How Can Technology Help Achieve Sustainable Agriculture in New Zealand?

Kellogg Rural Leadership Programme

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Disclaimer

Acknowledgments

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Executive Summary

This report examines the potential of disruptive innovation and emerging technologies to enhance the sustainability and resilience of New Zealand's sheep, beef, and dairy farming systems. It also explores the drivers, barriers, and impacts of technology adoption on farms. The report draws from peer-reviewed literature and semi-structured interviews with, industry representatives and scientists.

The main findings of the report are:

- New Zealand's agricultural sector faces significant challenges in reducing its environmental impact, especially in terms of greenhouse gas emissions and nitrate leaching, while maintaining its economic viability and social acceptability.
- Disruptive innovation and emerging technologies can offer solutions to these challenges by improving farm productivity, efficiency, profitability, and environmental performance.
- The adoption of these technologies is influenced by various factors, such as cost, risk, regulation, consumer preferences, social norms, knowledge, skills, and infrastructure. These factors can act as drivers or barriers depending on the context and the stakeholder perspective.
- The impacts of technology adoption on farms can be positive or negative depending on the type, scale, and distribution of the technology.

To facilitate the transition to more sustainable and resilient farming systems through disruptive innovation and emerging technologies, the report recommends the following actions:

- The industry should foster a culture of innovation and collaboration among farmers, researchers, policymakers, businesses, and consumers to identify and address the needs and opportunities of the sector.
- The industry should invest in research and development to generate evidence-based knowledge and solutions that are relevant, accessible, and applicable to New Zealand's farming context.
- The industry should provide farmers with education and extension services to increase their awareness, understanding, and skills in using new technologies and practices.
- The industry should engage with stakeholders and the public to communicate the benefits and challenges of technology adoption and to build trust and acceptance of new products and processes.
- The industry should advocate for supportive policies and regulations that enable innovation and technology adoption while ensuring environmental protection, animal welfare, food safety, and social justice.

This report aims to stimulate discussion among the policy, farming, academic, and wider communities to help shape a future that will safeguard New Zealand's social, economic, and environmental well-being.

1.0 Introduction

Farmers have been identified as significant contributors to the current environmental state, leading to the implementation of policies to encourage them to take an active role in managing the environment. As a response to these policies, farmers have been making investments in their farming operations to maximise profits while minimising environmental impact.

While farmers have already begun adopting practices to manage their environmental impact, more needs to be done to support them in becoming more strategic in their efforts. This includes developing and implementing green innovation and technologies that consider both environmental and economic considerations. However, public scrutiny, pressure, incentives, and regulatory controls can complicate views held on farms, halting the ability of farmers to be early adopters of innovative developments with positive environmental implications.

Climate change response is a fundamental aspect of our framework. Currently, the emphasis is on utilising forests to sequester carbon as the primary response to climate change, generating significant public discourse. Offsetting our carbon footprint, rather than mitigating it, is a crucial component of this strategy. Opportunities need to be identified amidst the commotion and explore alternative methods as a farming community to mitigate the effects of climate change.

Sustainability is crucial to our future success in reducing the impact of our farms on the climate and securing New Zealand's reputation as the world's most sustainable provider of high-value food and fibre. Transitioning to sustainable agriculture can have positive impacts on farm productivity and make the agricultural sector more resilient. However, the adoption of new technologies and practices can face strong resistance, and the conversation for change can often be slow and challenging. Farmers should be provided with thought leadership and tools to support knowledge development and growth, enabling the sector to transition and open doors to new opportunities.

The efficacy of the on-farm intervention in mitigating environmental impact is uncertain, particularly for technologies still under development, the scale of adoption across the country will significantly affect the amount of mitigation that any on-farm intervention can achieve. These findings highlight the need for change through three key challenges of New Zealand sheep, beef, and dairy farmers transitioning to sustainable agriculture, reducing biogenic methane and nitrous oxide emissions, and reducing nitrate leaching.

2.0 Project Scope and Objectives

Drawing from peer-reviewed literature and semi-structured interviews, this report aims to encourage discussion amongst the policy, farming, academic, and wider communities to help shape a future that will safeguard New Zealand's social, economic, and environmental well-being.

The objectives of this research project are as follows:

- Analyse and understand the potential of how disruptive innovation and emerging technologies can be applied to New Zealand farming models.
- Increase the understanding of the changing global circumstances in which NZ must navigate its future.
- Increase the understanding of technologies that are available to our industry and how they can enhance our farming practices and provide resilience.
- A discussion of the drivers, barriers, and impacts of technology adoption on farms and stakeholders in rural communities.
- Evaluate the results and compile recommendations for the industry.

3.0 Methodology

A combination of research tools was utilised.

3.1 Primary research, literature reviews,

The literature reviews were carried out to explore the sustainability of New Zealand's agricultural systems, what the current influencers are, and what farming management practices can improve it. The review focuses on the concept and outcomes of sustainable agriculture.

3.2 Secondary research, interviews with subject matter experts

Seven Interviews with subject matter experts was chosen as the method of data collection to allow for additional insights and thought generation. The semi-structured interview method was chosen which allowed for conversations to flow outside of the template of questions This approach enabled conversations to flow organically beyond the confines of the predefined set of questions. Interview questions were set before interviews were completed and varied slightly depending on the interviewee and their area of knowledge as a subject matter expert as shown in Appendix 1 - Interview questions.

A variety of interviews were carried out with two Scientists, four Industry thought leaders and a nutritional farm specialist.

To analyse the data collected from these interviews, a thematic analysis approach was used. Thematic analysis allows researchers to explore and uncover the subjective experiences, perspectives, and interpretations of participants. It helps researchers gain a deeper understanding. Braun, V., & Clarke, V. (2006).

This involved identifying key themes that emerged from the qualitative research findings.

- To become familiar with the data collected from the interviews, I thoroughly read and analysed the transcripts to comprehensively understand the content.
- I identified and assigned labels to significant units of text, including words, phrases, and sentences that represented important ideas or concepts.
- By searching for patterns and connections within the labelled data, I grouped them together to form initial themes.
- I carefully reviewed and refined the initial themes by revisiting the labelled data, ensuring accuracy and consistency by comparing them.
- I defined and named the themes, providing clear explanations of their meaning and relevance to the research question.
- I organized and mapped the themes into a logical structure, considering their interrelationships and how they connected to each other.
- In interpreting and reporting the findings, I contextualised the themes within the research objectives, conducting a detailed analysis of each theme. I supported my analysis with evidence from the data, including relevant quotations and examples.

The themes served as a framework for organising and presenting the insights obtained through the interviews. This qualitative research methodology provided a comprehensive understanding of the subject matter and helped uncover valuable perspectives from the experts in their respective fields.

3.3 Limitations of this research

Potential bias: selected literature reviews and the sources chosen to review. This could lead to a skewed interpretation of the available evidence.

Time constraints: conducting a comprehensive literature review is a time-consuming process. There's potential that not all relevant literature on a topic has been reviewed, which could mean important sources have been missed.

Due to time limitations, not all the desired interviews were possible. Originally the author wanted to have multiple interviews with subject matter experts on each category biogenic methane, Biochar, Ecotain, and new technologies, however, the small number of available interviewees at the time of the study meant that for some categories only one subject matter expert was interviewed.

4.0 Literature Review

This literature review aims to explore the main themes related to emerging technology and sustainable agriculture. The review analysed various sources, including academic articles, government reports, and industry publications, to identify the main themes discussed by different authors and researchers. Insights were gained into the relationship between emerging technology and sustainable agriculture by comparing, contrasting, and evaluating the perspectives presented in the selected references.

Theme 1: Sustainable Agriculture

Sustainable agriculture aims to balance economic, environmental, and social factors in farming systems to meet present and future needs while preserving the environment and promoting social well-being. Various sources emphasise the importance of sustainable agriculture practices. The Ministry for Primary Industries (MPI) in New Zealand highlights the need for resilient, sustainable, and profitable agriculture (MPI, 2020). Teagasc (2018) defines sustainable agriculture as an approach that integrates natural resource management, economic viability, and social responsibility. The Ministry for the Environment (2022) recognizes sustainable agriculture as a crucial component of New Zealand's climate action and emphasizes the reduction of greenhouse gas emissions from farming.

Ministry for Primary Industries (MPI), New Zealand, 2020. The MPI is a governmental organization responsible for supporting and regulating New Zealand's primary industries, including agriculture. The reference highlights the importance of resilient, sustainable, and profitable agriculture. While it provides a general perspective on sustainable agriculture, it lacks specific details or examples to illustrate sustainable practices. As a government body, the MPI's stance on the significance of sustainable agriculture carries weight and reflects the national agricultural priorities.

Teagasc, 2018. Teagasc is the Agriculture and Food Development Authority in Ireland, providing research and advisory services. This reference defines sustainable agriculture as an approach that integrates natural resource management, economic viability, and social responsibility. Teagasc's definition offers a holistic perspective, acknowledging the multidimensional nature of sustainability in agriculture. It provides a comprehensive framework that emphasizes the need for a balance between environmental, economic, and social aspects in farming systems.

Ministry for the Environment, New Zealand, 2022. The Ministry for the Environment in New Zealand is responsible for environmental policy and stewardship. This reference recognizes sustainable agriculture as a crucial component of the country's climate action efforts. It specifically highlights the importance of reducing greenhouse gas emissions from farming. The inclusion of sustainable agriculture in New Zealand's climate action agenda indicates a commitment to addressing agricultural environmental impacts and aligns with global sustainability goals.

Theme 2: Emerging Technology

Emerging technology refers to new or advanced technologies that have the potential to significantly impact industries, including agriculture. Christensen (1997,

2003) discusses the challenges faced by established firms when new technologies emerge, emphasizing adaptability and innovation to remain competitive. The Business Dictionary (n.d.) defines emerging technology as technologies in the early stages of development with the potential to create a significant impact in the future. The Ministry for Primary Industries (2018) recognizes the role of research and innovation in reducing agricultural greenhouse gas emissions.

Christensen, C.M., 1997, 2003. Clayton M. Christensen, a renowned scholar and business strategist, discusses the challenges faced by established firms when new technologies emerge. While this reference does not focus directly on sustainable agriculture, it offers valuable insights into the broader implications of emerging technologies in various industries. Christensen's work emphasizes the need for adaptability and innovation to respond effectively to technological disruptions, which can be relevant when considering the integration of emerging technologies in agriculture.

Business Dictionary, n.d. The Business Dictionary provides a concise definition of emerging technology as technologies in the early stages of development with the potential to create a significant impact in the future. Although this reference does not offer specific insights into sustainable agriculture, it establishes a general understanding of what constitutes emerging technologies. It serves as a starting point to contextualise the potential impact of emerging technologies in the agricultural sector.

Theme 3: Impacts of Emerging Technology on Sustainable Agriculture

The integration of emerging technologies in sustainable agriculture has the potential to bring about significant changes in farming practices. Degen (2010) discusses the role of digital and social media marketing in influencing consumer behaviour and promoting sustainable agricultural practices.

Degen (2010) focuses on the impact of digital and social media marketing on consumer behaviour and sustainable agricultural practices. This theme emphasises how emerging technologies, particularly in the realm of digital and social media, can influence consumer choices towards sustainable and environmentally friendly agricultural products. Through effective marketing and communication strategies, emerging technologies can raise awareness about sustainable farming methods, organic produce, fair trade practices, and local food systems. This can result in consumers making more informed decisions and actively supporting sustainable agriculture.

Comparing Themes: The integration of emerging technologies in sustainable agriculture can address the challenges identified in sustainable agriculture practices. For instance, sustainable agriculture aims to reduce greenhouse gas emissions from farming (MPI, 2020), while emerging technologies offer new opportunities to improve agriculture productivity, efficiency, and sustainability (Business Dictionary, n.d.). The use of emerging technologies can potentially contribute to mitigating the environmental impact of agriculture by reducing emissions and improving resource management.

Sustainable agriculture practices, such as reducing nitrogen and methane emissions, can be supported by the application of emerging technologies. The agriculture

Victoria (n.d.) highlights the importance of managing livestock methane and nitrogen emissions to minimize their environmental impact. Research by Beukes et al. (2019) explores the use of rumen manipulation and methane-inhibiting vaccines as potential strategies to reduce methane emissions from livestock. Zhang et al. (2021) discuss the potential of gene editing technologies in mitigating methane emissions from livestock. These studies demonstrate how emerging technologies can offer innovative solutions to address sustainability challenges in agriculture.

Agriculture Victoria, n.d. Agriculture Victoria is a government organization responsible for supporting and regulating agriculture in the state of Victoria, Australia. This reference emphasizes the importance of managing livestock methane and nitrogen emissions to minimize environmental impact. It recognizes the significance of addressing emissions in the livestock sector and hints at the potential role of emerging technologies in mitigating these emissions. However, it does not provide specific examples or technologies.

Beukes et al., 2019. This research study explores the use of rumen manipulation and methane-inhibiting vaccines as strategies to reduce methane emissions from livestock. The reference offers specific scientific insights into emerging technologies that can potentially contribute to addressing sustainability challenges in livestock farming. It demonstrates the application of emerging technologies to mitigate methane emissions, highlighting their potential role in sustainable agriculture practices.

Zhang et al., 2021. This research study discusses the potential of gene editing technologies in mitigating methane emissions from livestock. It presents a cutting-edge application of emerging technologies to address environmental challenges in agriculture. The reference provides scientific evidence and potential strategies for reducing methane emissions, showcasing the possibilities of emerging technologies in sustainable agriculture.

The reviewed literature highlights the importance of emerging technologies in promoting sustainable agriculture. Thematic analysis helps identify the interconnectedness between sustainable agriculture and emerging technology. the references provide a diverse range of perspectives and insights into the themes of sustainable agriculture and emerging technology, by examining multiple references, it demonstrates how sustainable agriculture practices can be enhanced and supported by the integration of emerging technologies, fostering a more sustainable and efficient agricultural industry.

While there are challenges associated with the adoption and integration of emerging technologies, they offer significant opportunities to enhance productivity, resource efficiency, and environmental sustainability in agriculture.

The authors and researchers analysed in this review provide valuable insights into the relationship between emerging technology and sustainable agriculture. By embracing emerging technologies and integrating them into sustainable agricultural practices, farmers and stakeholders can contribute to the development of resilient and profitable agricultural systems while minimizing environmental impacts.

Further research is warranted to explore specific emerging technologies and their potential applications in different agricultural contexts. Understanding the social, economic, and policy implications of adopting emerging technologies in sustainable agriculture will be crucial for successful implementation and widespread adoption.

5.0 Findings and Discussions

Sustainability in agriculture is the ability to produce food, fibre, and other products indefinitely without damaging or depleting the resources on which it depends. This section explores the challenges and opportunities for achieving sustainability in agriculture in New Zealand, focusing on the impacts of greenhouse gas emissions, especially biogenic methane, and the policies and technologies that aim to mitigate them. The section also discusses the social and economic aspects of sustainable agriculture and how they affect farmers' decisions and practices.

5.1 Sustainable Agriculture

According to Sustainability in Agriculture (n.d.), sustainability in agriculture is defined as the ability of a farm or agricultural system to produce food, fibre, or other products indefinitely without damaging or depleting the resources on which it depends. This entails meeting the needs of the present generation without compromising the ability of future generations to do the same and allowing other species to co-exist with us. Key factors that contribute to sustainability in agriculture include soil health, water conservation, and energy efficiency. Sustainable agriculture must also be economically viable, environmentally sound, and socially responsible.

The integrity and health of the biosphere/ecosystem, the future well-being of its population, and the capacity to preserve this integrity in the mid to long term are represented by the concept of "sustainability." As concerns over the sustainability of New Zealand's agricultural systems continue to grow, efforts are underway to increase the adoption of sustainable agricultural practices. A cohesive strategy involving the government, industry stakeholders, and research institutions is needed to affect this transition. Setting ambitious targets without providing viable alternatives to farmers or obtaining their buy-in is unlikely to be successful.

Agriculture occupies 53% of the total land area in New Zealand. The meat and wool sectors (sheep, beef, and deer production) represent 75% of the agricultural land, while the dairy sector occupies 12%, and forestry 11%. The horticulture and arable sectors each cover 1% of the agricultural land.

Nearly half of New Zealand's greenhouse gas (GHG) emissions come from agriculture. Methane from livestock digestive systems and manure management accounts for around three-quarters of agricultural emissions, while nitrous oxide from nitrogen added to soils is the next largest source. Nitrogen, used as fertiliser, can leach from the soil into groundwater or run off into waterways. Leaching also occurs from urine or dung from livestock. In 2017, of the estimated nitrate leached from livestock, 65% was from dairy and 15% from sheep, (Stats NZ,). As a result, 70% of river lengths have been modelled to have nitrogen concentrations above the expected range for natural conditions between 2013 and 2017.

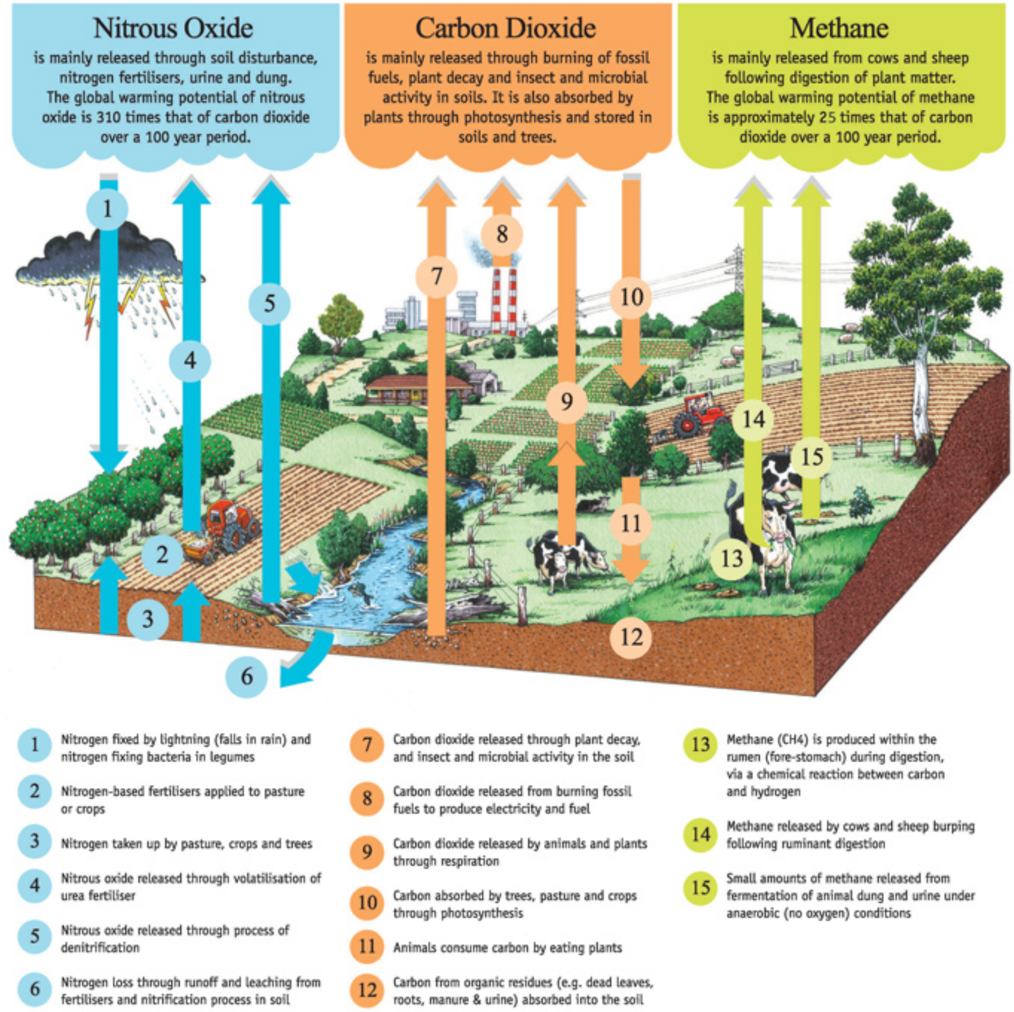


Image 1: Greenhouse gas cycles in agriculture (https://agriculture.vic.gov.au/climate-and-weather/understanding-carbon-and-emissions/greenhouse-gas-cycles-in-agriculture)

Due to the effects of climate change, the New Zealand Government has implemented the Zero Carbon Amendment Act (2019) and the National Policy Statement for Freshwater Management (2020) to improve degraded water bodies, including wetlands, streams, and groundwater. The Zero Carbon Act (2019) provides a framework to reduce all greenhouse gas emissions, including carbon dioxide, nitrous oxide, and methane. The Climate Change Commission will monitor progress towards achieving the Paris Agreement's quantitative targets, including reducing methane by 10% below 2017 levels by 2030 and 24-47% by 2050.

The National Policy Statement for Freshwater (2020) sets standards for managing freshwater, including four related to agricultural activities. To maintain high agricultural productivity while ensuring environmental sustainability and resilience, pathways for achieving this balance need exploration. New Zealand uses emerging and disruptive technologies in the pastoral and horticultural sectors to increase productivity and tackle environmental impacts. However, industry buy-in is crucial for progress toward the intended goals. (Ministry of Primary Industries, 2020)

5.1.2 What is Biogenic methane and why is it important?

Greenhouse-gas-induced climate change has emerged as the biggest challenge to sustainable agriculture in New Zealand, Agricultural emissions make up almost half of the total emissions. Biogenic methane accounts for more than two-thirds of agricultural emissions. In 2020, the volume of greenhouse gas emissions from the agricultural sector in New Zealand amounted to 39.5 million metric tons of carbon dioxide equivalent (Statista, 2022).

The introduction of the Climate Change Response (Zero Carbon) Amendment Act 2019 as an amendment to the Climate Change Response Act 2002 signified the New Zealand Government's intent to abide by the Paris Agreement and support the global effort to combat climate change. One of the cornerstones of this amendment is to reduce net emissions of all but one greenhouse gas to zero by 2050. The exception is biogenic methane, to which a softer target is applied; the targeted reduction in biogenic methane is 24–47% below 2017 levels by 2050 (Ministry for the Environment, 2022).

Given that livestock accounts for almost 90% of the country's gross methane emissions and that the dairy sector, the foremost contributor of methane, continues to grow and remains vitally important to the country's economy, achieving a 24–47% reduction over the next 30 years will be challenging.

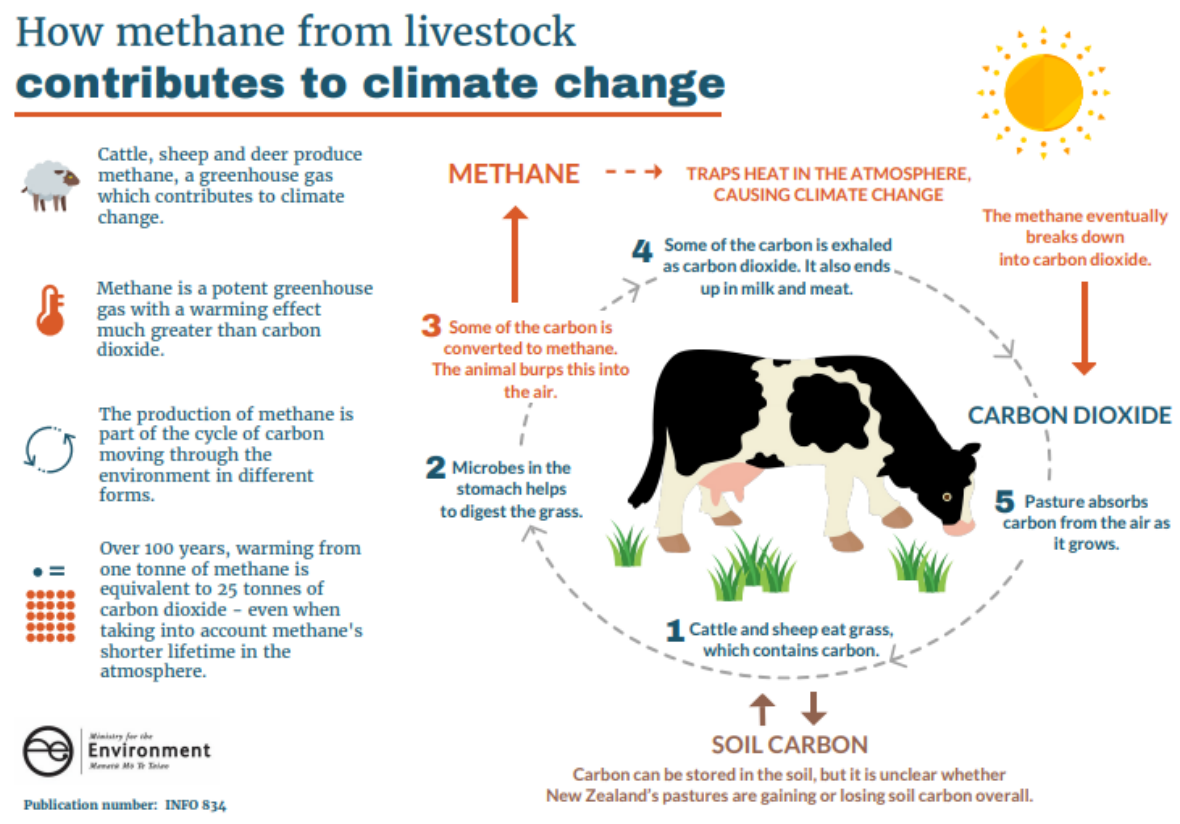


Image 2: Methane from livestock (https://environment.govt.nz/assets/Publications/how-methane-from-livestock-contributes-climate-change-11-june.pdf)

Methane is the main greenhouse gas produced in grazing systems. Ruminant livestock (cattle, sheep, and goats) have microbes in their rumen called methanogens. These microbes produce methane (from the fermentation of feed) that is then belched out. Feed with lower digestibility produces more methane than higher-quality feeds. Belched methane represents energy lost from your production system that might otherwise be converted to the milk, meat, or fibre that generates income (Agriculture Victoria, n.d.).

Unlike long-lived gases such as carbon dioxide (CO_2) and nitrous oxide (N_2O), Methane is a short-lived gas that does not accumulate in the atmosphere in the same way. However, it is much more effective at trapping heat than CO_2. The Zero Carbon Act is unique in its approach as it recognizes that biogenic methane needs to be reduced but not necessarily to net zero, unlike long-lived gases. Short-lived gases, such as biogenic methane from animals and plants, have a relatively short lifetime. Although these gases can maintain warming if sustained, an increase in their concentration contributes to warming. Conversely, decreasing the concentration of these gases can have a cooling effect. In contrast, long-lived gases like CO2 and N2O contribute to warming if their emissions are not net zero.

5.1.3 What is nitrous oxide and why is it important?

Nitrous oxide is a potent ozone-depleting substance that has the potential to remain the dominant ozone-depleting substance throughout the 21st century if its emissions are not controlled. Reducing nitrous oxide emissions is crucial for the recovery of the ozone hole and for mitigating anthropogenic climate forcing (Ravishankara, Daniel, & Portmann, 2009).

Nitrogen is an essential nutrient for plant growth and is heavily applied in agricultural systems. However, nitrification, the process by which soil microorganisms convert ammonium to nitrate, can lead to nitrate leaching and gaseous nitrous oxide production, causing up to a 50% loss of nitrogen availability for plants. Additionally, nitrate leaching can result in the eutrophication of groundwater, drinking water, and recreational waters, toxic algal blooms, and biodiversity loss. Nitrous oxide, which is emitted during nitrification, is a potent greenhouse gas with a global warming potential 300 times greater than carbon dioxide (Davidson, 2009).

In agriculture, nitrous oxide is released into the atmosphere when microorganisms act on nitrogen from various sources, such as animal urine and dung, synthetic fertilisers, and legumes. Approximately 1% of the nitrogen in the soil, from any source, is lost as nitrous oxide. Farmers often use nitrogen-based fertilisers, legumes, or animal manures to enhance soil nitrogen and promote crop and pasture growth. Grazing ruminant livestock excrete most of the nitrogen they consume in urine and dung, creating concentrated nitrogen patches in the soil. For example, a urine patch can contain the equivalent of up to 1000 kg N per hectare, while fertiliser application rates are typically 30-50 kg N per hectare (although there may be several applications per year). Therefore, reducing the amount of nitrogen in the farming system and minimizing the proportion of excess nitrogen in the soil that is transformed into nitrous oxide can help reduce emissions (Eaglesham et al., 2019).

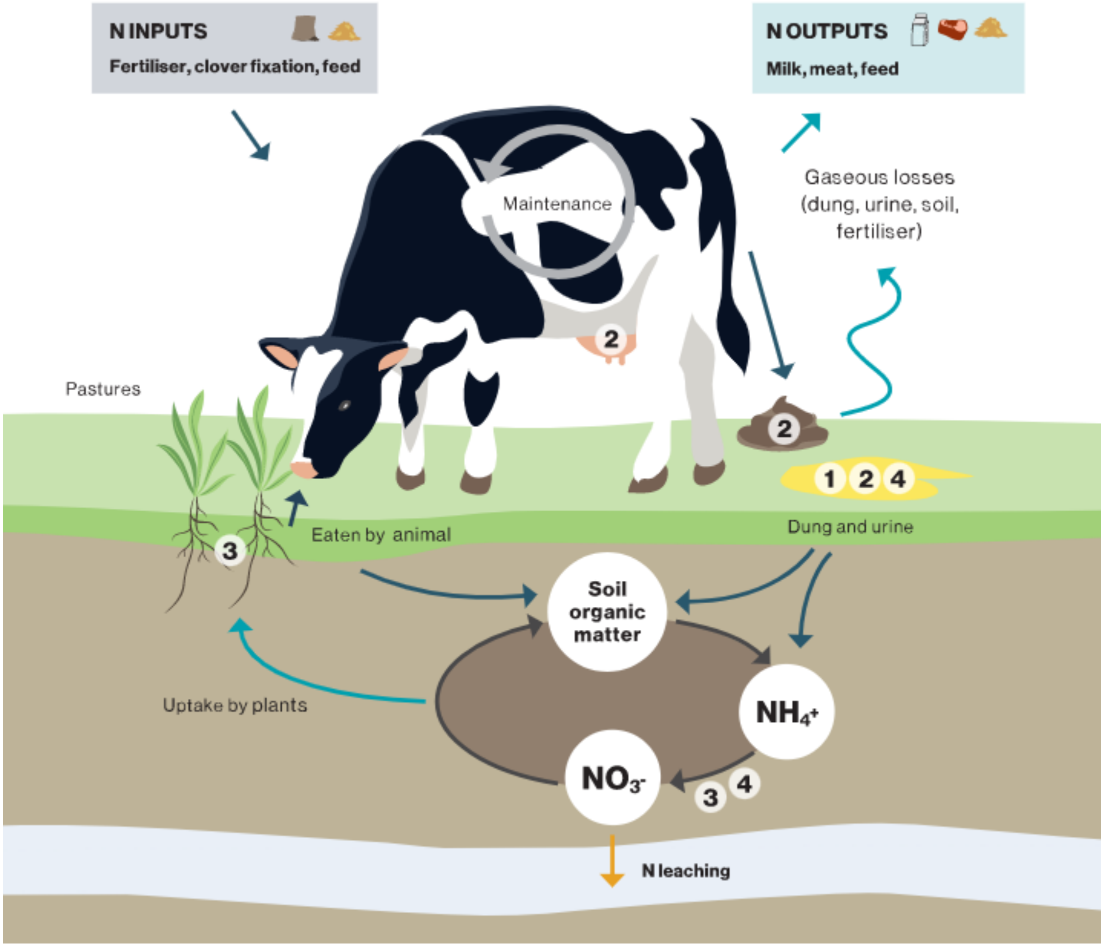


Image 3: Nitrous oxide emissions from agriculture, Image: De Klein CAM, Pinares- Patino C, Waghorn GC (2008).

5.1.4 What is nitrate leaching and why is it important?

A wide range of human activities impact freshwater bodies, including agriculture, forestry, horticulture, urban development, and mining (Environmental Guide, n.d.). The quality of freshwater is influenced by both point-source and non-point-source discharges. Point source pollution refers to contaminants that enter the catchment from one isolated source, such as a sewage treatment plant or a dairy milking shed, while non-point source pollution refers to contaminants that enter the catchment from multiple diffuse sources, such as runoff from pasture areas (Environmental Guide, n.d.).

Point source pollution has been decreasing in the past few decades due to upgrading treatment system technology and developing alternative disposal methods, such as applying effluent to land instead of discharging it into waterways (Environmental Guide, n.d.). The Resource Management Act of 1991 and progressively stricter controls on discharge practices have also contributed to the decline of point source pollution (Environmental Guide, n.d.). Under most New Zealand regional and district plans, point source pollution from agricultural activities is now prohibited (Environmental Guide, n.d.).

The focus has now shifted to reducing non-point source agricultural pollution, which includes nutrients, fine sediments, and pathogens that are mobilized by livestock and found in many New Zealand waters (Environmental Guide, n.d.). Diffuse or non-point source pollution comes from various activities that involve no distinct single source, making it more difficult to manage with regulations (Environmental Guide, n.d.).

Agricultural activity produces significant nutrient pollution, mainly in the form of nitrogen and phosphorus, which are essential building blocks for all life on Earth (Environmental Guide, n.d.). However, when present in excess, they can be harmful to waterways and disrupt natural processes of growth and decay (Environmental Guide, n.d.). Nitrogen is primarily lost as nitrate leaching through the soil profile into groundwater and surface water (Environmental Guide, n.d.).

Excessive nitrogen levels are highly toxic to fish and some aquatic organisms and can also affect humans and animals that drink the water, while lower nitrogen levels can cause excessive growth of unwanted plants that degrade swimming and fishing spots and have adverse effects on the aquatic ecosystem (Environmental Guide, n.d.). Nitrogen leaching from agricultural systems is a global environmental concern.

5.2 Emerging Technology

5.2.1 Emerging technology and disruptive innovation

The New Zealand Government aims to increase the value of agricultural exports while preserving the natural environment and expects farmers to adopt pro-environmental management practices and new farm technologies (Ministry for Primary Industries, n.d.).

Disruptive technology, also known as disruptive innovation, is a term used to describe the application of a new technology that fundamentally changes the way a business or industry operates (Christensen, 1997; TechTarget, n.d.). While the term is sometimes misused to describe new technology that improves upon existing technology, disruptive innovations make products and services more accessible and affordable to a larger population (Christensen, 1997). To succeed in the face of disruptive change, farms must master the disciplines of ideation, incubation, and scaling (Christensen, 2003).

Emerging technology refers to new technologies that are currently in development or are expected to be available within the next five to ten years and are likely to have significant social or economic effects (Business Dictionary, n.d.). Emerging technology can displace old technology, whereas disruptive technology focuses on market opportunity identification, competition, and adoption (Christensen, 1997). The adoption of new practices and technologies is more likely after farmers see them demonstrated within their networks (Klerkx & Rose, 2009).

The potential of disruptive innovation and emerging technology to transform New Zealand agriculture by offering new opportunities, improving efficiency and sustainability, and enabling adaptation to a constantly changing environment should not be overlooked.

The agriculture sector in New Zealand can benefit from disruptive innovation and emerging technology, which can bring about new business models and innovative ways to increase efficiency and revenue for farmers. Implementing emerging technologies can assist farmers in optimising their operations, reducing their environmental impact, and achieving their sustainability goals. The potential of disruptive innovation and emerging technology to transform New Zealand agriculture by offering new opportunities, improving efficiency and sustainability, and enabling adaptation to a constantly changing environment should not be overlooked. Acknowledging the labels of "emerging technology" and "disruptive technology" is important as it creates awareness of technological options. To encourage adoption, farmers are more likely to embrace new practices and technologies after seeing them demonstrated, with the most effective demonstrations being those that occur within farmer networks.

Generating new ideas is the first step of successful change, research and development have the responsibility for new and or improved contributions, With efforts focused on the development of new and improved functionality, however pressures to sustain revenue and performance in the face of competition can drive towards incrementally improving current business rather than developing new ideas, these incremental changes are exploitative they simply improve existing approaches and build on existing capabilities.

The early adopters model plays an important role in the uptake of disruptive innovation and emerging technology in the New Zealand agriculture sector and their response to environmental impacts.

Early Adopters: Early adopters in New Zealand agriculture are farmers who are willing to try new and innovative practices, technologies, or methods that have the potential to improve their productivity and reduce costs. They play a critical role in promoting sustainable practices and mitigating environmental impacts by providing feedback and sharing their experiences with others. Early adopters are often innovative, risk-takers who are open to change, and they can act as role models for others.

Early Majority: The early majority is the next group of farmers who adopt new practices and technologies after the early adopters. They are willing to adopt new practices and technologies, but only after they have been proven successful by early adopters. Early majority farmers are essential in promoting sustainable practices as they help to drive the adoption of new technologies and practices to a wider audience.

Late Majority: The late majority consists of farmers who are cautious about adopting new technologies and practices. They usually wait until new technologies have become mainstream before adopting them. They may also require additional support and education to adopt new practices, which is where extension services and research can play a critical role.

Laggards: Laggards are farmers who are resistant to change and reluctant to adopt new technologies and practices. They are often stuck in their traditional ways of farming and may require significant persuasion to adopt new practices. In some cases, laggards may require regulatory intervention to encourage them to adopt new technologies and practices that can mitigate environmental impacts.

According to Small et al. (2016), farmers, scientists, and veterinarians are the most trusted sources of information for farmers in New Zealand. Trust among farmers is also influenced by farming tradition, cooperation, and lack of price competition, particularly among dairy farmers who are members of cooperatives (Diederen et al. 2003; Sligo and Massey 2007). Due to the absence of direct competition for international markets, sharing information among farmers can increase personal trust, making other farmers more trusted than regional councils, even if the latter has greater expertise (Kromm and White 1991; Rosenburg and Margerum 2008).

To promote the adoption of good practices and new farming technologies, governments can encourage diffusion through professional networks that rely on trusted connectors with large personal networks (Wu and Zhang 2013; Gladwell 2002; Degen 2010; Andreoli and Worchel 1978; Carr and Tait 1990). According to Rogers' (2003) typology of innovation, innovators and early adopters pioneer new practices, and connectors can help to diffuse innovative practices even if they are not among the first to adopt them.

5.3 Impacts of Emerging Technology on Sustainable Agriculture

5.3.1 Emerging Technologies

Fit for a better world was released in July 2020 and is a program of work towards 2030 committed to meeting some of the greatest challenges faced today, their roadmap lays out New Zealand's Government's plan for rebuilding a better economy over the next 10 years. It brings together actions, investments, and resources that will work together to accelerate the transformation. It spans all the food and fibre sectors and brings together significant opportunities to add value across the agriculture, horticulture, fisheries and marine, and forestry sectors.

This roadmap presents a unique opportunity to lead in the realm of science, particularly in addressing water quality preservation, reducing biogenic emissions, and balancing economic prosperity with environmental impacts. This endeavour significantly contributes to value enhancement across the food and fibre sectors, not only by resolving existing challenges but also by generating new prospects. Collaborative efforts involving government, Māori, industry, and science are underway to develop science and mātauranga plans.

The Ministry for Primary Industries (MPI) directly invests in scientific research related to climate change and sustainable land use through various funding programs.

A partnership group of Fit for a better world, Te Puna Whakaaronui, New Zealand's food and fibre sector think tank, is an exhilarating hub of ideas and analysis dedicated to transforming the industry. As a pivotal initiative of the Fit for a Better World Acceleration Roadmap, Te Puna Whakaaronui delivers cutting-edge insights, strategic analysis, and visionary thought leadership. Its primary mission is to empower the food and fibre sector to thrive amidst evolving consumer preferences, environmental challenges, technological breakthroughs, and global prospects.

By spearheading targeted inquiries and providing long-term perspectives, Te Puna Whakaaronui becomes an exhilarating catalyst for sector-wide adaptation. It further fuels public engagement and lively discussions, actively seeking out innovation and technology through collaboration with experts in biotechnology, alternative proteins, sustainability, and related fields.

Budget 2022 allocated $338 million over four years to accelerate research and development into new tools and practices farmers can use to reduce emissions.

The Thought Leaders Group within Te Puna Whakaaronui enriches the work program with international expertise, industry insights, and business acumen. Additionally, Te Puna Whakaaronui conducts research and analysis on emerging technologies, including the development of an extensive compendium featuring over 100 current and future technology capabilities, such as modern genetic technology, poised to impact the food and fibre sector.

In April 2023 Fit or a better world released the biological emissions reduction science and Matauranga plan, (The Plan) Guided by the priorities of the Fit for a Better World program, the Plan focuses on accelerating R&D for new emissions reductions technologies with a focus on reduction of methane and nitrous oxide emissions. Other factors such as soil carbon, economic analysis of the mitigations and impacts on farm systems viability, or social science systems analysis to understand barriers and motivations/incentives for adoption were out of scope for this specific Plan but are being explored and advanced through relation initiatives and programs of work (mpi.govt.nz). A Stocktake of Agricultural Greenhouse Gas Research in New Zealand."

The New Zealand Agricultural Greenhouse Gas Research Centre coordinated this effort, to identify priority actions for acceleration, a prioritisation process was undertaken, building upon the initial coordination work by the Pastoral Greenhouse Gas Research Consortium. A portfolio of prioritised mitigation measures was established to ensure the development of options targeting methane and nitrous oxide emissions, encompassing various sectors and classes of mitigations to balance risks and uncertainties associated with each technology.

Based on this framework, the following mitigation solutions have been identified as priorities for acceleration:

1. Methane inhibitors, specifically the utilisation of 3NOP in New Zealand grazing systems, and the development of New Zealand-focused inhibitors (including synthetic bromoform-based inhibitors) that effectively operate within grazing systems.
2. Nitrification inhibitors, with a focus on developing new inhibitors tailored for specific purposes.
3. Methane vaccine, initially aiming to establish proof of concept.
4. Low emissions animal genetics.

It is important to note that these priority actions may evolve over time to align with progress, emerging knowledge, and new opportunities. The specific mitigation solutions outlined in this plan reflect the current situation and represent the most promising options for immediate acceleration.

Securing additional public and private funding for research and development (R&D) and infrastructure aimed at reducing biological emissions is crucial to ensure the successful implementation of this plan. This funding will provide the necessary resources, including the development of long-term capabilities, capacities, and infrastructure required to meet both national and international emissions reduction targets. It will also facilitate equitable access for all farmers to suitable mitigation solutions, including through Māori-led R&D initiatives. Increased funding installs long-term confidence for organizations to invest in enhancing their capabilities and infrastructure, as well as attracting new personnel to engage in research endeavours within these fields.

The current state reveals significant gaps in capacity, capability, and infrastructure necessary to expedite the progress of mitigation solutions and approaches. This delay in their availability to farmers poses a challenge in achieving our emission reduction targets. To overcome these hurdles, it is imperative to establish a steady flow of individuals equipped with the requisite knowledge, training, and capabilities. Addressing bottlenecks and capacity constraints related to methane and nitrous oxide is crucial for effective responses.

To build Aotearoa New Zealand's capacity and infrastructure, supporting the development and implementation of biological emissions reduction solutions and approaches will accomplish the following:

1. Tackle the primary bottleneck concerning access to greenhouse gas measurement infrastructure, such as open circuit calorimetry utilizing respiration chambers.
2. Explore alternative technologies and proxies for greenhouse gas measurement and predictive capabilities to alleviate strain on existing infrastructure.
3. Ensure the establishment of a resilient network of skilled individuals and enhanced capacity capable of meeting our aspirations and fostering the accelerated development of mitigations.

As a result of the Plan's efforts, a portfolio of priority mitigations has been identified, expected to have the greatest impact on our farming systems. While all mitigations will benefit from the broader actions outlined in this Plan, this priority area specifically focuses on addressing the unique needs and stages of development of these priority mitigations.

To ensure the successful development and adoption of sufficient solutions, a thriving pipeline of potential solutions within R&D is essential. By directing our efforts toward these priority solutions, we can achieve the following:

1. Increase the likelihood and expedite the timeline of effective solutions being made available to farmers in Aotearoa New Zealand by 2030.
2. Embrace a combination of scientific research and Mātauranga Māori knowledge, leveraging the wisdom and understanding from both systems to establish a distinctive and tailored response to emissions reduction.
3. Accelerate the development of options relevant to Aotearoa New Zealand, including delivery mechanisms and effectiveness within pasture-based systems.

The advancement of breakthrough foundational science plays a crucial role in the development of emerging and evolving mitigation technologies. It serves as the cornerstone for creating new mitigation strategies. To achieve this, a comprehensive system is necessary, capable of fostering a robust platform for R&D. This includes mechanisms to support long-term research programs, ensuring funding certainty, and cultivating the required expertise.

Establishing feedback loops is vital for learning from the progress made in the current generation of mitigation solutions. This iterative process enables continuous improvement by leveraging insights gained from implementation and real-world applications. By incorporating these elements, we can effectively drive innovation and propel the development of cutting-edge mitigation technologies.

The advancement of breakthrough foundational science plays a crucial role in the development of emerging and evolving mitigation technologies.

The domestic regulatory regime in Aotearoa New Zealand plays a vital role in facilitating the safe and effective development and utilisation of new technologies. Understanding and navigating complex regulatory requirements are crucial to avoid unnecessary costs and delays.

It is essential for approval processes to operate efficiently during both trial and commercialisation phases. Collaborative efforts among international regulators offer opportunities to exchange information, enhance understanding, and establish global standards and approaches, particularly through organizations like CODEX. Furthermore, the emission reductions achieved through the application of new technologies must be accurately captured in the national Greenhouse Gas Inventory, farm-level emissions calculators, and accounting systems.

What can be achieved? By fostering strategic global partnerships and advancing relevant standards (e.g., CODEX), Aotearoa New Zealand can streamline regulatory processes and enhance emissions accounting. This will encompass the following:

1. Facilitate the navigation of regulatory complexities for researchers, developers, and other stakeholders.

2. Support the continuous development of the Greenhouse Gas Inventory, ensuring its adaptability to incorporate new technologies.

3. Establish domestic and international regulatory acceptability and science-based approaches to the utilization of new mitigation technologies.

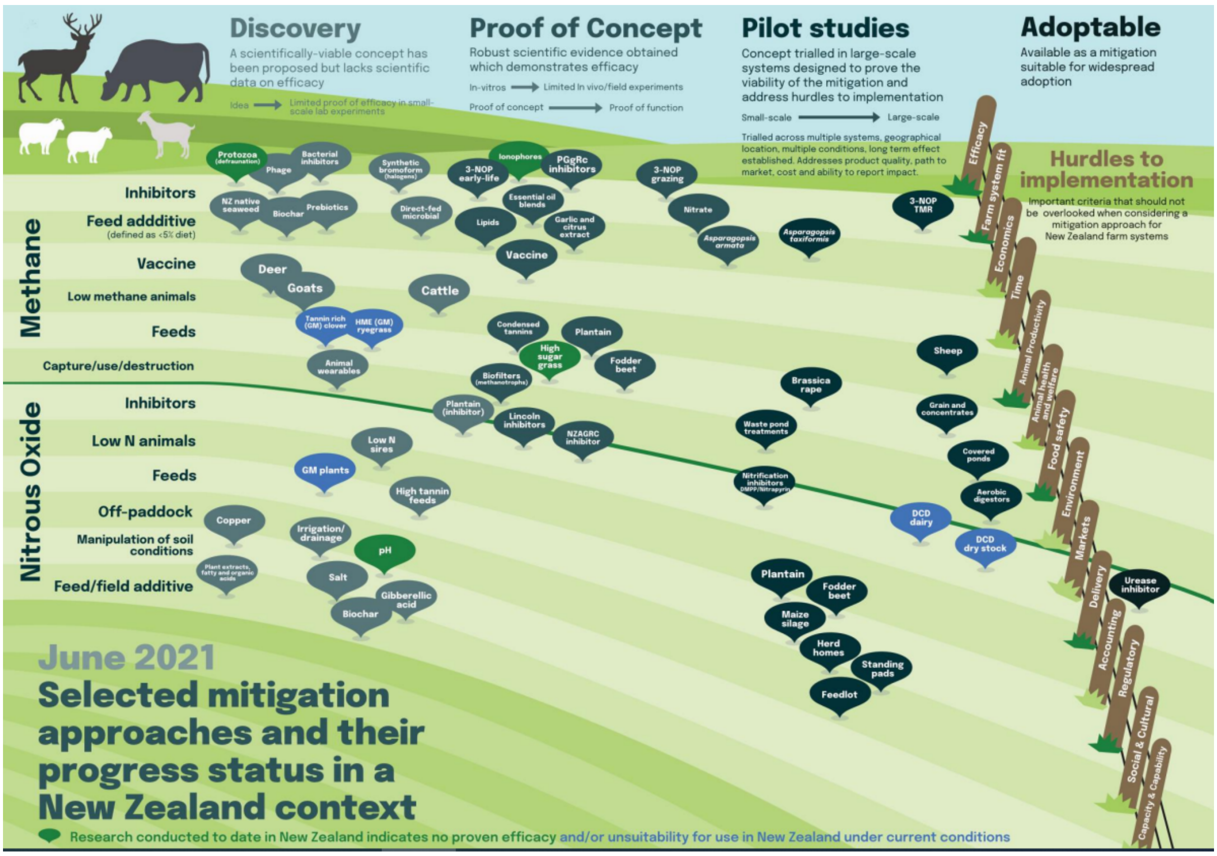
4. Promote alignment between domestic and international regulatory processes and outcomes.

Through these efforts, regulatory procedures will be streamlined, emissions accounting will be improved, and Aotearoa New Zealand will be better positioned to tackle climate change while leveraging the use of effective mitigation technologies.

Prioritisation plays a crucial role in directing efforts and delivering solutions to farmers. Mitigation solutions that can be readily adopted fulfil the following criteria: they possess sufficient evidence of their greenhouse gas reporting and accounting framework, they have obtained regulatory approval for their use, they have gained acceptance or approval from processors and other stakeholders in the downstream supply chain, including customers and end-consumers, as well as from New Zealand society as a whole.

Solutions developed in collaboration with farmers, starting from an early stage, to ensure that their feasibility and suitability in real farming situations are demonstrated, thereby increasing the likelihood of their adoption and overall effectiveness in reducing emissions.

Image 4: Selected Mitigation approaches and their progress status in a New Zealand Context, https://fitforabetterworld.org.nz/



5.4 Methane Strategies

5.4.1 Methane Mitigators

The effort to reduce agricultural emissions moved forward in 2022 with the signing of a memorandum of understanding by the Government with agribusiness leaders, in a joint venture as part of the new Centre for Climate Action on Agricultural Emissions.

The Ministry for Primary Industries signed the agreement alongside representatives from ANZCO Foods, Fonterra, Ngāi Tahu Holdings, Ravensdown, Silver Fern Farms, and Synlait.

It has been announced as a long-term partnership between the Government and industry where industry funding will be matched by the Government.

The joint venture is a key component of the Centre for Climate Action on Agricultural Emissions. The Centre was announced as part of the $338.7 million in funding allocated over four years to strengthen the role of research and development for new tools and technologies to reduce on-farm emissions which were announced in the 2022 Budget. This includes the Government's funding component of the joint venture.

Without new technologies, the overall potential to reduce biological GHG emissions on-farm is reduced substantially. On-going investment in science and commercialisation pathways to develop such mitigations is therefore critical to the agriculture sector.

5.4.2 Genetics

The amount of methane produced by animals per kg of dry matter intake varies naturally. The dairy, beef, and sheep industries have breeding programs in place to enhance livestock performance and resilience. Selecting low-emitting animals to reduce emissions aligns with the existing industry practice. However, adopting such practices depends on the net benefits to farmers, including emissions and other animal production properties. Gene editing is a rapidly evolving technology that could expedite progress in this area compared to conventional breeding techniques. However, it may also face opposition from certain markets.

Gene editing could potentially benefit New Zealand agriculture by reducing biogenic methane emissions by creating low-emitting animals that produce less methane during digestion. This approach could help New Zealand's agricultural sector meet its obligations under the Paris Agreement and the Zero Carbon Act to reduce greenhouse gas emissions, including biogenic methane, by 24-47% by 2050 (Ministry for the Environment, 2019).

A literature review conducted by Zhang et al. (2021) evaluated the potential of gene editing technologies to reduce methane emissions from livestock in New Zealand. The review identified several genetic targets for methane reduction, including genes involved in methanogenesis, feed digestion, and rumen microbial populations. By using gene editing to modify these genes, it may be possible to create low-emitting animals that produce less methane.

Gene editing could potentially offer a more efficient and precise way to breed low-emitting animals compared to conventional breeding methods. By creating animals with specific genetic modifications, farmers may be able to reduce methane emissions without compromising productivity or other desirable traits. More research and investment is needed to ensure that any gene editing interventions are safe for animals and do not have unintended consequences on the wider ecosystem.

5.4.3 Methane Inhibitors

A methane inhibitor is a substance or chemical compound that reduces the production of methane by inhibiting the activity of methanogenic microorganisms in the digestive systems of ruminant animals such as cows, sheep, and goats. Methanogens are microorganisms that produce methane as a by-product of their metabolic process during feed digestion in the rumen. Methane inhibitors work by blocking the enzymatic pathways critical to methanogen growth, ultimately reducing their population, and limiting their ability to produce methane. Inhibitors can be delivered as a feed additive, included in water, or administered through a bolus inserted into the rumen.

Using methane inhibitors can potentially improve animal performance by retaining energy that is usually lost as methane. This energy could then be used for growth and production, ultimately increasing the efficiency of the farming system. However, the cost of administering methane inhibitors is a key challenge to their widespread adoption as a mitigation option. The economics of using methane inhibitors in New Zealand agriculture depends on the cost of the inhibitor relative to the value of the emission reduction achieved. Further research and investment are necessary to determine the optimal use and administration of inhibitors and their cost-effectiveness (Beukes et al., 2019; Ministry for Primary Industries, 2018).

5.4.4 Methane Vaccine

Recent studies suggest that a successful methane vaccine would stimulate an animal's immune system to produce antibodies in saliva that would inhibit the growth and function of methane-producing microbes (methanogens) in the rumen (Ministry for Primary Industries, 2018). A vaccine has the potential to work across all ruminant species and farming systems, making it an ideal solution for New Zealand's grazing-based systems (Ministry for Primary Industries, 2018). The development of such a vaccine is challenging, and current research is still in the development phase. Researchers in New Zealand have managed to produce antibodies against methanogens in sheep blood and saliva that have resulted in decreased methane emissions in laboratory experiments (Beukes et al., 2019). To date, they have not achieved successful suppression of methane in animals through vaccination. Despite the challenges, a vaccine is a highly desirable option for mitigating enteric methane emissions because it requires no changes to farming systems, leaves no residues in products, and is suitable for all ruminant farm animals (Ministry for Primary Industries, 2018).

Developing a methane vaccine involves three steps: producing a prototype vaccine that is effective in reducing methane emissions from either sheep or cattle in respiration chambers, further refining the vaccine to achieve a minimum of a 20% reduction in methane emissions without affecting production and making an effective vaccine available on the New Zealand market (Ministry for Primary Industries, 2018). The New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) is supporting research to develop a prototype vaccine. While vaccination trials in sheep have not yet resulted in reduced methane emissions, in vitro studies have shown that a vaccine can produce high levels of antibodies in sheep saliva, bind to methanogens' antigens in rumen fluid, and inhibit their growth and function (Beukes et al., 2019).

The current focus of research is identifying the appropriate antigens that will effectively suppress the growth and function of methanogens in the rumen. An international panel reviewed the vaccine program in December 2019 and confirmed the value and suitability of the research approach (NZAGRC, n.d.). Efficient mitigation of methane emissions will require changes in farm systems, which means farmers must adapt to the impacts of climate change and relevant policies. Investment in extension and monitoring tools is necessary to support farmers in implementing mitigation strategies effectively (Ministry for Primary Industries, 2018).

5.5 Ecotain takes N Mitigation to a new level

Forage herbs have become a crucial component of summer-proofing farm systems across New Zealand, with benefits supported by industry groups such as DairyNZ and Beef + Lamb New Zealand (BLNZ) (Hatch, 2021). One such herb is Ecotain environmental plantain, a narrow-leaved plantain that can thrive in different soils, rainfall patterns, and climatic conditions (Davies-Colley et al., 2018). Ecotain is an upright, winter active plantain with total annual dry matter (DM) production similar to traditional ryegrass-based pastures. However, it is capable of achieving higher DM production and feed quality during summer months.(Hatch, 2021).

Like chicory and legumes, Ecotain is processed faster in the rumen than ryegrass, increasing the potential for dairy cows to consume more daily intakes (Davies-Colley et al., 2018). In summer, cow appetite can be reduced due to high temperatures, high fibre content, and low protein pastures, but Ecotain can overcome this problem by having a low dry matter percentage and being upright, making it more easily grazed by the cow (Hatch, 2021). Ecotain also has good protein levels and high energy, averaging 11-12 MJ ME/kg DM, which can potentially lead to improved milk production during summer (Davies-Colley et al., 2018).

For sheep and beef farmers, Ecotain plantain offers a novel pasture option that can provide opportunities for creating pastures that were previously the domain of grasses (Hatch, 2021). For beef systems, Ecotain's benefits are in improving low-quality pasture, and its ability to grow in moderate fertility (Davies-Colley et al., 2018). Cattle systems can also benefit from its ability to provide micronutrients such as copper and selenium (Hatch, 2021).

Ecotain is regularly used in a pasture mix with grasses, legumes and other herbs, or grown as a pure stand crop for specific purposes. Once established, it can be reseeded easily, particularly in lighter, drier soils, allowing for regeneration over time, though this can lead to disease build-up and increased dead material, resulting in the death of original plants. Productivity can be maintained for 2-3 summers with good grazing management of wet soils, weed control, and reseeding through summer grazing. While Ecotain may not have the longevity of some perennial grasses, it has shown potential as a short to medium-term pasture option, similar to Italian or hybrid ryegrass. Ecotain pastures can enhance animal performance, particularly in spring, summer, and autumn, while also promoting animal health, milk production, and nutrient content. Trials have demonstrated the efficacy of Ecotain in reducing nitrate leaching in the urine patch. (Ruralco NZ Ltd., 2020).

"The planet is facing big challenges, and Ecotain® is our way to ensure we are stepping up to them. It sets a benchmark for sustainable products. It drives action and collaboration for sustainability. It is our holistic approach and guiding star to constantly strive for sustainability excellence."

(https://www.clariant.com/en/Sustainability/Safe-and-Sustainable-Solutions/Discover)

Ecotain is a highly effective tool for reducing nitrogen leaching from the urine patch. By employing four distinct mechanisms, it has the potential to reduce N leaching by to 89% when combined with other forage strategies. The first mechanism, Dilute, increases the volume of urine excreted by animals, resulting in a more dilute form of nitrogen that reduces the N load in the urine patch. The second mechanism, Reduce, decreases the amount of dietary N excreted in urine when Ecotain is included in the cow's diet. The third mechanism, Delay, slows down the conversion of ammonium to nitrate, providing plants more time to take up N and reducing the potential for leaching. The fourth mechanism, Restrict, reduces the nitrification rate in soil and restricts nitrate leaching.

The presence of Ecotain in the soil reduces nitrification, likely because of a biological nitrification inhibitor. Lysimeter studies have shown that nitrate leaching from urine patches is significantly reduced (70-80%) under Ecotain. Additionally, the drainage of water below the root zone is also reduced under Ecotain pastures. These soil effects are not yet accounted for in Overseer, which predicts leaching. The Plantain Potency and Practice Programme is currently investigating these mechanisms and their potential effects under different levels of Ecotain and in various soil types/environments.

Ecotain is an excellent forage option in terms of both agronomic and environmental benefits.

In terms of agronomic benefits, Ecotain has been shown to produce a similar quantity and quality of dry matter as ryegrass pasture, increase feed quality and/or supply during summer and autumn, improve the speed of sward recovery after summer dry, improve cool season activity of pasture base, and establish and compete in perennial ryegrass pastures.

Ecotain has been found to have positive impacts on animal performance, including elevating mineral content (Zn, Cu, Se, Mg, Ca, K), reducing facial eczema spore levels, and reducing dag production in sheep. It has been found to promote live weight gain with a higher dressing out percentage in lambs and cattle.

How it works

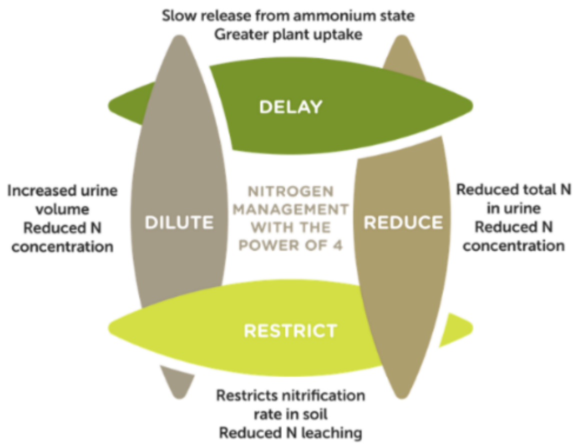


Image 5: Ecotain Science, How it works, The Power of 4, (http://www.nsentinel4.co.nz/ecotain-science/)

A lysimeter study demonstrated the effectiveness of Ecotain in reducing nitrate leaching. When urine from animals grazing normal pasture was applied to an Ecotain mix, a 45% reduction in leaching was recorded, demonstrating the Restrict function. When urine from animals grazing the Ecotain mix was applied to the same sward, an 89% reduction in leaching was recorded, showing the four mechanisms working together. Furthermore, the study found that a mix containing just 20-30% Ecotain can still provide a 74% reduction in leaching, suggesting that moderate rates of Ecotain can be highly effective at reducing nitrogen leaching (LUDF, 2021).

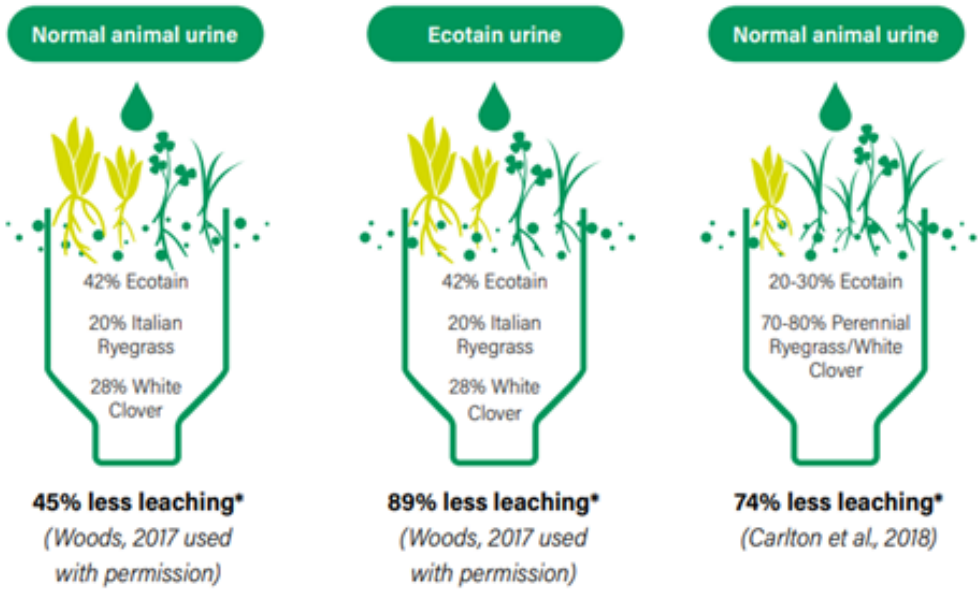


Image 6: Nitrate leaching reductions using different urine and pasture mix treatments from lysimeter research.

Research has indicated that plantain, specifically the Agritonic cultivar, can reduce nitrous oxide (N2O) emissions from the urine patch by 53% in pastures where 30% of the forage is comprised of plantain. This finding was observed in two separate experiments. In the first experiment, urine from cows grazing 30% Ecotain™ pastures, with a nitrogen content equivalent to 750 kg N/ha, showed a reduction in N2O emissions. This was in contrast to the ryegrass/clover control, which had a nitrogen content equivalent to 1000 kg N/ha. The second experiment, where urine from cows grazing ryegrass/clover pastures with a nitrogen content of 610 kg N/ha was applied to all treatments, also showed a reduction in N2O emissions from Ecotain™ pastures. This suggests that the soil nitrogen retention effect described in leaching is also effective in reducing N2O emissions. However, further research is needed before incorporating the N2O emissions reduction potential of plantain into models like Overseer. Additional studies are currently underway at Massey University and as part of the NZ Agricultural Greenhouse Gas Research Centre to better understand the potential of plantain in reducing N2O emissions (DairyNZ, n.d.).

5.6 Biochar as a solution

Recently, the interactions between black carbon and the nitrogen cycle have been recognised, and the use of biochar is being studied as a potential solution to reduce N2O emissions, which is a potent greenhouse gas that contributes to climate change (Spokas et al., 2012). Biochar has been found to enhance soil properties by reducing the leaching of nitrogen into groundwater, increasing cation-exchange capacity, moderating soil acidity, improving soil fertility, increasing water retention, and increasing the number of beneficial soil microbes (Biochar International, n.d.). Biochar is a versatile enhancer that can improve almost any soil, with the greatest impact expected in areas with low rainfall or nutrient-poor soils (Biochar International, n.d.). In addition to improving soil properties, biochar has been shown to act as a stable carbon sink, with the carbon remaining sequestered for longer periods than it would in the original biomass (Lehmann et al., 2003; Rondon et al., 2007; Steiner et al., 2007; Kimetu et al., 2008).

The inclusion of biochar production as a climate change mitigation strategy is supported by scientific evidence, particularly about reducing N2O emissions. However, in New Zealand, the field trials and commercialisation of biochar are hindered by a lack of supply to serve potential applications and low demand due to its novelty. Biochar's absence of recognition in the emissions trading scheme and a deficit of information at the official level further compound its niche status in the marketplace. Despite these challenges, biochar's proven residence time in soils and superb resistance to chemical and biological breakdown makes it a valuable carbon sink, with a market in verified carbon credits as an obvious means of valuing the process. Incentives, such as government subsidies and a carbon marketplace with oversight by an independent public agency or consortium, can encourage biochar production and deployment at scale. The source of biomass for treatment by pyrolysis is the debris and slash remaining after commercial forestry blocks have been harvested, and a requirement for source reduction of this material can be a powerful driver of increased biochar production. In situ, pyrolysis achieves an average of 75% volume and mass reduction, and the end product can be directly applied to enhance the future productivity of forest soils.

The source of biomass for treatment by pyrolysis is the debris and slash remaining after commercial forestry blocks have been harvested, and a requirement for a source of reduction of this material can be a powerful driver of increased biochar production.

In light of the promising potential of biochar as a climate change mitigation strategy, further investment in research, development, and deployment of biochar technology in New Zealand is recommended. This could involve supporting more field trials to investigate the effectiveness of biochar in various soil types and applications, as well as increasing education and awareness efforts to promote the use of biochar among farmers and other stakeholders. Policies and incentives that encourage the production and deployment of biochar at scale, such as subsidies and a carbon marketplace, could help overcome the current barriers to its commercialisation. By investing in biochar technology, New Zealand could not only reduce greenhouse gas emissions but also improve soil health and productivity, making it a win-win solution for both the environment and agriculture.

This section has examined the concept of sustainability in agriculture and its implications for New Zealand's primary industries. It has shown that agriculture is a major contributor to greenhouse gas emissions, particularly biogenic methane, which poses a threat to the environment and the country's commitments under the Paris Agreement. It has also reviewed the current policies and initiatives that seek to reduce emissions and improve water quality, such as the Zero Carbon Act (2019) and the National Policy Statement for Freshwater (2020). Highlighting some of the emerging and disruptive technologies that offer potential solutions for enhancing productivity and sustainability in the pastoral sectors. It has also acknowledged the challenges and barriers that hinder the adoption of these technologies, such as cost, regulation, and social acceptance. Finally, it has emphasized the need for a holistic and collaborative approach that involves all stakeholders in the transition to a more sustainable agricultural system.

6.0 Conclusion

This report has explored the potential of disruptive innovation and emerging technologies to transform New Zealand's farming models and enhance their sustainability. It has also discussed the changing global circumstances that affect the agricultural sector and the drivers, barriers, and impacts of technology adoption on farms and rural communities. Based on the literature review and the interviews with subject matter experts, the report has identified some key findings and recommendations for the industry.

Some of the key findings are:

- New Zealand farmers are facing multiple challenges, such as climate change, environmental degradation, market volatility, consumer demand, and social pressure, that require them to adapt and innovate their farming practices.
- Disruptive innovation and emerging technologies can offer solutions to these challenges by improving farm productivity, efficiency, profitability, resilience, and environmental performance. Some examples of these technologies are precision agriculture, biotechnology, alternative proteins, blockchain, and artificial intelligence.
- However, the adoption of these technologies is not straightforward and depends on various factors, such as cost-benefit analysis, availability of information and support, compatibility with existing systems and values, regulation and policy, social acceptance, and ethical considerations
- Technology adoption can have positive and negative impacts on farms and rural communities, such as creating new opportunities, enhancing skills and knowledge, increasing competitiveness, reducing emissions and waste, but also displacing labour, disrupting traditional practices, increasing inequality, and creating new risks and uncertainties.

7.0 Recommendation

Based on the findings of this report, the following recommendations are proposed to help the industry harness the potential of disruptive innovation and emerging technologies to achieve sustainable agriculture in New Zealand. These recommendations are aimed at addressing the key challenges and opportunities that the sector faces and enhancing its social, economic, and environmental performance.

- Promote innovation and collaboration: The industry should foster a culture of innovation and collaboration among farmers, researchers, policymakers, businesses, and consumers to identify and address the needs and opportunities of the sector.

- Invest in research and development: The industry should invest in research and development to generate evidence-based knowledge and solutions that are relevant, accessible, and applicable to New Zealand's farming context.

- Educate and support farmers: The industry should provide farmers with education and extension services to increase their awareness, understanding, and skills in using new technologies and practices.

- Communicate and engage with stakeholders: The industry should engage with stakeholders and the public to communicate the benefits and challenges of technology adoption and to build trust and acceptance of new products and processes.

- Advocate for supportive policies and regulations: The industry should advocate for supportive policies and regulations that enable innovation and technology adoption while ensuring environmental protection, animal welfare, food safety, and social justice.

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Appendix

Appendix 1

Interview questions Introduction

- Can I please record our interview? Completely private and for project use only
- The Chatham House Rule will be used by default
- Are you happy If I send some follow-up questions if I need to?

These questions are to provide a semi-structured interview format and further discussion is encouraged.

Questionnaire

1. What is our current strategy to respond to climate change in NZ agriculture?
2. How are we utilizing this response to our advantage?
3. How can we intensify agriculture with our current climate change strategy?
4. From your point of view, what disruptive technology is available that we are not currently accessing to improve our response to climate change?
    a. How could these technologies reshape agriculture in New Zealand?
5. How can these technologies further enhance our livestock farming practices and resilience in the NZ sheep and beef sector?
6. What do you believe motivates and influences farmers to adopt or reject the integration of new technologies into their farming systems?
7. What is the impact of the narrative around the current climate change response?
8. Where do our key messages come from?
9. Who are the key influencers?