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CSIRO submission to consultation on Agriculture and Land Sectoral Plan

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Executive Summary

This submission focuses on three areas central to the development of the Agricultural and Land Sectoral Plan:

- Options for emissions reduction and barriers to their adoption, and actions that can improve adoption.
- The climate change adaptation and mitigation nexus; and
- Innovation system actions to support the change.

Recommended actions are made throughout the document, and while all are important, the highest priority actions recommended for consideration relate to:

1. Layering of emerging agricultural options will be necessary given there is unlikely to be a single solution across the sub-sectors. Addressing enteric emissions in livestock, and fertiliser related emission in cropping, are the biggest levers for reducing agricultural emissions overall. Progressing action through reducing the greenhouse gas intensity of agricultural products may link productivity and emissions reductions goals and creates future options around agricultures contribution (more production with same emissions, same production with less emissions and more land diverted to other options etc).
2. Adoption of low emissions practices, currently constrained by a lack of information on the contextual applicability of mitigation options, particularly the relationship between mitigation activities and productivity, and the unclear profit effects. Building a strong evidence base of best bet practices for regions and the relationship of these to profit and generation of other values (biodiversity etc) will be important. Central to this will be low-cost measurement and verification processes, data standards, access to data and interoperability to drive the development of decision support and services to farmers and producers.
3. Taking a whole of food system approach. While some emissions reduction will be achieved with on-farm, single commodity facing technologies, more options exist by taking a whole food system approach. This unlocks whole of supply chain actions, cross-sectoral activities, and new energy-commodity farm configurations of the future. Adoption of known low emissions practices is severely constrained by the poor on-farm business case for their use. Looking for ways to use incentives and whole of value chain action to scale these technologies will be important.
4. The uptake of climate smart agriculture practices, which will likely require a significant upskilling within the sector, increased sophistication in the service sector and better decision support infrastructure, to navigate the emerging changes in farming systems, market opportunities and the growing digitisation of Australian agriculture. Transition challenges likely require longer term programs and investments, and because actions will need to span typical government portfolios (energy, environment, agriculture) may be served well by some form over overarching innovation governance.

5. Seeking to reduce agricultural emissions and increase carbon stocks in the land at the same time as climate change impacts unfold. It will be important to consider the moving climate baseline when planning new infrastructure and or making forward commitments from agriculture to provide industrial feedstocks. Climate change risk must inform all emissions reduction actions.
6. Australia's Indigenous and agricultural enterprises and estates, which make an important contribution to Australia's natural wealth and are vital to the nation's ecosystem services and low emission future. These contributions, and the management role played by local land managers, including Indigenous land managers, are not well accounted for in existing carbon or biodiversity accounting and business model frameworks. To assist activities, we need to focus on how Indigenous participants can equitably and efficiently enter emerging carbon markets and create both commercial and cultural values.
7. Futures thinking and scenario development, which can play a role in designing preferred futures and practical pathways for working towards them. Many of our current modelling approaches consider the future as the immutable consequence of current trends, reinforcing the inertia of current policy and management practices, and downplaying our collective ability to create better futures for ourselves and the generations that follow. It will be important to review approaches to economic modelling to assess their utility for supporting climate policy. New and more flexible approaches are emerging that support participatory evaluation of policy options with policy makers, enabling the design and evaluation new and preferred options for attaining net zero emissions.

Introduction

CSIRO welcomes the opportunity to provide input to the Department of Agriculture, Fisheries and Forestry's consultation into the Agriculture and Land Sectoral Plan.

Australia, along with the rest of the world, has committed to deep emissions cuts. The scale of ambition cannot be achieved without contribution from the agriculture and land sector. The land sector has contributed to declining national emissions over recent decades through increased carbon storage, predominately from afforestation and avoided deforestation. However, emissions from agriculture have broadly remained the same.

Australian agricultural systems, including cropping and livestock production, are among the most greenhouse gas efficient in the world as measured by greenhouse gases produced per unit of finished product. Although this has ensured access to discriminating markets such as canola into the EU biodiesel market, we should not expect the emissions intensity of global competitors to remain constant. We expect that as emissions are reduced in other Australian sectors, an increasing focus will be on the agricultural sector to contribute to overall emissions reduction, especially where feasible emissions reduction technologies exist. For example, we have seen this in livestock methane in overseas jurisdictions.

Significant investments into low emissions practices are seen overseas, such as the recent US$5bn USDA investments into climate smart agriculture. While some of this may spill over to benefit Australian producers, adoption and applicability of practices is notoriously context-specific and likely requires deep producer trust to overcome barriers to adoption and for local market mechanisms that incentivise adoption to evolve.

Domestic research, development, and extension is needed to see widespread adoption of low emissions practices. It is important however not to see the need for change simply being an on farm or up-to-farm gate problem. To significantly reduce agriculture emissions, and for agriculture to contribute to national mitigation efforts more widely, will require building infrastructure, systems, and skills. This includes enabling infrastructure such as high-speed rural internet, logistics and infrastructure to support bioeconomy feedstocks from a diversified farm sector, digital infrastructure to support low-cost measuring, reporting and verification and local scale and contextually relevant decision support. It also includes standards, sustainability credentials and mechanisms for changing agriculture supply chain functions, skills, and an enhanced service sector to support more complex land management. Connection to other economy sectors that provide inputs to agriculture will be important to ensure the embodied emissions in agricultural inputs, such as fertiliser and crop protection products, are reduced.

CSIRO has long supported the Agriculture and Land sector through roadmaps, technology development and capability building. Commentary and broad background to this submission draws on five recent pieces of analysis developed by or commissioned by CSIRO.

- The 2023 **'Reshaping Australian Food Systems: A roadmap towards a more sustainable and resilient future for Australia's food, its environment and people'** (CSIRO Futures 2023) details actions to facilitate agricultures emissions reductions.

- **'Low emissions pathways for Queensland agrifood'** (Battaglia et al. 2022) provides a detailed assessment of practices and actions and their scalability, which was developed for Queensland but has broader national relevance.
- **'Australian grains baseline and mitigation assessment'** provides a benchmarking and evaluation of emissions reduction options for grains in Australia (Sevenster et al. 2022)
- The **'GHG Ag-tech Roadmap'** looks at aspects raised by the roadmap and explores the digital ecosystem required to develop a thriving and trusted emissions services industry in agriculture to support adoption of on-farm, low-emission farming practices (The Growth Drivers 2023).
- **'Australia's sequestration potential'** is a stocktake and analysis of sequestration technologies (Fitch et al. 2022).

CSIRO is preparing an Ag2050 scenarios-based roadmap in collaboration with the Department of Agriculture, Fisheries and Forestry that asks what farming might look like in 2050 and describes possible future farming systems and key shifts and actions needed to bring them about (Ag2050).

In addition to road mapping and fore sighting activities, CSIRO remains committed to developing practice and technology options to enable low emissions agriculture. To date these have included technologies such as:

- FutureFeed - a feed supplement to reduce livestock methane production
- SCANS (soil carbon assessment system) - underpins existing field assessments for soil carbon methods (SCANS info)
- The production of underpinning and enabling digital infrastructure such as the Australian National Soil Information System (ANSIS)
- A range of Apps such as the 1622 app to assist in reduce impacts of N fertiliser in sugar production on both emissions and great barrier reef water quality (Sugarcane actions).

In addressing the questions, and to avoid repetition, we have integrated many of the questions into an options, barriers and actions sections (incorporating your questions 1, 3, 5, 6, 11), a response to question 2 on mitigation/adaptation interaction; and a final section which combines the remaining questions under the broad framing of how to build the enabling innovation and institutional capability to address these challenges (your questions 4, 8, 9, 10).

CSIRO response to the Questions

Options, barriers and actions to enable scaling of practices.

(addressing questions 1, 3, 5, 6, 11)

High-level summary:

- Layering of emerging agricultural options will be necessary given there is unlikely to be a single solution across the sub-sectors. Most agricultural emissions are from livestock enteric emissions. The major source of emissions from cropping are from fertiliser.
- Adoption of low emissions practices is constrained by lack of information on the contextual applicability of mitigation options, particularly the relationship between mitigation activities and productivity, and unclear profit effects.
- Some good data exists on agricultural practices. However, the dispersed way the data is collected, and the fragmentation of the data sets means it is difficult to generate regionally specific and enterprise-level recommendations.
- Benefit stacking (layering biodiversity, carbon and potentially cultural benefit payment) may help overcome what are often marginal business cases for adoption of low emissions practices.
- Agreed sustainability credentials, underpinned by low cost on-farm performance evidence, with informatics systems that build trust in claims, may be a useful way of redistributing value along value chains and improving the on-farm incentive for practice adoption.

The following table (Table 1 This table describes some of the key barriers that are limiting the adoption of low emissions technologies and practices and provides options to address those barriers. A more comprehensive review of options is required, and an excellent overview of options can be found in Battaglia et al. 2022.outlines major areas, barriers, and opportunities in sub-sectoral areas. An overarching section is included at the end.

CSIRO recently contributed to the RD&E stocktake undertaken by the Department of Climate Change, Energy, the Environment and Water (DCCEEW) that documents activities in each area and is available upon request.

Table 1 This table describes some of the key barriers that are limiting the adoption of low emissions technologies and practices and provides options to address those barriers. A more comprehensive review of options is required, and an excellent overview of options can be found in Battaglia et al. 2022.

Target Area	Barriers to Action	Opportunities and enabling actions
Livestock [3.1]	**3.1.1** While supplements offer potential for reducing methane production (between 40-80% when animals can be accessed regularly), practicality and cost of supplements beyond a feedlot or dairy setting is limiting scaling to grass fed and rangeland animals. **3.1.2** Availability of supplement supply due to current production constraints in the supply (*Asparagopsis* case) and the preferential delivery of products to international markets (3NOP case) is slowing adoption of anti-methanogenic supplements. **3.1.3** Long time frames for regulatory approval and development of ERF methods are delaying market entry of new feed supplements. **3.1.4** When existing supplements are not available or cannot be delivered to the animals, regional suitability of deploying alternative options such as anti-methanogenic pastures and associated production and emissions production benefits are not clear	**3.1.1, 3.1.2** and **3.1.3** Scale supplement use in intensive feeding situations and develop slow-release mechanisms for anti-methanogenic supplements to rangeland animals – which even if low in efficacy, could contribute significant abatement given the substantial number of animals on rangelands. ○ Consider supporting trials of technologies and provide incentive mechanisms that build collaboration along value chains. ○ Consider promoting infrastructure investments and regulatory support to allow early access to low emissions feed supplements for Australian producers. ○ Development and approval of ERF methods in parallel with the piloting of new feed supplements and delivery mechanisms to reduce the time to market for new options. ○ Engage early in international supplement and bioproducts prospecting and vaccine research to ensure Australia well positioned to be early adopter with access to product supply. **3.1.4** Enabling gains in herd efficiency through uptake of precision grazing technologies with/without modified pasture composition to optimise available feed/fodder quality. ○ Build evidence base for productivity and emissions reduction base and develop extension networks to build trust in recommendations. ○ Encourage concessional loan or other finance mechanisms to defray up-front cost of capital investment in precision ag techniques. **3.1.4** Build capacity in nutritional advisory component supported with region specific best practice and likely productivity effects.

Target Area	Barriers to Action	Opportunities and enabling actions
		3.1.4 Investigate support or financing of pasture regeneration with forage legumes as drought resilience measure and emissions reduction strategy. **3.1.4** Improved information on anti-methanogenic crops and shrubs. ○ Improve prediction of realised methane and production gains. ○ Promote adoption through extension services and provision of bioeconomic modelling data of financial, feed base resilience and environmental benefits data. ○ Build and ensure access to underpinning digital infrastructure (soils, climate, tenure, animal numbers and location etc) at relevant scales to enable relevant decision support tools and evaluation metrics.
Cropping [3.2]	**3.2.1** There are few meaningful incentives for farmers in terms of increased revenue, lower operating costs, or access to capital. It is accepted that regulatory and market access constraints (e.g. CBAMs) are coming but these are not seen as requiring urgent action on farm. **3.2.2** Farm advisory sector capability in measuring and reporting on Greenhouse Gas (GHG) emissions is variable which can limit contextually relevant advice on best practice. **3.2.3** With the available GHG analysis models providing different results to farmers, there is low trust in the accuracy	**3.2.1, 3.2.5 and 3.1.4** Encourage concessional loan or other finance mechanisms to defray up-front cost of capital investment or operating costs in options that either lead to a reduction in actual emissions or the emissions intensity of production. **3.2.2, 3.2.3 and 3.2.4** Research to enable scenario modelling at enterprise scale (and hyperlocal scale) to assess benefits and trade-offs relevant to paddock condition and history, climate (future and current). This will require the development of trusted data on outcomes that allows for regionally relevant assessments. To date, poor metadata and inconsistent/non commensurate measurement has prevented the integration and interpolation of trial results. ○ A priority would be considering the development of data standards and a data architecture that allows federation of data and delegated access to drive innovation and support the build of a service industry of the back of this data. ○ Standards and data aligned to international methodologies to maintain market access. ○ Build integrated multi-scale (paddock to enterprise) models that draw on publicly available data (including remotely sensed data) with on farm histories and research data

Target Area	Barriers to Action	Opportunities and enabling actions
	of outputs, and this stymies evaluation and action. **3.2.4** Availability of scenario analysis at paddock to enterprise level that include seasonal variation in weather requires use of multi-year averages to assess mitigation and carry out benchmarking adding complexity to practice evaluation and carbon crediting processes. **3.2.5** For cropping there are options to decrease emissions intensity of production without impact on productivity (and potentially increasing productivity) but many of these options do not result in overall reduction in greenhouse gas emissions. **3.2.6** At the farm level net emissions reduction will be driven by a combination of activities including changes in carbon storage and emissions reduction. The aggregate compliance costs from each of these actions where they sit under different ERF methods or other market mechanisms can disincentivise action. **3.2.7** On farm emissions (scope 1) are dominated by emissions associated with fertiliser and lime and crop product use	to explore production gains, risks and trade-offs of options for emissions reduction aligned to the Integrated Farm Method and would support 3.3.1 Biofuels. **3.2.2 and 3.2.6** Deployment of the Integrated Farm Method creating the opportunity for a portfolio of activities at the farm level. This may be broadened where benefit stacking (biodiversity and carbon for example) is permitted increasing the value proposition for action. The development of regionally specific decision support tools that allow: ○ The carbon benefits to ecological intensification and regenerative practices need to be assessed against the emissions footprint to understand the net impact (including risk of increased N_2O). ○ Consideration of whole farm composition and re-purpose of marginal land or less productive parts of farms to carbon storage activities or energy crops. Biodiversity, natural capital assessment tools and other co-benefit assessment tools could support market formation around these co-benefits. ○ Concessional loans and other market mechanisms linked to the Integrated Farm Method to reduce compliance requirements. **3.2.4** While already increasing in uptake, further expansion of mixed farming options provides an opportunity to increase returns from land with lower inputs and may decrease unit product emissions. Opportunities in mixed farming that could be expanded in trial and demonstration include the use of dual-purpose crops, better utilisation of green/brown manures, technologies to inform grazing decisions and control grazing technologies (virtual fencing etc.) to maintain and enhance forage quality and ground cover, using shrubs and other novel vegetation crops to bridge feed gaps. This would provide data to integrated multi-scale (paddock to enterprise) models. **3.2.7.1** Use the development of hydrogen to support green fertiliser production.

Target Area	Barriers to Action	Opportunities and enabling actions
	(pesticides etc.) and consequently changes in embodied emissions in these inputs is required to drive down on farm emissions.	
Fuel & Energy [3.3]	**Biofuels**: Market demand for biofuels is emerging, particularly in hard-to-abate sectors including aviation, marine transport and mineral processing. There are existing technologies that have been commercially proven overseas that allow biofuel production to supply these markets. **3.3.1** Access to low C, biogenic feedstocks is a key bottleneck for development of these technologies. This presents an opportunity for the farm sector. **3.3.2** Opportunities for farm sector will not just be dependent on production of biomass but whole supply chain logistics, sustainability standards and regional impact measures.	**3.3.1** We need to understand how bioenergy crops fit into farming systems, including the potential benefits and costs. There are a range of feedstock options that will need to be matched to growing environment, farming system and downstream processing pathways. New oil seed, grain or cellulosic energy crops could be grown as rotations or on parcels of less productive land within farms. There are emerging opportunities to integrate tree crops (managed forestry and coppiced natives) into rangeland grazing systems to provide both biogenic feedstocks through partial harvests and on-farm co-benefits such as animal shelter, biodiversity and habitat, and soil/water management benefits). This is directly linked to options for integrated multi-scale (paddock to enterprise) models that allow for production gains, risks and trade-offs of options and stacked benefits for 3.2.4 and 3.2.6. **3.3.1** To enable farmers to capitalise on this opportunity, the biofuel industry value chain development could include the logistics, transport, fuel refining needed to deliver biofuels to end customers. There is also a need to ensure sustainability by assessing the risk of growing food versus fuel and the ways to overcome this could be by integrating biofuel feedstock production with food production. Where “marginal land” is considered for biofuel feedstock production, a rigorous assessment of the true yield potential and alternative uses (e.g. natural capital) of those lands needs to be considered. The development of Australian suitable sustainability standards for biofuel production could be helpful, as will tools such as biodiversity assessment tools and natural capital accounting frameworks that allow corporate investors to assess the fuel range of co-benefits and impacts from land-use change to energy crops or from residue harvesting.

Target Area	Barriers to Action	Opportunities and enabling actions
	On- farm energy production: There is a perception that solar farms are a binary choice between food and solar panels. Agrivoltaics offer the potential for integration of solar farms with food production. **3.3.3** Resistance and social acceptance issues exist around conversion of farming land to solar farms. **3.3.4** There are technical challenges to be addressed with the integration of food or bioenergy production and solar panels such as shading of crops and damage to panels by livestock.	**3.3.3** Where we see land transitions to renewable energy production there is an opportunity for better integration of competing land uses. Considerations include landscape level planning for energy development placement and how highest value land use interacts with placement of transmission lines versus keeping fertile land in production. **3.3.4** As the renewable energy industry continues to scale there is an opportunity for farmers to become energy producers, further diversifying income streams. Some farmers are already engaging with solar developers to host panels on their land, or to agist sheep on land owned by solar developers. However, there has been little to no works exploring agrivoltaics as a means of optimising both solar energy and food production on the same areas of land. While there is an opportunity for novel farming practices (e.g. agrivoltaics, growing crops and pastures under and around solar panel installations) that can enable dual-land use, realising these requires significant changes in design to standard solar farm installations. o Dual use with crops will require research into panel spacing, mounting systems, light mosaics to understand the microclimates created by the panels and equipment which will inform crop selection and potential production. This could be tied with an understanding of the whole of system productivity of the paddock (energy plus crop) when designing an agrivoltaics farm. o Grazing sheep under conventional solar farms is currently in practice but these systems are far from optimised for dual use and are not robust enough to incorporate large animals such as cows or horses. Research into what would be required to strengthen the infrastructure and cost benefit analysis into the need for additional infrastructure vs the incorporation of large animals would be important.
Carbon storage in the land [3.4] **(these topics were recently**	**Afforestation and farm forestry** **3.4.1** Economics – high cost of implementation with high upfront costs resulting in poor cash flow.	**3.4.1** Opportunities for increasing economic viability could include reducing costs associated with project development and registration, financially recognising the agricultural and environmental co-benefits associated with revegetation and developing mechanisms for forward crediting (to

Target Area	Barriers to Action	Opportunities and enabling actions
quantified and reviewed for barriers in Fitch et al. 2022)	**3.4.2** Total project size can be too small to attract support or for efficiency of operations. A problem of engaging smaller farms and land managers in carbon farming activities is emerging. **3.4.3** Availability of suitable land and potential conflicts over water use and competition with agricultural production. Significant expansion can change regional economies and employment. Climate change risk both to permanence of carbon stocks but also to changed landscape fire risk. **3.4.4** Can adversely affect land valuation as reduces arable hectares in land valuation without upside benefits being included in valuations. **3.4.5** Potential industry and supply chain limitations include ensuring adequate source material (either seeds or tubestock) and accessing suitably qualified skills and best-practice establishment methods will limit opportunity at least in the early years of activity scaling. **3.4.6** Farmers and producers may not look to sell into markets carbon credits generated through on farm forestry	buffer early growth years, when sequestration rates are lowest, and establishments costs are high) **3.4.2** Permanent vegetation planting activities are already supported by the ERF and its associated market mechanism. Creating market mechanisms that allow smallholders to participate with limited costs would provide additional opportunities. Conglomerates of smallholders to allow a regional approach could reduce the barriers to entry. **3.4.3** Building evidence base of where and when activities such as shelterbelts provide on farm benefits will help overcome implementation barriers. Linking on farm vegetation establishment to biodiversity goals could create pathway for multiple payments and align to multiple corporate goals. Development of tools to assess biodiversity value change associated with practice change will be required at multiple scales. **3.4.5** Analysis of source material supply chains to identify gaps for targeted investment or grants for research. **3.4.6** As identified in the crops section, integrated multi-scale (paddock to enterprise) models would allow for land holders to understand the potential for nature-based offsets and insetting.

Target Area	Barriers to Action	Opportunities and enabling actions
	activities but retain them to improve the carbon footprint of the farm and improve the net greenhouse gas efficiency of produce from their enterprise.	
	Soil Carbon: **3.4.7** Uncertainties in how to set realistic and achievable SOC stock change targets, and uncertainty over which practices will build SOC or reduce emissions. **3.4.8** Uncertainty on the risk of carbon loss under a variable and unpredictable climate. **3.4.9** High MRV (measurement, reporting and verification) costs involved in bring soil carbon projects to market with appropriate confidence to meet market requirements. The high up-front cost and slow returns over extended periods from soil carbon projects present a cash flow disincentive	**3.4.7 and 3.4.8** Consider investing in scenario work to examine risks to permanence of soil carbon stock changes and revisit risk reversal buffers. This could be supported by a network of long-term experiments at benchmark sites to understand soil carbon dynamics so appropriate risk provisions can be made. **3.4.9** Significant opportunities exist to reduce the cost of MRV (measurement, reporting and verification) using next generation space-time models (shift to hybrid measured-modelled approaches which harness the accuracy of measured approaches with less conservative deeming of carbon stock change, and the lower cost MRV process of modelled methods). Continued investment in proximal sensing techniques, improvement in underpinning data layers to allow for improved model accuracy, investigate and implement the use of time series of remotely sensed datasets as model drivers in the development of next generation of soil carbon model (empirical models), and finally consideration of investment in the use of UAV datasets for generating high spatial resolution digital soil carbon datasets.
Cross-cutting	**CC.1** There is low trust in existing digital support tools for identifying emissions reduction practices. This is exacerbated by lack of consistency and the difficulty to	**CC.1, 3.2.3** The establishment of data standards and open-data access as conditions for support of research and development, and development of data architecture to federate such data (as the existing Australian Agrifood Data Exchange proposes).

Target Area	Barriers to Action	Opportunities and enabling actions
	integrate these tools into normal farm management /data workflows. **CC.2** While good science on management practices and greenhouse gas modelling exists, the service sector and 'curious' producers have trouble accessing this quality science. **CC.3** The collection of high-quality data on greenhouse gas emissions from enterprises is a challenge for many producers and limits attribution and comparison of actions and reduces the capacity to report performance to markets. **CC.4** There is a low likelihood of wide scale value capture by farmers and producers from low emissions reduction factors under existing market mechanism. Creating value from the reduction in GHG intensity requires mechanisms to join up through supply chain action and requires a step change in though value chain collaboration/coordination.	**CC.2** Where possible, the agriculture community could prioritise key models and analytics as APIs for use by the broader ag innovation ecosystem. **CC.3** Resolving the cost to producers of collecting high quality emissions data can only be addressed through work to drive the cost of measurement to near zero for reporting. This will be most likely achieved through the development of improved models drawing inputs from existing farm management systems (the planned integration of FarmPrint with farm management systems is one example) supported by remote sensed or proximal data and spatialised digital surfaces of driving variables (such as the Soil and Landscape Grid of Australia). **CC.4, 3.2.3** There is an opportunity to convene actors across the agriculture value chain and agree on actions to build data and model standards and mechanisms to enable on the ground action. The GHG Ag-tech Roadmap' (TDG 2023) documents a pathway to delivering this outcome.

How can we progress emission reduction efforts whilst also building resilience and adapting to climate change?

(addressing question 2, 11)

Key points:

- Future climate change and climate vulnerability, could be considered as key criteria to include for all cross-sectoral future decisions, including those decisions related to mitigation actions.
- It will be important to build monitoring and evaluation approaches that assess changing risks to existing and newly created carbon stocks and energy crop activities.
- Understanding the implications of a moving climate baseline on infrastructure and investments associated with mitigation.
- Increased farm management complexity in the face of climate change and with a potentially diversified production mix will require building both human and institutional capacity. Investment in skills and supporting decision support and an enhanced and capable service sector will assist adaptation and risk mitigation.

We already see significant climate change and climate change impacts on agriculture and further climate change is likely including increase in air temperatures, more heat extremes and continued decrease in cool season rainfall across many regions in southern and eastern Australia (State of the Climate 2022). Impacts of climate change are influenced by system capability (skills, technologies such as fore sighting, institutional arrangements around financing, learning and networks) and a high system capacity means that Australia has high adaptive capacity (IPCC AR6 WG2 report). A long history of dealing with a highly variable climate has led to farming systems and an institutional landscape that has adapted Australian agriculture well to climate variability, and this will assist in reducing agricultural vulnerability to climate change. However, should the world fail to constrain global warming below 1.5^{o}C, increasing levels of climate change could push the system beyond adaptive levels.

It will be important to evaluate agricultural and land-use based mitigation strategies in terms of their co-benefits for climate change adaptation, biodiversity and ecosystem goods and services. Rather than aiming to maximize for singular objectives, mitigation solutions could be approached from a systems lens that seeks to realise multiple economic, social and environmental objectives. Identifying solutions that also benefit local adaptation efforts and help to maintain key ecosystem services and functions, will be key to maintaining the foundation for agriculture-based livelihoods in a changing climate. Future climate change and vulnerability could be key criteria to include for future decisions including those related to mitigation actions.

Climate change adaptation must be approached in a dynamic and iterative manner. Priorities of adaptation measures will often have to be context specific, focused on the hazard exposure of the region. This includes strengthening preparedness through early warning systems and seasonal forecasts and providing decision-support tools for policy and practice. Where we are shifting from known or lived experience into new environmental configurations or climate patterns, building reflexivity and learning capacity into systems will be important. On the ground, this might look like farmer learning networks and capability building through extension networks, and efforts to increase the capacity of the service sector to deliver advice in a probabilistic framework. This will equally apply to emissions reduction activities and include monitoring and ongoing assessment of the permanence risks to nature-based sequestration activities and to the development of new farming configurations for energy production.

In addition to strengthening the capacity to respond to already observable climatic changes, it will be important to consider more systematic changes over the medium and longer-term if we are to avoid (maladaptive) structural lock-in. We are on a warming curve and the risk landscape will likely continue to change. Research and innovation, coupled with targeted capacity development and a supportive enabling environment, will be critical to build and diversify our solutions portfolio. This includes diversifying crop and livestock traits to be better adapted to changing climatic conditions, reducing pressures on scarce natural resources through precision farming, advancing nature-based solutions and protected agriculture schemes, diversifying supply chains, considering the role of novel foods, enabling dietary shifts for improving human and planetary health – alongside other measures. In the emissions and future energy cropping areas, this will include considerations of future production of feedstocks in relation to refining and production facilities. It will be important to consider the moving climate baseline when planning new infrastructure and or making forward commitments from agriculture to provide industrial feedstocks.

Climate change adaptation should be seen as part of the broader risk management effort. The recent years have been a stark reminder that the risk landscape for Australia's agrifood and land-use systems is rapidly changing. Our food systems are increasingly confronted with a confluence of climate and environmental hazards as well as socioeconomic shocks. These are further compounded by underlying stressors and the growing geopolitical uncertainty. Not only in the context of the climate crisis, but in general it is important to prepare for multiple change scenarios. Complementing climate change mitigation efforts, this implies that agri-food systems need to have sufficient agility and in-built redundancy to manage, adapt to and if necessary, transform in response to a variety of risks, so that food and nutritional security is ensured now and in the future. This requirement, combined with a potentially higher complexity associated with low emissions farming (owing to regulatory processes, increased commodity diversification as energy crops and combined with traditional commodity classes) could place increased demands of farm management. The uptake of climate smart agriculture practices will likely require a significant upskilling within the sector, increased sophistication in the service sector and better decision support infrastructure, to navigate the emerging changes in farming systems, market opportunities and the growing digitisation of Australian agriculture.

Supporting and enabling change

(addressing questions 4,8,9,10)

Key points:

- Different capabilities are likely required to deal with systemic and transformational problems, such as transitioning to net zero and climate change adaptation than those for driving efficiency and incremental improvement.
- Transition challenges likely require longer term programs and investments.
- Innovation for low emissions agriculture must embrace cross-sectoral and whole of value chain opportunities. A whole of food system view will assist in realising opportunities beyond on farm incremental change.
- Co-innovation processes will be key to create adoptable practices which requires a move away from linear investment models.

Australia's agricultural innovation has served it well to drive the competitiveness of the sector and directing RD&E to support efficiency. Australia's agriculture sector is among the most efficient in the world and is supported by the RDC (Rural Development Corporation) system that closely couples producers and users within subsectors (RDCs) in the selection and direction of research and development. While there have been cross-sectoral functions established within the RDC system (such as Climate Research Strategy for Primary Industries (CRSPI), Agricultural Innovation Australia (AIA)), these have not always been well-resourced or coordinated with the larger sectoral RDCs.

This configuration could be improved to help deal with transformation or with whole-of-sector challenges. Transformation describes fundamental changes required to ways of doing things made necessary by the scope and scale of the challenges being faced, and the fact that they were at least partly caused by our current ways of doing things. Smaller incremental or transitional changes may be insufficient to manage changes with the scope and scale of causes and impacts that characterise climate change. They are also a by-product of past strategies that emphasised market-led innovation and are likely to require novel and efficient forms of public leadership to address.

Building an innovation system that supports the mitigation of greenhouse gas emissions, while simultaneously building climate change adaptation for Australia's agrifood innovation system is likely to require:

- Recognising that sector transformation and adaptation in the face of the net zero and climate change adaptation needs connected investment. This is because the societal value of emissions used to generate food and fibre is likely to be higher than emissions generated in other sectors of the economy, and because many of the lowest cost opportunities for greenhouse gas mitigation will lie in those other sectors (such as aging power stations). With the absence of a comprehensive market-based solution such as emissions trading, another mechanism is needed to ensure the lowest cost mix of emissions reductions pathways towards net zero across the whole Australian economy.

- Recognising that for both mitigation and adaptation, opportunities that span agricultural sub-sectors exist, and that value chain reconfiguration or transformation can drive action. A whole-of-agrifood system approach is needed to realise these opportunities. For example, mixed farming systems offer productivity and emissions reduction opportunities that tend to fall between Meat and Livestock Australia and Grains Research and Development Corporation investments. Other opportunities are likely to emerge from the integrated analysis of food production, transport, processing and retailing.
- Recognising that within a whole-of-agrifood system approach, a whole of landscape approach is needed. This is because realising the most effective and lowest cost adaptation and mitigation opportunities needs to consider the collective effect that landholding enterprises have at a landscape scale. This could build on the enterprise scale focus of the Cooperative Research Centre for Net Zero Agriculture.
- Recognising the role that futures thinking and scenario development can play in designing preferred futures and practical pathways for working towards them. Many of our current modelling approaches consider the future as the immutable consequence of current trends, reinforcing the inertia of current policy and management practices, and downplaying our collective ability to create better futures for ourselves and the generations that follow. It will be important to review approaches to economic modelling to assess their utility for supporting climate policy. New and more flexible approaches are emerging that support participatory evaluation of policy options with policy makers, enabling the design and evaluation new and preferred options for attaining net zero emissions.
- Addressing the fact that emissions are produced on farm, though the additional value from low emissions products is usually accrued further down the supply chain (supermarket shelves, finance, food or animal feed company corporate scope 3 emission reduction goals) and investigating the role of informatics and credential or stewardship systems to redistribute profit or benefits along value chains to enable action of the ground. This will be an exercise in investing in low-cost measurement and verification systems, data standards, agreed and accessible assessment and analytic frameworks, and through value chain agreement on performance criteria that are fair equitable and attainable.
- Recognising the power of co-innovation and creating investment models that go beyond linear models of research investment. On-farm innovation would likely benefit from funding that fuses practical and business knowledge from farmers/producers with technical expertise to create feasible, locally applicable, and contextually appropriate options. Co-innovation with Indigenous carbon groups can show the way to create new approaches and market mechanisms to simultaneously unlock cultural and emissions reduction options. Through value chains bring together the different system actors to agree on how value creation will occur (be these through data standards and protocols or using instruments such as forward purchasing agreements to de-risk on the ground investments).

- Recognising the future will more complex and will require increased skills and support and potentially additional institutions charged with whole of sector emissions reduction strategy over and beyond the creation of the sectorial decarbonisation plan. Farmers and producers will likely be faced with changing markets and increased regulatory barriers, whilst adapting to climate change. Funders will likely be confronted with deeper system uncertainty and competition for funds in the face of unfolding needs. They will be challenged to look outside their traditional sectors by the need for cross-sectorial or through value chain options for practice change and adaptation. Regulators will likely be working against a moving climate baseline. Australia could consider implementing an overarching model for innovation coordination. Overseas examples include the:
    - Te Pun Whakaaronui thinktank in New Zealand which provides research, thought leadership, strategic insight and advice to sector participants, industry bodies, Indigenous groups and agri-business.
    - UK Innovate, which is a national innovation integration mechanism that marshals national capability to meet cross sectorial goals plays within the United Kingdom.
- Australia's Indigenous and agricultural enterprises and estates make an important contribution to Australia's natural wealth and are vital to the nation's ecosystem services and low emission future. These contributions, and the management role played by local land managers, including Indigenous land managers, are not well accounted for in existing carbon or biodiversity accounting and business model frameworks. To assist activities, we need to focus on how Indigenous participants can equitably and efficiently enter emerging carbon markets and create both commercial and cultural values.

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