditions that need to be established for effective climate change policy reform and transitions. As introduced in section 1.4.1, the perspective taken in this thesis extracts insights from both SPPI and transitions literatures. Transition approaches, for example, offer ongoing system change perspectives, and open debates within SPPIs on climate change goals and alternate pathways. SPPI approaches, as demonstrated in this thesis, have the capacity to recognise the multiple perspectives and actors at the heart of knowledge uptake and innovation, and provide detailed insights on how to bring key voices to the table and on concrete mechanisms that can support transition steps. Through the bridging framework developed and elaborated in this thesis, examination of the linkages and disconnects between science and both specific policy frames and larger societal climate change goals enabled assessment and explanation of what makes an effective SPPI relevant to societal objectives, and what the capacities and obstacles to science uptake are in an operational context. The span of this approach generates useful insights for the management of fragmentation in climate governance, in particular with regard to the capability of SPPIs to drive partnerships that can address gaps in cohesion (e.g., see Chapter 6).

The development and analysis of SPPIs in this thesis is also of value to policy implementation literature and theory. Success in policy clearly depends upon implementation, the role of policy in implementation processes is still an area of active theorisation, and weak collaborative understandings of problem-solving requirements, among other factors, are reasons for policy failure (e.g., Bullock et al., 2021; Howlett, 2019; Hudson et al., 2019). Robust SPPIs, as defined in this thesis, can be beneficial for varying implementation contexts and processes and have the potential to help close observed implementation gaps which have been identified in the literature (e.g., Kieslich & Salles, 2021). This research clarifies that measures to close implementation gaps can be driven from implementation as well as policy, and the often assumed one-way link between policy and implementation is found to be insufficient. The successful transition cases explored in this thesis, for example, were in considerable part enabled by experimentation and leadership from implementation or practice actors. Further, in such dynamic contexts as climate change adaptation, this research finds that the prescriptiveness of policy can be a factor that limits the effectiveness of implementation, which suggests that policy and its determinants need to be a central (and not contextual) variable in implementation theory.

Finally, this research contributes to the emerging theorisation of climate change adaptation. Adaptation is now being recognised as a complex governance challenge, where empirical studies reveal a continuing implementation gap in the integration of adaptation objectives into sectoral policies and practices, and a lack of clarity regarding outcomes achieved (e.g., Runhaar et al., 2018). As noted, there is a growing literature on barriers to climate change adaptation, including calls to better understand how transformative adaptation processes can be enabled where non-linear changes in the climate system demand beyond-incremental responses (e.g., Biesbroek et al., 2014; Park et al., 2012). Barriers have conventionally been understood in such literature as impediments, or as failures in design or execution of the governance processes; however, such descriptions can oversimplify institutional reform processes for adaptation, and there is little guidance on how such barriers can be overcome (Biesbroek et al., 2015; Patterson et al., 2019).

This thesis contributes to theories of climate adaptation governance in two ways. First, the case studies reveal the likelihood of incompatibilities in the knowledge systems of actors and institutions central to realising adaptation outcomes within a policy regime. Existing sectoral policies and regimes have gained social legitimacy from delivery of now entrenched and self-reinforcing practices, and will be challenged by demands for transformative change. The extended understanding of SPPIs developed in this thesis provides a useful framework to identify and understand the coexistence of multiple perspectives on adaptation, and how they interact to shape preparedness for institutional change processes. Its application across five cases not only supported comparative analysis but suggests relevance to a wider range of cases.

Second, the case studies demonstrate the central roles of non-state actors in policy regimes for adaptation. Industry and other practitioners contributed essential capacities for adaptation reforms in the case studies of this thesis, including experimentation, learning what works and what does not work in particular contexts, and approaches that bridge experiential knowledge with climate change knowledge. Achievement of long-term reforms for adaptation are in this way likely to hinge on complementary and interactive roles of both state and non-state actors. Overall, the approach developed here finds SPPIs to be powerful *activity spaces* for adaptation within regimes that can help build cohesion in goals and approaches over time, overcome fragmentation, and contribute to addressing the implementation gap in adaptation mainstreaming. Figure 7.3 summarises the empirical, conceptual and theoretical scholarly contributions of this thesis.

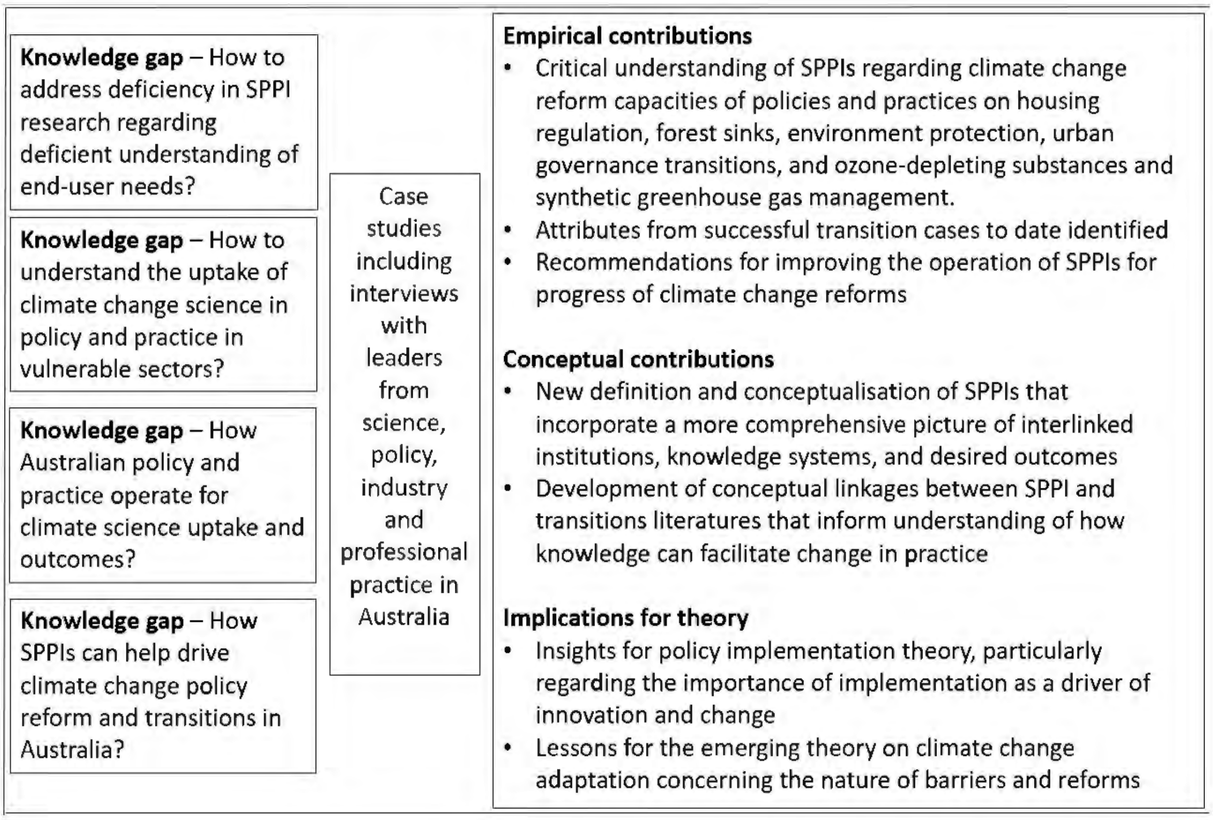


Figure 7.3. Summary overview of research approach and contributions.

7.4 Research scope and future directions

Drawing on the five case studies, this thesis demonstrates that effective SPPIs have characteristics that can overcome obstacles to the use of knowledge, and to social processes that can build shared support for progressing essential reforms important for climate change adaptation and de-carbonisation. The focus on SPPIs in this thesis responds to growing calls for science to have a greater role in the design and implementation of transition pathways for climate change and sustainability, and to the knowledge gap identified in Chapter 1 regarding how science needs to underpin the new learning, leadership and governance approaches required for climate change transitions.

Beyond the scope of the case studies in this thesis, there are other sectors in Australia where climate change knowledge needs explicit consideration and uptake. With regard to the water supply sector, particularly in the Murray-Darling Basin, recent research shows a lack of uptake of relevant climate change science and policy path-dependency that has subordinated the risks of climate change in water allocation agreements (Alexandra, 2017; Pittock & Finlayson, 2011). Additional analyses on the operation of SPPIs could further elucidate the precise nature of obstacles to science uptake and point to how decision-processes need reform. Similarly, while there has been less research in Australia on climate change impacts and risk management in the electricity sector, there is growing recognition internationally and domestically that greater consideration to climate change impacts is needed for energy security (e.g., Gerlak et al., 2018; Smith & Brown, 2014; Troccoli, 2011). Additional studies could also generate deeper insights into how effective SPPIs can relate and operate across scales (from niche innovation, to policy and practice regimes, to wider landscapes), and into the commonality or uniqueness of barriers such as prescriptive policy settings, or insufficiently translated climate change science.

Transitions for climate change adaptation or decarbonisation clearly depend on multiple interacting institutions, policies, technologies and reforms. Case studies in this thesis reveal the importance of policy mixes in designing reforms, where it is recognised that achieving climate change goals will typically go beyond a single policy domain and depend on the outcome-focus and coherence of multiple policies. For instance, as was noted in Chapter 4, achievement of threatened species protection goals requires better alignment of Protected Areas with off-reserve conservation measures which relate to the majority of potential habitat for those species. Also, the case study on managing ozone depleting substances and synthetic greenhouse gases in a successful transition (Chapter 6) found that success depended on the reinforcement of policies to cap emissions with policies that incentivise industry capture and re-use of the emissions, and that support industry and science networking across scales. It is clear from this case study that the transition would have been much less effective if only one policy was in place. Policy mix research for transitions is a relatively new and growing field (e.g., Kern et al., 2019), and there is a need for greater consideration on how knowledge and SPPIs can inform and enhance coherence in interlinked policy mixes.

Further opportunities to build on the research of this thesis include drawing on approaches such as network analysis to provide complementary insights into the relationships between actors within a SPPI, and on concepts from sustainable transition scholarship to better understand the role of macro structures in conditioning actor behaviour within a regime.

Power dynamics and politics are also important to SPPIs, with recent research finding that SPIs can fail where power structures are too centralised, or where top-down policy approaches only poorly enable information sharing or collaboration in problem-solving (e.g., Kieslich & Salles, 2021). It was found in both the successful transition cases presented in this thesis (Chapters 5 and 6) that trust, equality, and respect were all essential for the operation of the informal partnerships that enabled knowledge sharing and solution-finding. The housing regulation and environmental protection legislation cases also identified that the power of vested interests, particularly where they align with government pro-development goals, can constrain consideration of climate change science. Further research could more strongly link robust SPPIs to social theories regarding power and conflict in knowledge uptake and use, and build understanding of the capacities of SPPIs to influence politically powerful actors with interests in maintaining current institutions and practices.

Finally, the social and political context is important in any research project. The research for this thesis commenced in 2017, when there was a conservative national government in Australia, and climate change was a very politically charged issue with progress in policy development repeatedly thwarted by an influential far-right group in parliament. Conducting social research in such a context increases the potential for interviewees that benefit from the status quo to align their views with current policy positions, and perhaps be less reflective of broader social trends and opportunities from stronger climate change action. Such points are a cogent reminder of the need for a deeper critical exploration of the underlying drivers and practices which affect perceptions and use of climate change science.

7.5 Conclusion

There are systemic problems with the capacity of Australia's policies and practices to effectively use climate change science to support adaptation and long-term decarbonisation action in climate-sensitive sectors. Despite numerous studies and reports that have described climate change impacts in Australia, along with sectoral exposure and likely vulnerability (e.g., Cresswell & Murphy, 2016; DCC, 2009; Stokes & Howden, 2010; Lawrence et al., 2022), climate change has received little serious and sustained attention in many policy settings. At best, robust SPPIs that support evidence-based successful activities are currently only niches within the overall landscape of governance for climate change adaptation and mitigation in Australia. This thesis makes an important contribution by revealing new insights into how these gaps and deficiencies need to be understood and acted upon, and how, particularly with regard to adaptation in Australia.

Through this study I have developed and employed an approach to analyse – and reconceptualise – SPPIs that is attuned to the multi-institutional complexity and dynamic goal-orientation of climate change transitions. This approach has been critically applied to policy regimes that underpin the achievement of climate-smart outcomes in Australia, and its application has identified a) major operational constraints that inhibit integration of climate science information, b) characteristics of effective SPPIs, and c) tailored reform proposals that scope an important forward agenda for Australian leaders in science, policy and industry. In recognition of the important role of government in enabling climate change solutions, realistic and practical recommendations and guidance have also been developed as part of this thesis to encourage more inclusive, reflexive and evidence-based collaboration in policy design processes.

Climate change calls for significant changes to policy and practice now, as well as into the future, in order to build preparedness for future impacts of a changing climate and to ensure that the magnitude of future impacts is constrained. The conceptualisation of SPPIs and reforms recommended from this research will enable governments and other leaders to better appreciate the reform agenda ahead, and collaborate proactively and effectively with science communities, industries and the public to build greater consensus on both challenges and possible solutions. This approach could be usefully adopted in other sectors and contexts across Australia to enhance networks and activity spaces on climate change capable of strengthening the long-term climate-resilience in communities, environments, infrastructure and industries.

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UNIVERSITY OF CANBERRA

18 July 2017

APPROVED - Project number 17-126

Ms Josephine Mummery
Institute for Governance and Policy Analysis
University of Canberra
Canberra ACT 2601

Extension granted to December 2021

Dear Josephine,

The Human Research Ethics Committee has considered your application to conduct research with human subjects for the project titled: ***"Climate change adaptation by Australian corporate organisations: the role of science in decision-making to manage risk."***

Approval is granted until 30 June 2020

The following general conditions apply to your approval.

These requirements are determined by University policy and the ***National Statement on Ethical Conduct in Human Research*** (National Health and Medical Research Council, 2007).

Monitoring:	You must assist the Committee to monitor the conduct of approved research by completing project review forms, and in the case of extended research, at least annually during the approval period.
Reporting Adverse Events	You must report any unexpected adverse events or complications that occur anytime during the conduct of the research study or during the follow up period after the research. Please refer these matters promptly to the HREC. Failure to do so may result in the withdrawal of the Ethics approval.
Discontinuation of research:	You must inform the Committee, giving reasons, if the research is not conducted or is discontinued before the expected date of completion.
Extension of approval:	If your project will not be complete by the expiry date stated above, you must apply in writing for extension of approval. Application should be made before current approval expires; should specify a new completion date; should include reasons for your request.
Retention and storage of data:	University policy states that all research data must be stored securely, on University premises, for a minimum of five years. You must ensure that all records are transferred to the University when the project is complete.
Contact details and notification of changes:	All email contact should use the UC email address. You should advise the Committee of any change of address during or soon after the approval period including, if appropriate, email address(es).

Yours sincerely
Human Research Ethics Committee

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