Building a balanced Australian Lamb Industry – Focussing on moving towards a low carbon economy

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Executive Summary

We all produce emissions, whether driving a car, getting on a flight, or brushing our teeth. So why does it matter?

This paper will investigate some of the key solutions and tools available for adoption to achieve a low-carbon production model for a grass-driven, prime lamb farm operation. Specifically, this will be isolated to a breeding operation, looking to turn off finished lambs ready for processing. Based on evidence and insights from my Nuffield travels. I will also examine how a prime lamb business can move towards a low-carbon future and the further research it inspired through sustainable practices, data capture, benchmarking, innovation adoption, market access, policy approaches and the impact of globalization.

In response to increasing global pressures, we are starting to see the regulatory environments change around emissions. Countries are looking at implementing a carbon tax, or regulation that puts a limit to emission outputs. These strategies should align with on farm productivity and profitability goals to support future protein demand and enable a strong future in the lamb industry.

If done well, policy and government regulation have the potential to create engagement and adoption of strategies of new and existing strategies to reduce emissions worldwide. This is evident through the strong leadership and industry support, as seen in the US, who have bolstered a substantial government stimulus to fund innovation and adaptation. These efforts aim to enhance productivity and reduce emissions. However, when these initiatives are poorly executed, there are significant risks and consequences, leading to low adoption of change and strong push back from farming communities.

As a net exporter of lamb, Australia needs to appreciate the driving incentives of global consumers and supply chain expectations. Without exports, the Australian sheep flock would be a fraction of the size, at potentially only 30% of current numbers, or 23M sheep, taken from Meat and Livestock Australia's 2024 projections. Therefore, Australian farmers should care about positioning their production systems toward a low-carbon economy, while balancing this goal with economic concerns.

Out of the 100 largest economies in the world committed to reducing emissions, 69 of them are companies and 31 are Countries stated in a Global Just Now report in 2016. Proving that it is industry driving this global transition to a low-carbon economy. For Australia to continue doing global business, it will need to align Australian farm businesses with the market.

Despite what many may think, reducing emissions doesn't need to be a zero-sum game. One key underpinning to this market alignment, is the mutually beneficial way of looking at carbon intensity. Through analysis of the carbon intensity of a grazing system, individual farm businesses can find opportunities to optimise their output. Ultimately, it is a dual benefit that results from producing more with the same or fewer resources, reducing waste, and maintaining profitability through an efficient cost structure.

Through travelling to several countries, such as Ireland, the United States of America, New Zealand, Israel, the Netherlands, and Denmark, I have developed a global perspective on what is one of the agricultural industry's greatest challenges. With Livestock being the weighted average of on farm emissions, chasing efficiencies is the first step. The exciting aspect I discovered, is that we have so many different minds and capital being diverted to this challenge around the world, which will result in multiple solutions and practice changes. Research projects in Ireland, New Zealand, Europe and Australia, are in support and will work toward positive change to support this transition to a reduced emissions economy and lamb industry .

This paper investigates where policy settings currently sit concerning various extremes in climate policy through a global lens, and the perspectives of producers and agricultural industry professionals as a result.

Furthermore, I will explore what emissions are in relation to a prime lamb farming landscape, and the different types of emissions within a grazing system. Through reflecting on diverse farming systems globally, I will highlight the importance of re-evaluating the entire farming process to optimize production. This ensures that emissions reduction isn't the sole focus and it is done with a balanced approach of profitability and productivity. A key metric to this balanced approach is looking at carbon intensity. Identifying carbon intensity will ensure you are implementing the most efficient production system you can from the resources you have.
Further to this, looking at the whole farm system and introducing legumes was a pivotal step towards improving carbon intensity. Finally, I will explore some of the exciting carbon research, abatement, and mitigation strategies I have encountered during my global travels. These are still mostly a working progress, but will provide supportive practice change in the future to enable emissions reduction in a lamb production system.

If producers embrace change and receive well-planned and executed guidance from industry and government to foster innovation, adaptation, and transformation, we can progress towards a low-emission production system. This system will continue to yield valuable protein, preserve the environment, enhance livelihoods, and align with market demands.

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Foreword

Amidst the ongoing global scramble for emissions reduction, this report explores some of the solutions for the Australian prime lamb industry. A lot of the thinking and concepts in this report can also be taken and applied across other industries. I hope that not only sheep enthusiasts, but also general agriculturalists can enjoy this report and get some tangible takeaways as well.

My background did not start with farming, as I began my career in the construction industry and only moved back to a family farm in 2015, where I now farm with my wife, Maddie McFarlane, and son, Moe. I am a fourth-generation Farmer at “South Mokanger” near Cavendish, Victoria.

We are currently a sheep and beef operation with 80% of our income coming from our sheep operation. For this reason, I decided to explore what I see as one of the largest challenges for the prime lamb industry- the emissions we produce at a farm level. With the world looking to place a price on carbon by incorporating a carbon tax,
the sheep industry is very exposed to what could be a costly and, in some extreme cases, business-destroying affair.

I set out to explore what the Australian lamb industry might look like in a low-carbon world and what the current adaptation opportunities are to ensure our industry and businesses thrive through this transition.

The Nuffield program enabled me to travel to 8 countries as part of the Global Focus Program. I was exposed to sheep industries in New Zealand, the US, and Ireland. This exposure cemented my understanding that Australia is very much a world leader in lamb production. I was also lucky enough to explore some other related topics, such as capital markets with Rabobank in New York, dairy automation in the Netherlands, whole farm finishing systems in New Zealand, and the famous Leachman beef stud in the US.

Nuffield is truly a life-changing experience and will continue to be through its incredibly diverse and extensive alumni network for years to come. Thank you, Nuffield and The William Buckland Foundation, for supporting me on my journey.

Figure 1: Johnny Gardner and Maddie McFarlane, Australia (Source: Author, 2022)

Table 1. Travel itinerary

Travel date	Location	Visits/contacts
Week 1	Singapore:	GFP: ANZ, Food Markets
Week 2	Japan:	GFP: The Farm Vegas & Tourism, Agri Shinoya, Ministry of Ag, Citrus farm Muchachan, Assai Farm, Kagawa Fishing, Wagyu beef farm Yuboku.
Week 3	Israel:	GFP: Kubbutz Ketura, Tovia research centre, Netafim, Tom & Zoha Beef ranch, Jerusalem, The Kitchen (Strauss Group),
Week 4	Denmark:	GFP: Sonderjysk Biogas, SLF advisory, Axel Mansson, Local Farm (beef, beer & bonfire), Agro food park, Musholm sea farming, Nordic harvest, Noumeal, Danish Ag food council, Think dk Garden.
Week 5	USA: Washington, Texas	GFP: Dudley's ranch, Vollemans dairy, Boggy Slough reserve, Tarleton Uni, Texas A & M Aglife research, West Fraser timber mill, Santa Rosa Ranch, NASDA, Bayer, United Stats Capital.
Week 6	USA: Austin, New York	Personal: Charlie Arnott, Integrity Foods, Leachman Ranch. Rabo Bank NY, American Lamb Board.
Week 7	Ireland:	Personal: Ballyfin, Tallow, Cork, Sheep Ireland, Kilcolgan Teagasc, Athenry, Lough Swilly SAC Dairy farm, Sheep saleyards, Grianan Ailigh, Burt.
Week 8	United Kingdom:	Sarah McFarlane, Energy transition for Rueters.
Week 9	The Netherlands:	Amsterdam, Melissant dariy, Wervershoof sheep dairy,
Week 10	New Zealand: North & South Island	Stoneyhurst, Derrick Moot, Ashburton, Align Farms, Glenthorne Station, Rangitaiki Station, Wilson Hellaby, Waikawa Farms, Whangara Farm.

Acknowledgments

Firstly, thank you to Nuffield and The William Buckland Foundation for selecting me and providing me the opportunity to travel so extensively.

Thank you to all the families, friends, business owners, and Nuffield scholars who generously gave their time and insights along the way. Everyone was so incredibly generous with their openness, knowledge, and passion, which truly made the Nuffield experience such an enjoyable process. The one major takeaway from Nuffield is it is all about the people you meet and the relationships you foster, so again, thank you.

I was lucky enough to do most of my personal travel with my wife Maddie. Thank you for joining me, Maddie; it is hugely powerful to have a partner share the Nuffield journey to strengthen alignment of thinking and meet challenges along the way. Thank you to my family for supporting my absence on the farm and keeping the wheels turning. This includes Will and Stephen who worked on the farm and managed without me for 4 months.

Abbreviations

AI	Artificial Insemination
CO2	Carbon Dioxide
CH4	Methane
DM	Dry matter
GHG	Greenhouse Gas
N20	Nitrous oxide
PLF	Precision Livestock Farming
IPCC	Intergovernmental Panel on Climate Change
SDG	Sustainable Development Goals

Objectives

- Objective 1: Importance of Policy.
- Objective 2: Understanding emissions – Data & benchmarking.
- Objective 2: Market access.
- Objective 3: Importance of legumes in sheep production systems.
- Objective 4: Carbon abatement & mitigation strategies.
- Objective 5: Soils & land management.

Chapter 1: Introduction

Within the fast-paced economic environment we live in today, there is a constant pressure for businesses to learn, evolve and progress. The Global issue of climate change is an increasingly urgent challenge to address via efficient adaptation. The Agricultural industry is far from immune from these pressures, particularly the livestock sector, broadly considered an emissions intense industry.

This report looks to investigate how a balanced approach to driving emissions abatement in the Australian Lamb Industry can be achieved. The key drivers identified include government policy, market access, whole farm systems, emissions specific innovation, soil carbon and biodiversity.

The Australian Prime Lamb Industry relies predominantly on export markets and as such, meeting both international and domestic policies and consumer expectations are imperative to maintaining healthy market access. This can be both mandated and supported via Government Policy. From The Netherlands to Ireland to The United States there are highly varied approaches to emissions specific policies.

Throughout the World, there is an abundance of research currently being undertaken. This report looks specifically to research in Australia, Ireland, New Zealand and The Netherlands, focused to improve farming systems and the related emissions outputs. Some research has been backed enough by data to be applied on the ground in farming systems. At a micro level, farm systems can be adapted to empower the individual businesses to make practice changes that both reduce emissions and benefit the business at large. Furthermore, Farms can look to improve soil carbon and biodiversity. These two topics are very challenging and deserved of their own in-depth papers, so this paper will touch on some of the research that has been done locally and some ideas for further investigation.

Whilst the solutions to emissions reduction in the Australian Lamb Industry and livestock industry at large are complex and layered, with a combined collaborative effort from farm gate, to Governing bodies, a balanced approach with significant results is possible. Significant emissions reduction can be for the betterment of all, but it will take all parties involved to activate a long-term solution.

Chapter 2: A global perspective on Policy

In this section, the importance of global-level policy setting will be explored. It will highlight why it is important for Australia to understand and align with other countries, in a manner that is considered and appropriate. It will also examine how certain countries are approaching policy with a singular focus on emissions, rather than using balanced thinking that considers food security, industry profitability, and investment in innovation and adaptation strategies to transition towards a low-carbon economy.

The Intergovernmental Panel on Climate Change's (IPCC) latest report states, "principally through emissions of greenhouse gasses, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2022. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use, and land use change, lifestyles and patterns of consumption and production across regions, between and within Countries, and among individuals" (IPCC, 2023). The debate over whether climate change is occurring should no longer be necessary and instead should focus on how we can progress into a low-carbon economy on the smoothest possible path.

The report also goes on to say some impacts are irreversible and should be looked at with an adaptation lens (IPCC, 2023). Therefore, there is a need to do better and reduce our emissions in a global pursuit to cap global warming.

With the global population set to reach 9.7 billion people, fuelling a doubling of protein demand by 2050 (Sweet, 2019), meat will continue to play a large role in filling these nutrition needs. Keeping this in mind, it can be short sighted to simply remove a large number of animals from the system, especially considering the importance of food availability and access to protein.

In 2020, the Australian red meat industry represented 10.3% of the national GHG emissions. More than 90% of this is associated with grazing and land management. Beef contributes 88% and sheep 11.6% of the total GHG emissions (Ridoutt, B., 2023). Despite the lesser extent for sheep, this is a shared problem of methane output, and these statistics reiterate how it is a critical challenge for the industry.

Carbon intensity is a measure of how efficient a production system is and is a key metric when assessing individual farm businesses on how much improvement there is in the system. The OECD/FAO 2023 – 2032 report outlines that global agricultural emissions are set to increase by 7.6%, which is lower than the predicted output growth of 12.8% (OECD-FAO, 2023). This data reiterates the importance of ensuring we can enhance the efficiencies of what we produce with the current resources that we have. With livestock to be generally estimated as 70% - 80% of the increase in GHG emissions, there is a global need to address the industry's total emissions to bring ourselves into accord to the Paris agreement. The Paris agreement was where 196 countries came together to decide upon a response to climate change by agreeing to try and limit global temperatures by 1.5 degrees Celsius (United Nations Climate Change, 2015). This agreement helps to align data and ambition on a global scale.

It is important to note that these numbers do not consider innovations that are currently in development, such as feed additives and vaccinations that inhibit methane output from animals.

Another source of governance supporting a new world of planning is the Sustainable Development Goals (SDGs). These goals aim to align countries in their planning by taking a balanced approach to reducing poverty, improving equality, protecting the planet, and ensuring people enjoy health, justice, and prosperity (United Nations Department of Economic and Social Affairs, n.d.). With one of the SDG's being zero world hunger, we will need crop yields to increase by 24% and protein 31% by 2030, outlined in the United Nations SDG's. Further demonstrating the need for balanced decision-making in trying to achieve both lower emissions and zero hunger.

Adding to the complexity of setting global policies, historically countries have had different GHG emissions. More developed countries have been emitting large amounts of GHG over a long period of time, while many developing countries have only recently begun to industrialise and thus emit GHG.

Different stages of development will result in countries having different priorities. Less developed countries, for instance, often focus on economic growth and poverty reduction. These countries typically have less access to capital, making it more challenging for them to innovate or invest in clean energy solutions. Geographical positioning also plays a role in a country's current energy landscape. For example, New Zealand already has a high proportion of renewables in its energy consumption, while Australia relies heavily on coal. This is due to each country's access to different energy sources. Figure 2 outlines the ambitions of individual countries, highlighting the varied and sometimes conflicting approaches to reducing emissions, which adds complexity to the overall challenge. International climate agreements, such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, provide a framework for countries to negotiate and set their emissions targets. These agreements acknowledge the differences among countries and allow flexibility in target setting depending on where each country sits in their journey.

International Policy Drivers:
Nationally Determined Contributions (NDC)

Country	Target
China	Peak 2030 CO_2 emissions: 60% to 65% per unit GDP compared to 2005
United States	50-52% below 2005 by 2030
European Union	At least 40% below 1990 by 2030
Germany	55% below 1990 by 2030
Norway	At least 40% below 1990 by 2030
Switzerland	50% below 1990 by 2030
United Kingdom	50% below 1990 over 2023-27
India	A 33-35% in EI by 2030 compared to 2005
Canada	30% below 2005 by 2030
Mexico	25% below business-as-usual by 2030
Russia	25-30% below 1990 by 2030
Australia	43% by 2030 and net zero by 2050

14 https://cait.wri.org/indc/#/map

Figure 2: Policy drivers for individual Countries (Source: Climate Watch, 2024)

Although Australia at present only has 4% of the global sheep flock, it is the highest exporter of sheep meat worldwide, with 48% of the global share of exports MLA's Global sheep meat industry and trade report (2022). This demonstrates the necessity to align with global expectations as exports underpin our market.

All these governmental goals and planning help us strive for a low-carbon economy. However, like running a business, allocating all resources to one area can lead to failure. This concept is captured in a statement by Bill Malcolm, a professor at Melbourne University, who notes at a presentation to Nuffield Scholars at Tangalooma, Queensland: "There are no maximums in maximum profit." (Malcolm 2020). Instead of focusing on maximization, we should aim for optimization. This statement underscores that emissions reduction should not come at any cost; on the contrary, balanced and thoughtful approaches are essential for addressing this complex problem. Bjorn Lomborg's assessment in "Welfare in the 21st Century" highlights the importance of climate policy, particularly in terms of where capital is best spent. He details one scenario of extreme emissions reduction that returns only 11 cents for every dollar spent. In contrast, an alternative, less "all-in" approach that focuses on adaptation measures rather than solely on stopping emissions provides an $11 return for every dollar spent (Lomberg, 2022). This type of thinking needs to be adopted when implementing climate policy.

After traveling to Ireland, New Zealand, and the US, it was interesting to see the various approaches being implemented in each country. These observations demonstrated that each country has its own methods, which can make it challenging to build alignment in the push for change. This was reinforced after COP27 in Egypt, where more than 35,000 individuals from industry and government convened to discuss vital actions for addressing climate change. However, little emerged from this meeting except for an agreement to establish a Loss and Damages fund. This fund aims to provide financial support to developing countries to help them cope with capital losses or damages resulting from climate-related effects, outlined on the United Nation, Climate Action website.

Another advancement in the alignment of international goals was the signing of the Global Biodiversity Framework (GBF) during the UN Biodiversity Conference in 2022. The goal of the GBF has four overarching goals to be achieved by 2050. Focussing on ecosystem and species health. Among the 23 targets to be achieved by 2030 are, 30 per cent conservation of land, sea and inland water, 30 per cent restoration of degraded ecosystems and halt the extinction of known threatened species and reduce the introduction and halving establishment of invasive species. United Nations Environment Programme (2022).

However, the true test of leadership is then translating and implementing the policies that underpin these ambitions. Policymakers need to carefully design and implement emissions policies while considering economic, social, and environmental factors, as well as work to mitigate the negative impact on vulnerable populations and industries. Balancing environmental goals with economic and social considerations is a complex challenge in the move to a low-emissions world and this complexity was evident during my travels.

There is a saying, “To a person with a hammer, everything looks like a nail.” (Maslow, 1966) Occasionally, aggressive or single-minded government policies may overlook the broader elements necessary for balanced decision-making. For instance, certain government incentives in New Zealand have prompted the conversion of productive land previously used for agriculture, into tree plantations to sequester carbon. It's crucial to acknowledge that this can yield both positive and negative outcomes. On the positive side, such a policy contributes to carbon sequestration, soil stabilization, and erosion prevention. However, challenges arise; monocultures can diminish biodiversity, and converting productive farmland can adversely affect communities by causing job and productivity losses. Most significantly, it can diminish food production and disrupt the entire food supply chain. This is called carbon leakage, when lamb production is taken from one of the most efficient, low-carbon intensity production systems in the world, and another market is allowed to absorb the demand, resulting in the net outcome of increasing the emissions output.

The transition from primary production to tree plantations requires thorough consideration beyond just carbon sequestration. The full ramifications of such a shift in New Zealand have yet to be seen, because of this regulation and the capital-chasing carbon markets that will follow.

Another example of a lack of balanced regulation can be seen in Sri Lanka, where a ban on the import and use of synthetic fertilisers, including synthetic nitrogen and phosphorus-based fertilisers, resulted in significant pushback from local communities. Published by Uditha Jayasinghe and Devjyot Ghoshal in a publication at Reuters in March 2022, points out the drop in yield from 60 bags of rice to just 10 for a local Sri Lankan farmer. This outlines how important balanced government policymaking is when planning and implementing change.

Whilst anecdotal, it was also incredible to get an insight into people’s attitudes towards emissions reduction. When visiting New Zealand, Ireland, and the Netherlands, all countries with very strong government regulations around emissions reduction, I witnessed farmer communities experiencing a real urban and rural divide. Most prominently, the farmer communities strongly resisted and disliked government policy.

In contrast, when visiting the US, despite having similar ambitious targets of emissions reduction, the government stimulus and financial backing to implement adaptation practices induced vastly different attitudes.
Using different language and recognising the impact on the US farmer community, the US implemented the Inflation Reduction Act, which provides $19.5 billion over 5 years to support conservation programs to support farmers and ranchers in adopting and expanding climate-smart activities and systems. U.S. Department of Agriculture (USDA 2023).

These examples highlight the role leaders play in prioritising and implementing change on items such as a transition to a low-emissions economy. Policymaking frequently involves complex and contentious decisions, which is where true leaders bear the responsibility of considering various stakeholders and ensuring that policies align with the broader goals and values of society. This contrast was particularly evident in several countries. In the US, there was a notable ability to inspire and foster trust in embracing change. This was achieved through the allocation of capital into the agricultural sector, encouraging adaptation and the adoption of climate-smart alternatives.

Conversely, in New Zealand, Ireland, and the Netherlands, the farming community often felt as though Governments were the villains and were left with the responsibility to reduce emissions on their own. In these cases, it might be considered that the stick approach was used, and they were implementing government regulation to build a cost into emitting emissions. Ultimately, New Zealand's approach was based on a tax system to reduce emissions and the US approach was based on incentives towards practice change, and the adoption of climate-smart interventions.

Chapter 3: Understanding emissions - carbon intensity and total carbon

Understanding emissions refers to comprehending the release of various substances into the atmosphere, specifically greenhouse gas (GHG). Emissions are a critical concept in the context of climate change, air quality, environmental protection, and efforts to reduce global warming.

It is important to provide some context around the different types of emissions made up from various sources. This includes human activities, natural processes, and industrial operations. There are 3 main types of emissions, carbon dioxide ($C02$), methane (CH_4), and nitrous oxide (N_2O). Although CO_2 and N_2O have a much longer atmospheric lifespan (100 years compared to methane, which lasts for around 10-12 years), methane is significantly more potent, equivalent to 28 times the impact of CO_2 when assessing its atmospheric impact over a 100-year period. This is outlined on the Agriculture Victoria website. Therefore, any reduction of methane would have enormous beneficial effects on global warming potential and these effects could be seen in just 12 years. Ag Victoria – Understanding carbon emissions.

As a red meat producer, the Australian production system is particularly prone to methane emissions. In most pasture-based production systems, between 70% and 90% of total emissions are generated by animal ruminants, primarily through enteric methane production. Wiedemann et al, (2022). Figure 3 shows an example of Melbourne University's carbon accounting tool for an Australian prime lamb production system. This methodology is held in high regard around the world as a tool that breaks down greenhouse gas emissions into 3 different scopes:

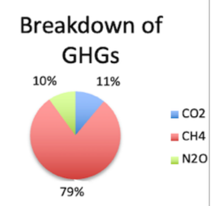
- Scope 1) Direct emissions from owned and controlled sources.
- Scope 2) Indirect emissions (for example, electricity).
- Scope 3) Product, not within the farm boundary (for example, fertiliser, fuel, or livestock transport).

This tool has become the industry standard for assessing the emissions output of livestock farm businesses in Australia. It offers a comprehensive breakdown of areas to focus on within your farm business. As Bill Malcolm, a Melbourne University Economics Professor, aptly puts it, "If you don't know where you are going, any road will take you there." Malcolm (2020) This underscores the importance of the initial step: measuring where your production system stands, and then understanding what can be done to improve it.

Beef & Sheep Greenhouse Accounting Tool

Outputs	beef t CO_2e/farm	sheep t CO2e/farm	total t CO2e/farm
Scope 1 Emissions			
CO_2 - Fuel	3.65	33.90	37.55
CO_2 - Lime	39.60	118.80	158.40
CO_2 - Urea	7.33	29.33	36.67
CH_4 - Fuel	0.00	0.01	0.01
CH_4 - Enteric	826.50	3,601.00	4,427.50
CH_4 - Manure Management	36.43	195.47	231.90
CH_4 - Savannah Burning	0.00		0.00
N_2O - Fertiliser	3.83	30.32	34.15
N_2O - Urine and Dung	61.98	176.54	238.53
N_2O - Atmospheric Deposition	6.93	21.87	28.80
N_2O - Leaching and Runoff	45.97	156.54	202.50
N_2O - Savannah Burning	0.00		0.00
N_2O - Fuel	0.02	0.21	0.23
Scope 1 Total	**1,032**	**4,364**	**5,396**
Scope 2 Emissions			
Electricity	0.85	33.15	34
Scope 2 Total	**1**	**33**	**34**
Scope 3 Emissions			
Fertiliser	28.09	135.04	163.13
Purchased mineral supplementation	0.00	0.00	0.00
Purchased feed	0.00	326.98	326.98
Herbicides/pesticides	0.00	0.00	0.00
Electricity	0.07	2.73	2.80
Fuel	0.92	8.44	9.36
Lime	2.50	7.50	10.00
Purchased livestock	683.28	18.63	701.91
Livestock on agistment			
Scope 3 Total	**715**	**499**	**1214**
Carbon Sequestration			
Carbon sequestration in trees	-105.58	-422.31	-527.89
Net Farm Emissions	**1,642**	**4,474**	**6,117**

Summary	t CO2e/farm
CO_2	643
CH_4	4,675
N_2O	579



Emissions intensity		
Sheep meat (breeding herd) excl. sequestration	**6.3**	kg CO2-e / kg LW
Sheep meat (breeding herd) inc. sequestration	**5.7**	kg CO2-e / kg LW
Wool excl. sequestration	**22.8**	kg CO2-e / kg greasy
Wool inc. sequestration	**20.8**	kg CO2-e / kg greasy
Beef excl. sequestration	**10.4**	kg CO2-e / kg LW
Beef inc. sequestration	**9.7**	kg CO2-e / kg LW

Citation: Lopez M.B., D
Framework for Beef a
Gas Inventory metho

THE UNIVERSITY OF MELBOURNE

Figure 3: Melbourne University GAF GHG Accounting tool (Source: Ozkan, S. 2014).

As it stands, agriculture and related land use contribute to approximately 12% of global greenhouse gas emissions, primarily from methane and nitrous oxide (Fell J, et al., ABARES, 2022). A superficial solution might suggest removing red meat from agriculture entirely. However, this approach oversimplifies the issue. While there may be underlying motives for such a proposal, it's essential to recognize the complexity of the global food system. Addressing this challenge requires well-considered and nuanced solutions.

The Food and Agriculture organisation of the United Nations states that, although 45% of the world's surface is suitable for agriculture, only 16% of this is crop able, 4% to biofuels and textiles and 80% to livestock. Ritchie H and Roser M., (2019).
However, in Australia, crop land accounts for approximately 6.7% of the country's surface allocated to Agriculture (Brown et al., (2023). Seeing these numbers outlines the complexity of land use to climatic areas, soil types, logistical areas of Australia's vast mass. This helps paint the picture of the pressure to reduce emissions in the livestock industry, as it is not as easy to say, just change the land use in most cases.

Understanding this complex challenge; for example, the report 'Pathways to climate neutrality for the Australian red meat industry' explains that total red meat GHG emissions have reduced by 64.9% in the years 2005 to 2020 (Ridoutt, B., 2023). This can be misleading when focusing on sheep, as the Australian flock reduced from 101 million head in 2005 to 66.7M head in 2020 (figure 4). This decrease was beneficial for the total emissions narrative for the Australian sheep flock; however, we have since seen the sheep flock increase and as of writing, the figure has reached a projected 78.75M in 2023, as stated in Ridoutt, B., (2023), industry projections. This may seem like a short-term victory for the industry, but it does not provide a long-term solution. While reducing total animals might appear to be an easy fix for the carbon problem, it overlooks the crucial need to balance emission reduction with ensuring food security for a growing global population.

	2005	2015	2016	2017	2018	2019	2020
Beef							
Total beef cattle[1] (M head)	25.2	24.6	24.3	24.9	25.1	23.7	22.3
Beef cattle pasture[1] (M head)	24.4	23.7	23.3	24.0	24.1	22.6	21.2
Beef cattle feedlot (M annual equiv[2])	0.82	0.93	0.94	0.94	1.03	1.11	1.11
Beef processed[3] (Mt HSCW)	2.03	2.48	2.08	2.11	2.27	2.38	2.08
Sheep							
Total sheep (M head)	100.7	70.9	70.9	75.7	74.1	69.0	66.7
Lamb & mutton processed (Mt HSCW)	0.62	0.71	0.69	0.70	0.74	0.73	0.66
Wool produced (Mt, greasy)	0.46	0.36	0.36	0.38	0.36	0.31	0.28

[1] excludes dairy cattle
[2] number of animals adjusted for days on feed
[3] excluding veal

Figure 4: Livestock numbers and red meat production in 2005, 2015-2018. Data from Australian National Greenhouse Gas Inventory activity tables and ABS annual Statistics (Source: Ridoutt, B., 2023).

According to Figure 5, farms contribute to approximately 90% of emissions along the supply chain. Meanwhile, Figure 6 highlights the improved efficiencies in the sheep production system by tracking total emissions from 2015 to 2020, measured through carbon intensity. Despite maintaining similar total numbers of sheep from 2015 to 2019, there was a notable 38% decrease in total greenhouse gas output for the Australian sheep flock. This achievement underscores the effectiveness of the Australian production system; this is particularly evident as there has been a slight increase in processed lamb and mutton output, as depicted in Figure 4. This outlines that improvement in efficiencies of our production systems can reduce emissions whilst ensuring we keep food supply.

Source of emissions	2005	2015	2016	2017	2018	2019	2020
Farm	141.86	78.71	58.92	55.97	64.57	50.71	47.18
Feedlot	2.53	2.55	2.41	2.45	2.63	2.81	2.98
Processing	1.42	1.34	1.15	1.15	1.21	1.23	1.09

Figure 5: Greenhouse gas emissions (Mt CO2-e) from farm, feedlot, and processing along the supply chain (Source: Ridoutt, B., 2023).

Source of emissions	2005	2015	2016	2017	2018	2019	2020
Cattle	125.83	71.98	56.55	55.81	61.46	48.19	45.21
Sheep meat	19.92	10.53	5.85	3.68	6.87	6.50	5.96
Goats	0.07	0.09	0.07	0.07	0.07	0.07	0.07

Figure 6: Contribution of beef cattle, sheep meat, and goats to greenhouse gas emissions (Mt CO2-e) from the Australian red meat sector (Source: Ridoutt, B., 2023).

The carbon intensity of the Australian sheep industry can vary depending on several factors, including farming practices, land management, and the entire supply chain. As seen from the breakdown of emissions in figure 3, carbon intensity is typically measured in terms of GHG emissions per unit of output of production, such as emissions per kilogram of meat or wool produced.

Total carbon output shows the total carbon emissions a business emits, from fuel, fertilizer, electricity, and animals (see figure 3). It is important to note that whilst carbon intensity is a directive of how efficient a production system is or how much wastage a system might have, it is total emissions output that faces social and legislative pressures from around the world. This is currently being used as a blunt political tool to reduce total emissions, which might not be the best outcome, if not accompanied by innovation and adaptation strategies. The average carbon footprint of lamb from cradle to farm gate is 14.2 kg CO2e per kg of live weight (LW). Country averages vary significantly, ranging from 6.0 kg CO2e per kg LW in New Zealand to 23.1 kg CO2e per kg LW in Spain (Mazzetto et al., 2021). The Australian sheep sustainability framework 2023 states Australia's average is 6.8 CO2e / kg LW. This shows that Australia is in a comparable position when it comes to efficiency of lamb production.

Focusing on carbon intensity initially might be a more effective way to improve production systems worldwide, as these practices can be implemented immediately, whereas adaptation and innovation strategies to reduce total on-farm emissions require a longer timeframe. Without further reducing sheep numbers to lower total emissions, the current best approach is to improve the carbon intensity of our production systems. However, this approach is not without complications. In some cases, improving the productivity of a sheep operation while reducing methane intensity can increase total net emissions (Gebbels et al., 2022). This trade-off highlights the challenge: reducing the flock size diminishes the protein available for human consumption, potentially harming food security.

This example demonstrates the complexities surrounding the balanced decision-making needed to navigate our way through this problem. One positive aspect is that it is a shared global issue, which was evident during travels through New Zealand, Ireland, the Netherlands, and the US, which all have methane reduction projects underway. The world is in an information accumulation stage, with all countries gathering data on current outputs from farm systems and animal performance. I will explore these efforts in more detail in the sections on carbon abatement and mitigation. By gaining an understanding of where your farm business sits within emission total output and emissions intensity, you can navigate toward the best strategies to improve the production system by aligning with government regulations, market access requirements, and productive and efficient on-farm practices.

Chapter 4: Market access

Why should farmers care? The establishment of the Paris Agreement, in December 2015, was the beginning of the international commitment to reduce emissions, inciting organisations to align themselves with carbon-neutral ambitions.

Although governments have a major role to play, initially, in 2016, of the 100 largest economies committing emissions targets, 69 were companies and 31 were countries, as stated in the Global Just Now report in 2016. Evidently, it has been companies and organisations that have been the initial trailblazers for change in this space. The drivers of change are not actually governments, but businesses, who are influencing market signals to move towards a low-carbon economy.

What is interesting is that when assessing emissions within any supply chain, farms always fall under an organization's scope 3 emissions (see figure 3). This focus has highlighted the typically segregated nature of the meat industry's supply chain. Now, for any organization to achieve its emissions reduction targets, it needs its scope 3 partners to collaborate. This is the first time I have seen a genuine pull-through effect in the supply chain, resulting in true alignment and shared goals.

Large organizations like Tyson Foods, the second-largest food processor in the US, and JBS, of comparable size, have committed to reaching net zero emissions. With most of their emissions coming from scope 3 (on-farm), there is a significant incentive to address the entire supply chain. Tyson Foods aims to achieve carbon neutrality across all operations by 2050, while JBS has set a target for 2040. Stated on both their websites. Initially, such commitments are viewed as market differentiation, like Coles' carbon-neutral beef and pork range, which is achieved through buying offsets. These retailers have sought to position themselves with a competitive edge in the market.

It is important here to explain offsetting and in-setting. Carbon in-setting involves implementing sustainable practices within an organisation's own operations or supply chain to reduce carbon emissions. Offsetting involves compensating for emissions externally through investment in carbon sequestration projects; that in turn provide carbon credits, allowing the organisation to emit emissions in another process and then claim neutrality.

Following on from the aforementioned Coles example, this entails going to the open carbon market and purchasing carbon credits from potentially offshore markets. This appears to be an economic decision, not an environmental one. This means that the economic premium for carbon-neutral beef is worth the extra cost of purchasing the credit.

This can sometimes mislead consumers into believing they are making an environmentally conscious choice when they are purchasing beef with the same carbon footprint as the steak next to it. There is some work to be done yet before the market can truly become carbon neutral within its own production system. Nonetheless, this provides a market indication of where we need to align, not only in remuneration incentives but also by hitting emissions reduction targets. There are positives to come out of this market development, with the market exploration of new technologies and on-farm practices being developed. Farm businesses can align with and access these developed markets by first understanding their production systems through a carbon calculator. Once they have this understanding, they need to demonstrate that they are leading in emissions efficiency to capitalize on these opportunities. It looks probable that the first adaptors may be able to extract a premium in these markets and this premium will become the market expectation in time. The crucial aspect here is that emissions are inherent in all production systems. Therefore, this necessitates an industry-wide approach. Currently, the focus is on carbon intensity. Corporations prioritize carbon intensity because they must continue selling products in the market. Carbon intensity serves as a metric to gauge the efficiency of production systems while awaiting the development of innovation and adaptation strategies.

Transition to a low carbon economy will require comprehensive transformation, taking time and capital. Following the capital upstream to its source, banks are starting to provide incentives. Banks are showing significant interest in aligning themselves with farms that are seen to be reducing emissions, improving landscapes and implementing sustainability goals. Both the Commonwealth Bank and National Australia Bank have released Agri green loans to support adaptations to a low carbon economy. It is no longer a time for environmental or political views, but rather, trying to align your business towards a strong economic future.

In saying this, according to Snapshot of Australia's Agriculture 2024 report, around 78% of Australia's agricultural products are exported, so we are accustomed to aligning with our overseas customers' expectations. Recently there have been some beneficial trade deals developed for Australian sheep meat, for example with the UK, where tariffs are to be eliminated after 10 years and provide a quota of 110,000 tonnes. (Department of Foreign Affairs and Trade 2023) Other major market developments include China, USA, Japan, and Indonesia who have all had long standing trade relationships with Australia.

Amidst global pressure to curb emissions, it's crucial to understand that the goal isn't to reduce emissions at any expense. It's encouraging to note that one of the key messages from 27th Conference of the Parties (COP27) in Egypt centred around food security. Incorporating this consideration into decision-making processes is vital when developing markets. Whilst we endeavour to transition to a low carbon economy, we need to ensure we do this in a measured way. This is where globalisation and policy are so important. Often the romantic narrative for environmental sustainability is to buy or source locally. This can be great for the individual family on any given weekend, however, when constant access to affordable food is viewed at a global scale, it does not always turn out to be the most efficient or achievable outcome.

Ensuring that the most efficient environment and resources are utilized to produce products at scale can lead to better environmental outcomes, while also feeding a larger portion of the world's population. During my travels, I encountered a term called "sustainable intensification." While this may appear contradictory at first glance, the benefits of intensification are evident. For instance, some meats, like lamb, require three times fewer emissions to produce per kilogram in certain regions. For example, New Zealand produces lamb at 6 kg CO_2e / kg LW compared to Spain's 23 kg CO_2e / kg LW. (Mazzetto et al., 2021).

So, there are some positives arising from this renewed focus on emissions, including a newfound appreciation for supply chain cohesion spanning from industry to capital markets. Where farm emissions fall under scope 3 emissions for processors, we are starting to see greater communication and understanding of the supply chain. There needs to be continued balanced thinking through this time of change, and governments need to set achievable parameters with a balanced focus on food security, productivity gains, and innovation in time horizons that are realistic and not too expensive. Then, businesses and industry need to drive innovation, adaptation, and implementation on the ground, which will flow through to farming systems.

Chapter 5: Farming systems – Legumes and finishing systems

Feed base is a key contributor to animal performance in a pasture-based system. Improving this can lead to a hugely efficient and profitable sheep enterprise. Legumes, such as clover or lucerne, are known for their high nutritional value, which contribute to sheep health and productivity. They do this because they are a rich source of protein whilst being highly digestible and palatable. Legumes, also have the ability to fix nitrogen from the atmosphere into the soil, which can improve soil health and help promote plant growth. (Flynn R & Idowu J., 2015).

Whilst in New Zealand, I met with Derrick Moot, a Professor from Lincoln University. Considering the carbon intensity aspect of the above discussion, we considered a more systems-based approach for the whole farm. Professor Moot detailed an 11-year study he led with Bog Roy station which transformed their farm into 14% of lucerne, specifically targeting a finishing system for their lambs. Figures 7 and 8 both show the transformational change of lambs weaned and growth rates from 2008 predevelopment to 2018 after the development of the lucerne area.

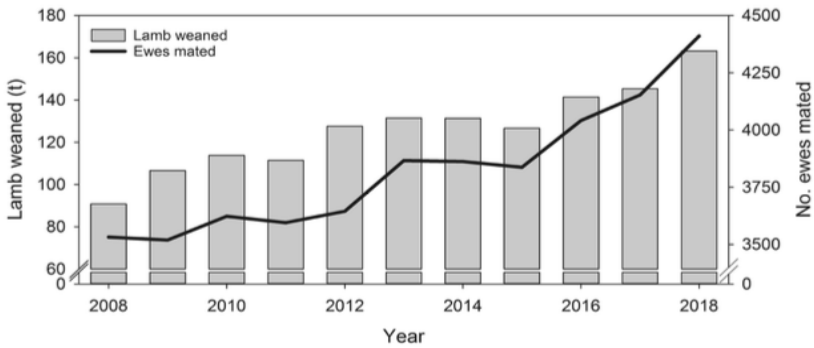


Figure 7: Change in Lambs weaned, and number of ewes mated Bog Roy Station 2008 – 2018 (Source: Moot et al., 2019).

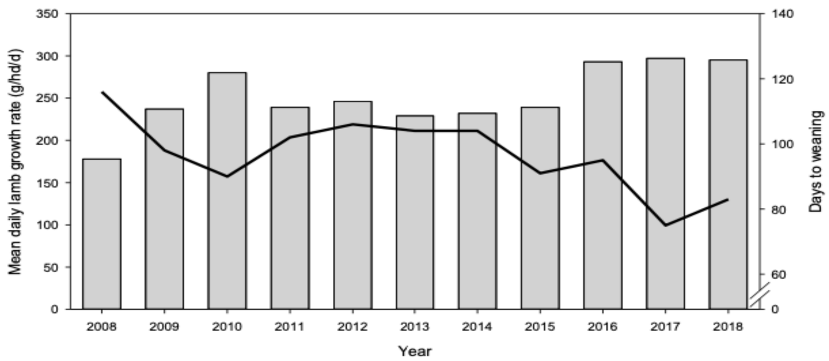


Figure 8: Change in pre-weaning lamb growth rates (g/hd/d) and time of weaning 2008 to 2018 at Bog Roy Station (Source: Moot et al., 2019).

This was a remarkable transformation for the Bog Roy station and shows how focusing on productivity gains has allowed them to produce more from the same amount of land, bringing the weaning age back 19 days and an increase of a total 40t on the dryland and 70t when including both dryland and irrigation.

Figure 9 shows that an increase in weaning rates, provides an almost equivalent

percentage reduction in the amount of carbon emissions for each lamb sold. Resulting in a 1% increase in total emissions for every 10% improvement of weaning rate over 100%.
Figure 9 outlines the data for a scenario of faster growth rates or reducing days to slaughter.

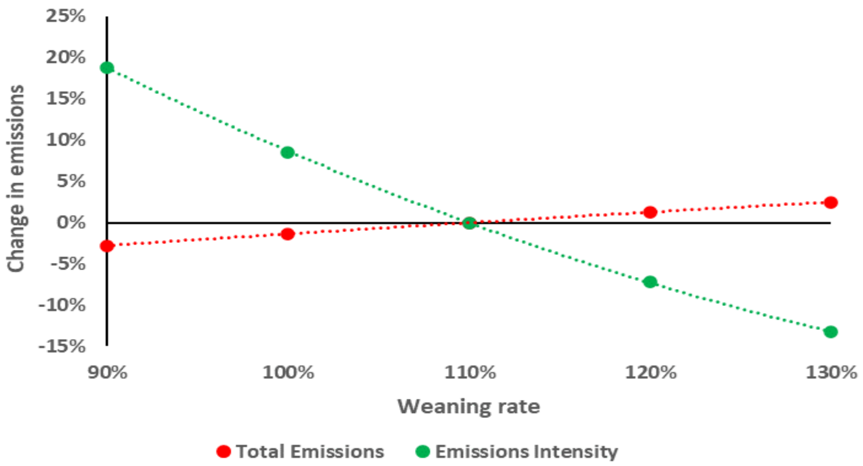


Figure 9: Faster growth rates or reducing days to slaughter (Source:McCormack, K., 2024).

McCormack, (2024) outlines in strategy 3 that improving growth rates or turning off lambs at 5kgs heavier, can improve your emissions intensity by 8%. The ultimate outcome would be to run fewer ewes, whilst maintaining the same kg of output.

This data was confirmed at the Teagasc research campus in Ireland, where PhD student Lisa McGrane conducted a growth rate trial. The trial aimed to determine if adding a legume or herb to perennial ryegrass could achieve shorter lamb finishing timeframes. The different types of forages included white clover, red clover, plantain, and chicory. Impressive preliminary results showed days to slaughter was reduced by 15.8-28.6 days with the addition of a companion forage. A closer examination showed that ryegrass/red clover was best for birth to weaning and ryegrass/chicory was best for weaning to slaughter, with both winning out respectively by 10g/day each. (McGrane et al., 2023). The red clover and ryegrass in total were 43 days less to slaughter compared to a straight ryegrass. This is an impressive result and reiterates the need for legumes in our pastures.

Figure 10: Teagasc research campus, Ireland (Source: author, 2022)

Legumes, such as clover, have been studied for their potential to mitigate enteric methane emissions in ruminant animals. Min et al., (2020), provides scope for how plant tannins affect microbiota in ruminants to reduce CH4 emissions. Methane, as stated earlier, is the most potent GHG and is the key challenge for the lamb industry when it comes to climate mitigation. Tannins can inhibit the activity of methanogens in the rumen, suppressing the total methane emitted. Several studies are currently underway to explore how this approach can be integrated into grazing systems. Implementing these forages can serve as a cost-effective method to reduce emissions while simultaneously supporting productivity gains, through increased growth rates and reduced time to reach finished weights. Consequently, this improves carbon intensity, productivity, and profitability.

What may appear a straightforward action, such as incorporating legumes into pasture systems or finishing systems, offers a triple win in terms of social, environmental, and financial outcomes. Taking a systems-based approach to a prime lamb operation, underpinned by legumes, will allow you to have a co-benefit of improving your carbon intensity, whilst improving profitability. Focusing on reproductive efficiency, lamb growth rates and reducing ewe numbers. Reducing ewe numbers can be counter intuitive, however, if achieved with accompanying the efficiency scenarios, will ensure building a more resilient prime lamb system.

Chapter 6: Carbon abatement & innovation

Generally, enteric methane from livestock makes up 70-95% of total emissions from a grazing operation, which is reaffirmed in Figure 3 above. (Wiedemann et al., 2022). This is arguably the livestock industry's greatest challenge and at this current time, there are no definitive solutions or quick fixes for reducing methane without reducing ewe numbers. While the initial strategies mentioned focus on increasing efficiencies within the production system as a crucial first step, it's also imperative to prioritize innovation and development. (Beauchemin et al., 2020), reviewed the history of research on rumen methanogens, where they analysed the key learnings and future challenges of methane abatement from published papers from the past 50 years.

It was found that there have been improvements over the past decades, due to efficiencies, however, this will not prevail as a reliable long-term solution due to the rising demand for protein around the world. Beauchemin et al., (2020), suggested, the future abatement may be achieved through animal genetics, vaccine development, early life programming of the rumen, diet formulation, use of alternative hydrogen sinks, chemical inhibitors and/or fermentation modifiers.

Furthermore, Beauchemin et al., (2020), found these strategies may only stimulate a reduction of 20-40% of emissions, therefore showing that there is need for a combination of whole number of systems and strategies to achieve the desired net zero.

This is supported by Harrison et al., (2021), who looked at carbon mitigation strategies, concluding that both emissions reduction and carbon sequestration would achieve the greatest net emissions mitigation. Harrison et al. go on to say that "the scientific community must shift attention away from the prevailing myopic lens on carbon, towards more holistic, systems based, multi-metric approaches that carefully consider the *raison d'etre* for livestock systems".

What these two studies reiterate is that there is no singular approach to such a complex system. Disrupting centuries of evolution requires time and ongoing research to develop and implement changes. The livestock industry will need to adopt a number of different tools to reach net zero. However, an immediate, tangible start is focusing on an efficient whole farm system.

Alcock et al., (2015), explores whole farm system intervention strategies that reduced GHG emissions for wool producing enterprises. Despite this research being wool focussed, the contents can be translated to lamb. Key interventions included selling animals at 18 weeks or 12 months, lambing time, joining age (7 Vs 19 months), increase in weaning rates, genetic improvement in fleece weight by 10%, feed efficiency and methane yield. (Alcock et al., 2015).

A summary of the results is presented in the table below, highlighting various interventions and their success in terms of percentage changes in profitability-focused attributes and emissions focussed. This reinforces the notion that emphasizing efficiency may lead to emissions reduction. However, according to the findings of Alcock et al., (2015), achieving equivalent profitability benefits required a $150 per ton CO_2 equivalent subsidy.

This suggests that solely prioritizing emissions reduction can negatively impact profitability.

Profitability:

Joining Age	18%	Flock management interventions
Weaning rate	15%	
Fleece weight	10%	

Reduced emissions:

Methane yield	-10%	Genetic improvements
Weaning rate	-8%	
Feed efficiency	-7%	
Fleece weight	-5%	

Figure 11: Profitability and reduction of methane (Source: Alcock et al., 2015).

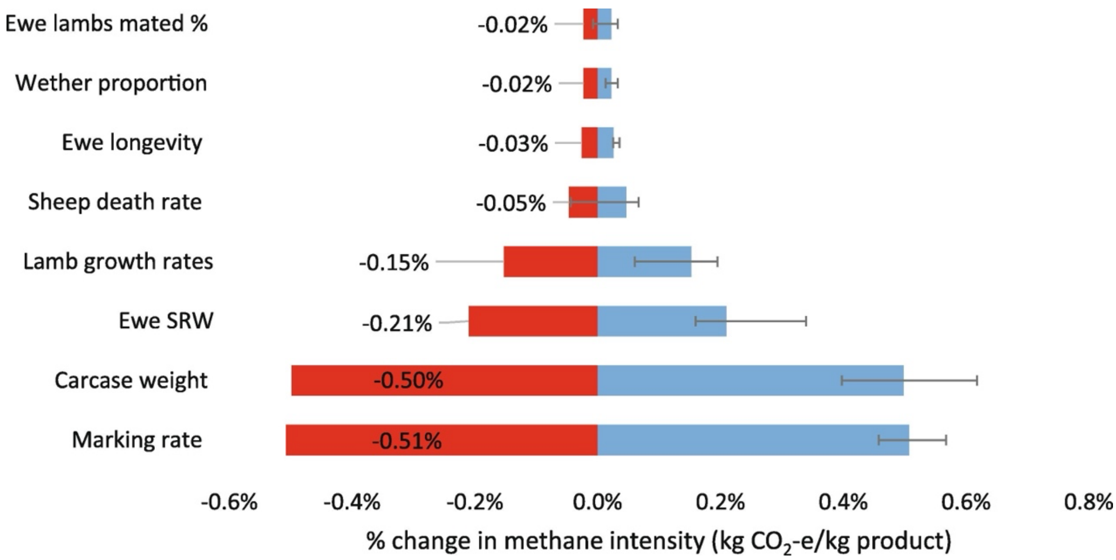


Figure 12: % change in methane intensity (Source: Gebbels, J, N., 2022)

While significant efforts have been invested in genetic selection, progress in this area tends to be gradual, typically advancing by only around 1% per year. Often what is missed is the ideal nutrition and animal health outcome needed to achieve the genetic potential of our animals.

Figure 12 provides a more updated look at the impact of sheep enterprise efficiency on methane emissions. Whilst increasing the efficiencies of the sheep enterprise and improves the carbon intensity, however, can in some cases, increase net emissions. There is a continued challenge in having animals that produce methane and whilst ensuring that our production systems are as efficient as possible, we still need to explore innovation and other interventions to support our transition.

Johnson et al., (2022) explores the genetic parameters for residual feed intake (RFI), methane emissions, and body composition in New Zealand maternal sheep. They found that the relationship between RFI and CH4 emissions were complex and although less feed eaten will lead to a lowered absolute amount of CH4 emitted, there was a negative phenotypic and genetic correlation between RFI and CH_4. This was also supported by Oddy et al., (2022), who outlined that portable accumulation chambers (PACs) can be used for genetic improvement and selection for GHG-efficient animals; however, PACs needs further work to increase their accuracy. Technologies used to capture methane measurements are elaborated upon in Figure 13.

The above shows that there is still a lot of research to be done to support accurate genetic traits. Initially, ensuring selection for flock efficiency will ensure working towards reduced emissions. These include moderate ewe adult weight, high fertility, high early growth rate, longevity or durability, age at first joining, health and nutrition.

Figure 13: Cow at Ellinbank research centre, Gippsland, Australia. Sheep Teagasc research program, Ireland (Source: author, 2022).

Figure 14 provides a snapshot of the mitigation methods that are considered when thinking about emissions reductions for animals. This figure reiterates the complexity of the system that we are trying to refine. As above, I have explored the factors that we have available at present for animal manipulation, and figure 14 describes the different technologies to reduce enteric methane emissions, with topics for animal manipulation, diet manipulation and rumen manipulation.

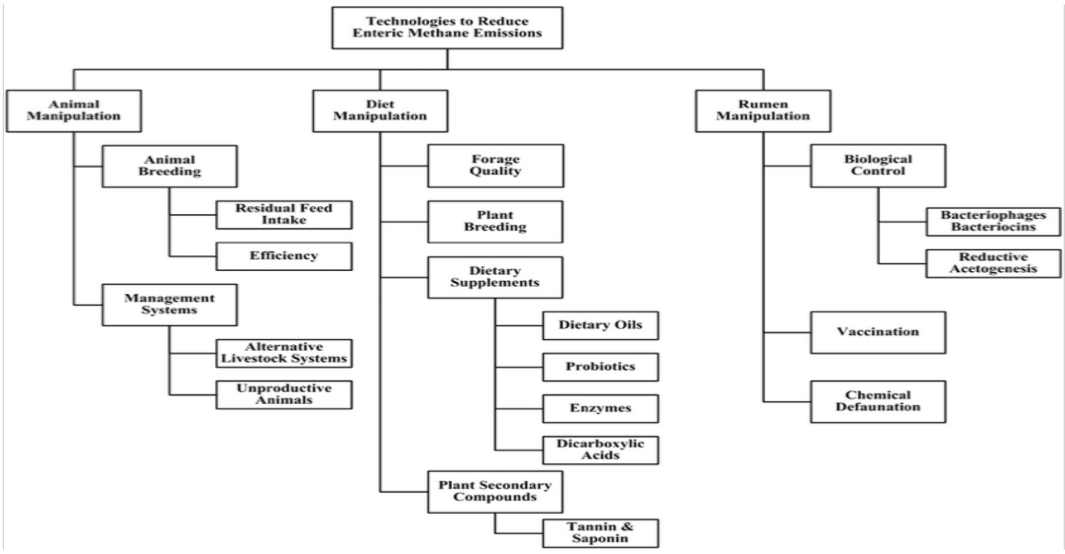


Figure 14: IPCC, Eckard 2010, Technologies to reduce enteric methane emissions (Source:Eckard et al., 2010).

6.1 Rumen manipulation

Rumen manipulation is in development currently and will be a key innovation to support reducing enteric methane in grazing systems. All methane mitigation can be defined as either animal manipulation (breeding efficiency, livestock system), rumen manipulation (vaccines and biological controls), or diet manipulation (dietary supplements and plant secondary compounds). (Eckard et al., 2010).

Rumin8 or bolus is the active compound in Asparagopsis (bromoform) used as a capsule and is in trials currently. Initial estimates are showing a 26-49% reduction in methane emissions in sheep. (De Bhowmick, G & Hayes, G., 2023).

6.2 Diet manipulation.

- Bovaer or 3NOP can reduce methane by 37-84% when 60-100mg of product is mixed into each kg of DM consumed. (Honan et al., (2019).
- Legumes contain oils, tannins, fats and other secondary plant compounds that inhibit methane production. When consistently included in diets, legumes can reduce methane 26pprox.. 30%. (Badgery et al., 2023).
- Fats and oils in the diet and reduces fermentation in the rumen, reduces methane and can increase liveweight gain. This can achieve around a 10-28% reduction of methane emissions. (Rasmussen et al., 2011).
- Mootral can reduce methane by 23-30% from 15g of product per day in cattle. Produced from garlic powder and citrus extract. (Roque et al., 2019).
- Asparagopsis is very well known; when dried it can reduce methane up to 80%. (Black et al., 2021).

Ongoing research is essential to identifying new and more efficient strategies for methane abatement. This includes exploring diet, rumen, and animal manipulation, as well as looking at the whole farm system to ensure the most efficient system is being executed. Some of these whole-farm systematic approaches include genetic selection, high-quality forages, grazing management, and achieving optimal animal performance.
It is important that a holistic approach is adopted when considering the different interactions between diet, genetics, and management practices. Such an approach is the most effective way to achieve sustainable methane abatement in sheep farming. Additionally, any intervention should be balanced to ensure that it does not compromise the overall health and productivity of the animal.

Moving on to the farm system, there is no doubt that the current tangible action for sheep producers is to implement new technologies and management strategies to ensure the most efficient system. Morgan-Davies, et al., (2021), explores this in more depth when analysing four different strategies based on farm labour input, farm profitability, and carbon footprint. These strategies include precision livestock farming (PLF) technologies, performance recording for higher genetic merit, artificial insemination (AI) for higher genetic merit, and the use of prolific breeds. Most of these approaches focus on the genetic selection of specific traits and shortening the generational interval. To advance PLF strategies, enhancing efficiencies through technologies such as walk-over weighing, pedigree matching via EID, temperature monitors, accelerometers, satellite imagery for pasture assessment, and feeding supplementation based on pasture availability will be crucial. Additionally, remote sensing of pastures and environmentally sensitive areas, along with virtual management systems, will become pivotal tools for effective grazing management.

In this study, Morgan-Davies, et al., (2021), helps to support the theme through this report, that improving efficiencies increases productivity and profitability. This builds resilience for farm businesses, not only regarding environmental resilience, but also by providing a larger capital base for increased adaptability in the future.

Focusing on implementing new technologies like those mentioned above, along with concentrating on two key performance indicators—reproduction rate and turn-off weight—will ensure maximum efficiency in a lamb operation. This will also enhance profitability and build resilience for a farm business to be able to adapt to future climatic challenges.

Until we have access to innovations that are currently being developed to reduce methane emittance of animals, increasing efficiencies within your farm business will put you into a competitive position to be agile when future technologies are released. Reductions in emissions are likely to be reliant on the development of new technologies and innovations, such as anti-methanogenic additives, improved forage quality, and genetic selection.

Chapter 7: Soil Carbon, biodiversity & land management

Soil carbon and land management are interconnected and plays a crucial role in the emissions conversation. In agriculture and environmental sustainability, soil carbon is said to be the saving grace for methane emissions, by sequestering carbon into the soil. With Australia's landscape being so vast and carbon levels being driven by rainfall, this is an unlikely panacea.

Meyer et al., (2018) state, that increasing soil organic carbon (SOC) can be difficult to retain consistently in Australia's climate. As noted above, most abatement methods will range 20-30%, whereas trees and soil have a large opportunity to do more than this. (Meyer et al., 2018).

As demonstrated by Doran-Browne et al., (2016), a property in South-West Victoria successfully reduced its emissions by 48% over a 14-year period.

Unfortunately, most of the sequestration of this property came from trees, and once trees have matured, their ability to be carbon neutral is reduced. There are many positives to having organic carbon in soils, such as improved soil structure, moisture retention, nutrient availability, and supported plant health.

Therefore, while planting trees and soil carbon sequestration are beneficial transitional methods, they cannot serve as the sole solutions for high stocking-rate farm systems. Due to its inherent fluctuations, carbon sequestration in soils represents an unstable method for balancing carbon within the farm environment.

The added benefits of animal health and biodiversity outcomes from strategic tree plantings must be mentioned, as it supports diverse microbial communities and beneficial organisms. This then contributes to nutrient cycling and pest control. These added benefits should be essential for improving grazing landscapes.
The best land management practices include reducing tillage, crop rotation, optimal rotational grazing, deep-rooted perennials, integrating tree plantations, and improving biodiversity.

Biodiversity is a relatively new concept in farming systems, and there are currently extensive projects under way to explore it. One notable example is the "Farming for the Future" project, run by the Macdoch Foundation's flagship program, which focuses on natural capital and biodiversity. Projects like these must be followed up with peer review once complete. To ensure credibility. There is huge scope to improve our biodiversity within our farming landscapes, and the first step is data accumulation to observe biodiversity and then what practices we can implement to improve it.

Soil carbon, tree plantings, and carbon credits are very important items when exploring emissions in the lamb industry, however, these could be individual Nuffield topics in themselves. I have purposely chosen not to explore these topics in-depth and instead focus on a system-based approach when thinking about emissions reduction. Ultimately, soil carbon and land management are interconnected, and the management of soil carbon is crucial for soil health, agricultural productivity, and climate change mitigation. One focus, when adopting any new practice in this area, is to ensure has peer reviewed scientific rigor to the adoption.

Sustainable land management practices can enhance soil health and improve natural capital, while supporting biodiversity and improving the overall productivity and profitability of agricultural land.

There is currently a revolution of biodiversity and ecosystem services, and with a large amount of financial capital being allocated to research, it is vital to start to get an understanding of measurements around biodiversity on our farms to ensure we continue to improve them over time while safeguarding our natural farm systems.

Conclusions

> "*To prepare adequately for the challenge of global warming, we must acknowledge both the good and the bad that it will bring. If our starting point is to prove that Armageddon is on its way, we will not consider all the evidence, and will not identify the smartest policy choices*". (Bjorn Lomborg, 2020).

This statement captures the direction, I believe some government planning around the World have taken. There is no doubt from the science that we need to move to a low-carbon economy. Whether you believe this or not, we are seeing strong demand from supply chains, capital markets and governments. There is a precarious global challenge to balance reducing emissions whilst maintaining food security. As per the example of Sri Lanka, there are some strong market incentives and government regulation have come at the cost of food security. There have been unrealistic timeframes put in place for emissions reduction targets rather than allowing time for innovation or adoption of new practices. Other circumstances have had incentives developed to create carbon credits that pay more than food production, resulting in prime agricultural land being used to plant trees, seen in New Zealand. These are some examples of what I think is government focusing on short term goals and incentives and in the process having influenced the wrong outcome. This is a very blunt tool, top-down approach to reducing emissions, however, it doesn't need to be a zero-sum game.

Farmers and policy makers should consider climate adaptation, as a win-win, through investing innovation, adaptation strategies and ensuring adequate timeframes. This viewpoint inherently means bigger investment and focus on research, entrepreneurship and incorporating balanced efficiencies in the farm system and adoption of new practices. Governments should set the parameters for more competition, innovation, and open markets at the policy level and then allow the market to adapt and flourish. Emissions reduction targets help to achieve feedback loops and transparency in our supply chain, enabling us to implement the most efficient practices on farm, tailored to our climatic parameters without damaging the natural system.

Emissions in lamb production, will be one of our generation's greatest challenges. Implementing supportive and balanced policies that capture emissions-reducing practices while enhancing productivity will lay the foundation for positive change in our industry. Through smart, supportive global policy we are able to improve the efficiencies of our farming systems to reduce our carbon intensity. As seen in the US, bringing capital allocation to the agricultural sector for the adoption of innovation and change towards a lower carbon economy, has also allowed the country to support continuous productivity and an open mind to adoption of new processes and most importantly buy-in from people on the ground. This is an example of how leadership can assist in building trust from government to producer, we can work towards a low carbon food supply chain that will increase food security and improve the environmental, economic, and social well-being of all involved. To ensure this does in fact last, it is essential that our markets mature into alignment along the entire supply chain, end uses demand more information of emissions footprints.

More-over, if we can rigorously examine our farming systems and benchmark emissions and financial output, we can then work towards optimization. This process is underpinned by understanding the carbon intensity of our farming systems and the full supply chain. Benchmarking your farm's emissions will support building a competitive advantage for your farm business. Once business operators have a benchmark, they can draw on those numbers to focus on the biggest contributors, such as weaning rate, growth rate, ewe standard reference weight, mortality and early maturing. Bog Roy's case study provides a great example of integrating a legume finishing system to increase growth rates and therefore reduce emissions intensity.

Whilst emissions specific Innovations are still in an infant stage there is great promise in products such as 3NoP, Asparagopsis. This is an evolving sector that is exciting and in the stages of refinement before they can be commercially applied.

By having a shared problem approach, will set the foundation for buy in along the whole supply chain. The Australian lamb industry has come a long way in the past 20 years, but through market development, supply chain maturity and on-farm innovation, there is a huge opportunity for it to now evolve into a low carbon, high productivity, global leader.

Recommendations

- Governments to invest in transition, adaptation, and innovation strategies for emissions reductions, whilst maintaining a focus on enabling agricultural productivity and open markets. Not emissions reduction at all costs.
- Build transparency and shared goals along the supply chain.
- Know you farm business's carbon intensity number and work towards optimisation. Benchmark your farm for carbon emissions using the free Melbourne University Sheep and Beef GHG accounting framework.
- Invest heavily in research and development for methane reduction in animals.
- Invest in research focussed on optimisation of whole farm lamb finishing systems. Underpinned by legumes and sheep genetic improvement.
- Further exploration is needed into methane inhibitors for grazing systems and restoring and enhancing biodiversity on farms.
- Further study around adaptive business models to take advantage of adapting climate variability.

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