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The findings and opinions expressed in this document are those of the authors.

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Abstract

Evaluating the benefits of publicly funded research is always a challenging task. This paper cannot produce air-tight quantification of the benefits of Sustainable Land Management and Climate Change (SLMACC) research. We do, however, demonstrate the key building blocks of significant impact have been obtained. First, it is clear that public funding has contributed importantly to New Zealand's positioning itself as one of the leading global contributors to agricultural mitigation research. Second, the prominence of the research combined with the low likelihood of research occurring on this scale without public support suggests strongly that the results would not have been obtained absent public funding. Finally, though the realization of ultimate environmental and/or economic benefits will depend on the evolution of farming practices and climate change policy settings, the advances in genetic markers for low CH4 animals and identification of emission-reducing management practices have the potential for GHG emission reductions that would be significant in environmental terms, and whose value at likely carbon pricing levels would be in the hundreds of millions of dollars. Although the results discussed are conditional on several factors such as future policy implementation, adoption rates and the practical availability of mitigation options and practices for different farm landscapes; the impacts, economic and environmental values attached to mitigation research cannot be overlooked and provide important insights to the benefits that public investments can make to the development of a more sustainable agricultural system for the country.

JEL codes

Q15; Q16; Q51; Q54

Keywords

Agricultural greenhouse gas mitigation; public funding analysis, science policy, climate change

Summary haiku

GHG research

has significant impact.

Public funds do help

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Tables and Figures

1 Executive Summary

A common way to evaluate publicly funded investments in a range of different contexts is given by cost-benefit analysis (CBA) and similar techniques. However, **benefits arising from public research can be difficult to quantify** because of long and variable lags, and the complexity of causal chains from research to benefits. **In addition, the aim of publicly funded research is generally to provide insight into or solve issues that in many cases have economic values that are difficult to monetise or simply cannot be monetised** (e.g. the value of existence of a species) These result in significant benefits that cannot be incorporated directly into a narrow economic CBA. Considering this, **in this paper we move from CBA analysis and provide a broader analysis of the impacts of and value from agricultural mitigation research in New Zealand, with a focus on two particular projects.**

Hence, this study has two main objectives:

1. to provide a general analysis of scientific trends of international agricultural mitigation research in order to compare New Zealand with the rest of the world in terms of number of scientific publications and citations; and
2. to evaluate the impact and value generated by two publicly funded agricultural mitigation research projects in New Zealand – specifically, two agricultural mitigation research projects funded by the Sustainable Land Management and Climate Change (SLMACC) Research Programme from the Ministry for Primary Industries (MPI).

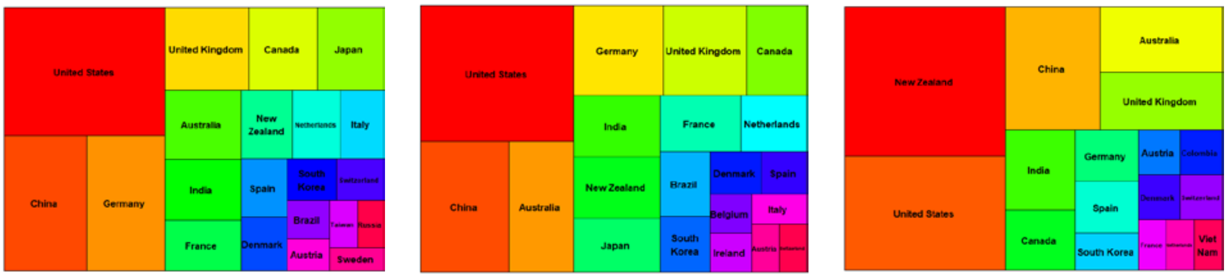
In addressing these two objectives, we directly complement the work done by van der Weerden et al. (2018), which provides a broader review of all agricultural mitigation projects funded by the SLMACC projects during the last ten years.

To address the first objective, we use data from Scopus (one of the largest repositories of scientific papers in the world) to analyse trends in publications and citations from the field of agricultural mitigation across countries and over time. To explore the second objective, we also use data generated from Scopus as well as from various research reports and papers. In addition, we incorporate insights retrieved from direct communication with the researchers and stakeholders involved.

1.1 Results from New Zealand's Impact on International Scientific Outputs and Citations

For objective one, we subdivided the agricultural mitigation science into five main research clusters: (1) Methane, (CH_4) inhibitors/vaccine, (2) Low GHG animals, (3) Low GHG feed, (4) Reduced nitrous oxide (N_2O) from soil/plants, and (5) Management interventions.[1] Considering these clusters, we performed a search in Scopus using key words provided by experts in the area. Data from Scopus **show countries with the largest scientific influence in terms of publications around the world, with New Zealand appearing within the top ten countries across the five research clusters** (Figure 1 to 5 in main manuscript). This leading presence is especially remarkable for the cluster "**Reduced N_2O from soil/plants", for which New Zealand is the leading country in the world in terms of scientific outputs** (Figure 5). Figure E 1 exemplifies these findings from three clusters.

Figure E 1: Countries relevance on clusters (from left to right) Methane inhibitors/vaccines, Low GHG animals, and Reduced N_2O from soil/plants. For more details, see Figures 1–5 in the main manuscript.



When disaggregating the country level data to research organisations, **we found New Zealand research organisations among the most influential worldwide in the five clusters**. Specifically, we found **AgResearch** as the organisation producing the largest quantity of research outputs in three out of the five clusters, while **Landcare Research, Dairy NZ, Lincoln University, and the University of Waikato** are also listed within the top 20 most relevant research organisations for the cluster "Reduced N_2O from soil/plants". For more details see Figure 3 to Figure 7.

Finally, in terms of citations, we contrast New Zealand's scientific impact with that of Australia and the rest of the world. We find that in general **New Zealand's impact (in the form of citations made to papers published in scientific journals) is increasing over time**, with the cluster "Reduced N_2O from soil/plants" having a notably higher citation rate than those of Australia and the rest of the world. For more details see Figure 8 in the main manuscript.

[1] See van der Weerden et al. (2018) for a detailed definition of these clusters. In simple words, they refer to science looking at: (1) options to reduce the generation of methane in the rumen of animals, (2) options to breed animals that produce less methane emissions in a natural way, (3) animal feed that helps having animal digestion emitting less GHG, (4) options to reduce or capture emissions from plants (study of plants better able to capture Nitrogen, for example) and soil (after animal excretion, for example), and (5) farm practices that could reduce overall farm emissions (for instance practices that improve fertiliser management or animal health).

1.2 Results from Value and Impact Analysis of Two SLMACC Projects

We performed impacts and value analysis of one "Low GHG animals" project and one "Management interventions" project. These projects are:

1. Project 1: Sheep, cattle, and methane predictors – MPI code: METH0901
2. Project 2: Farm management and GHG for the pastoral sector (also named: Systems analysis to quantify the role of farm management in GHG emissions and sinks for the pastoral sector) – MPI code: C10X0902.

More details of the technical contribution of these projects are summarised in section 6.1. In simple terms, Project 1 focused on advanced evidence to identify a trait in ruminants (especially sheep) to naturally reduce the amount of methane they generate; Project 2 created and improved different models to better predict and understand the linkage of several farming practices to GHG emissions.

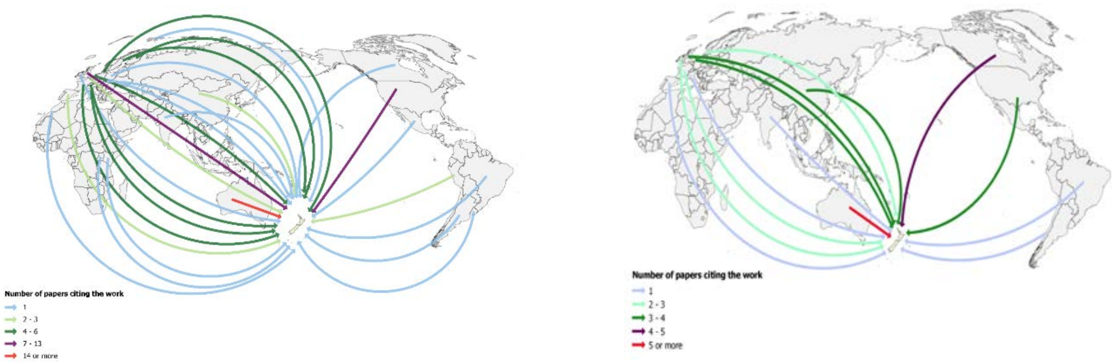
1.2.1 Impact Analysis

We looked at the impacts on science and on stakeholders. In science, impact is related to the influence of a project's generated knowledge, which is commonly assessed by its number of publications, the quality of the journal of publication, and the number (and significance) of citations accrued in a particular period. On the other hand, the impact on stakeholders relates to the changes that the research project produced in next- or end-users. Thus, if research output(s) generates change in practices or influences decision-making, then stakeholder impact is generated.

For science impacts, **we found that Project 1 produced a peer-reviewed paper that accrued a very high number of citations over time** (Pinares-Patino, 2013). After standardising the paper's citations by discipline, publication year, and publication type (using the Scopus field-weighted citation index [FWCI]) the citation impact of Pinares-Patino (2013) **was 11 times higher than that of the average paper worldwide**. This value shows a very high scientific impact produced by this paper, which has received interest not from just New Zealand researchers but from organisations across **29 different countries**, as seen in Figure E 2.

On the other hand, **Project 2 produced six peer-reviewed papers acknowledging the SLMACC Programme as their funding source**. All these papers have been published in high-impact journals, as seen in Appendix Table D. From these papers, **Beukes et al. (2011) has received the largest number of citations**. This paper's FWCI reveals that **its citation impact has been four times higher than that of the average paper worldwide**. This value shows a high impact produced by Beukes et al. (2011), which has received citations from **15 different countries**, as also seen in Figure E 2.

Figure E 2: Country of origin of affiliations from authors citing Pinares-Patino (2013; left) and Beukes et al. (2011; right). Colours show the number of citations, with orange and purple arrows showing the largest numbers and light blue the lowest. (For better resolution, see Figure 16 and Figure 17 in the main manuscript.)



With respect to stakeholder impact, it is important to differentiate the impact generated in next-users and in end-users. While the former refers to other researchers and organisations, the latter refers to farmers.

Next-users' impacts: **Both projects contributed importantly to build the foundations for further development of research**. Project 1 provided researchers with basic key information for selecting low-emission animals. It generated **data that was important to advance this area of research, which is now close to developing a formal mitigation option** in the form of low-emission sheep. Project 2's modelling and results have provided a **better understanding for addressing GHG emissions from available farm practices** (management interventions), which was less clear before.

End-users' impacts: For both projects, the **impact on end-users at this point in time is still negligible**. This is mainly due to the lack of incentives for farmers to address GHG emissions on-farm. While low-emission sheep are close to becoming a formal tool to reduce GHG emissions, and the farming practices studied in Project 2 can be enhanced to reduce emissions on-farm, the extent of their adoption in the short-to-medium term is still unclear given the uncertain policy framework to curb biological emissions in New Zealand.

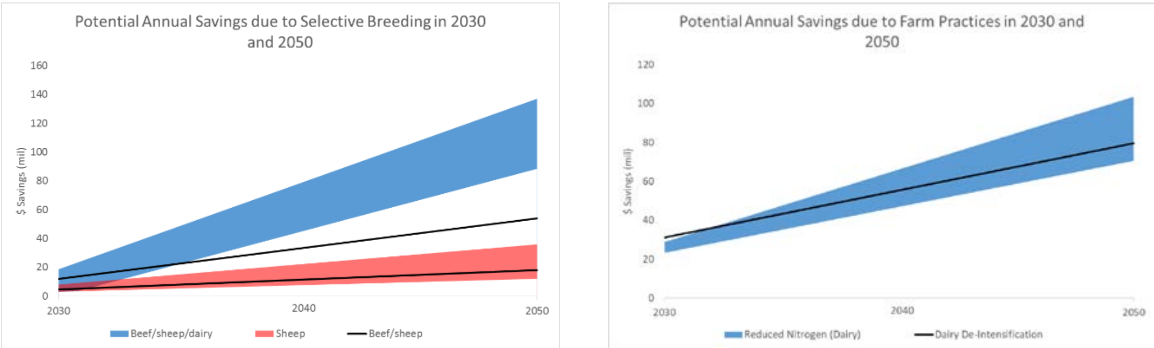
1.2.2 Value Analysis

For this evaluation, we **estimate the *potential economic use value* of the realisation of the products (the mitigation option/practices) that the SLMACC projects have helped to build, assuming a future carbon price imposed on agricultural emissions**. Thus, we base our estimates on recent modelling conducted in New Zealand of low-emitting animals (e.g. selective breeding, a mitigation option related to Project 1), and reduced nitrogen use and dairy de-intensification (practices related to Project 2). These emission reduction potentials, and their related assumptions, are modelled and described in Reisinger and Clark (2016) and in recent NZAGRC modelling (Reisinger et al. (2018).

Assuming emission prices at the level of $31.17 per ton of CO_2eq in 2030 and $44.23 in 2050, for selective breeding (Project 1) **we estimate potential savings that farmers might accumulate from using low-emission sheep in their flock between 2030 and 2050 could be between $159 and $462 million** (the orange area in the left-hand side chart of Figure E 3). This equates to **$561–1,630 potential savings per farm per year** – assuming no change in the number of farms post-2012 – or **$5.70–19.30 per sheep**. If expanded to the beef and dairy sectors, the **total annual savings to New Zealand by 2050 could be four to seven times greater** than the savings considering sheep only (area denoted in blue in LHS of Figure E 3). Also, if the price on emissions increase to, say, $100 per ton of CO_2eq by 2050, the **savings would be between $13 and $44 per sheep**.

Assuming similar emission price trends, for Project 2 we estimated that potential cumulative savings over the period from 2030 to 2050 could be **between $984 and $1,389 million for dairy de-intensification** (blue area in RHS chart of Figure E 3) and **$1,163 million for the reduction of nitrogen inputs**. Assuming the number of dairy cattle farms in New Zealand in 2012 remains static (12,150), this could mean an average saving of $3,858–5,446 per farm per year for reduced nitrogen inputs and of $4,559 per farm for dairy de-intensification – assuming no change in the number of farms over years. Alternatively, considering projections in the number of dairy cows to 2050, the value would amount to $108–180 per cow for reduction in nitrogen and $127–151 per cow for de-intensification over the 21-year period.

Figure E 3: Potential savings from mitigation-related technologies from Project 1 (left) and Project 2 (right). Value estimates are obtained by considering the modelling output for the "Low GHG animals (selective breeding)" and "Reduced nitrogen and dairy de-intensification" options as shown in the reports of Reisinger and Clark (2016) and Reisinger et al. (2018).



In terms of environmental values, if monetisation of the benefits of mitigation is not desired, they can be characterised simply in terms of the physical reductions in emissions. The ranges of avoided annual emissions by 2050 are predicted to be around 273–3,100 and 3,393–3,140 kt CO2-eq, for Projects 1 and 2, respectively.[2] Although these amounts are a tiny fraction of all New Zealand emissions, let alone the world's, the difference could be more substantial if extended to other countries with similar pastoral-based livestock systems, i.e. if New Zealand research was taken up by farmers internationally.

These results should be considered together with the assumptions used (see Appendix Table E for details) and also the reality that farmers might face **barriers to the adoption** of these options/practices, **including skills that might be needed to apply them in various contexts**. Abstracting from these, although for Project 2 the GHG reduction potential is more limited to the New Zealand context, for Project 1 a low-emission sheep could be introduced in different farming systems across the world. In the ideal scenario of full adoption of these animals across the globe, this would mean a potential reduction of up to 425 billion tonnes of CO_2eq in a year, which is around five times all New Zealand's gross CO_2eq emissions in 2013.

Finally, it is important to mention that the development of both low-emission animals and the linkage of management practices to lower emissions discussed here have been result of the coordinated efforts of several organisations and research projects, as briefly summarised in section 5. This means that it **is not possible to attribute the whole estimated economic and environmental values to a particular entity such as the SLMACC Programme**. However, it

[2] Ranges from various scenarios and assumptions as shown in Appendix Table E. The range for Project 2 assumes both reduction in nitrogen inputs and dairy de-intensification are adopted and that the resulting emission reductions are cumulative.

can be argued that an important part of the **potential values shown here are envisioned because of the contribution from the SLMACC Programme**.

1.3 Concluding Remarks

Evaluating the benefits of publicly funded research is always a challenging task because of the long and uncertain lags between research and impact, the conditionality of impact on external factors, the difficulty of quantifying non-economic benefits, and the difficulty of knowing how possible impacts differ from the counterfactual of no public research. The current analysis faces all these challenges, and so we cannot produce air-tight quantification of the benefits of SLMACC research. We have, however, demonstrated that the key building blocks of significant impact have been achieved.

- First, it is clear that public funding has contributed importantly to New Zealand's positioning itself as one of the leading global contributors to agricultural mitigation research. While this is not sufficient to prove significant broader benefits, it is certainly a necessary condition and a major accomplishment in and of itself.
- Second, the prominence of the research combined with the low likelihood of research occurring on this scale without public support suggests strongly that the results have been obtained as a result of public funding.
- Finally, the advances in genetic markers for low CH_4 animals and identification of emission-reducing management practices have the *potential* for GHG emission reductions that would be significant in environmental terms, and whose value at likely carbon pricing levels would be in the hundreds of millions of dollars. However, the realisation of ultimate environmental and/or economic benefits will depend on the evolution of farming practices and climate change policy settings.

We show and discuss in this work that with a potential future regulation of agricultural emissions, the use of on-farm mitigation options can generate important economic savings for the agricultural sector and importantly reduce the carbon footprint of farms. The results discussed are conditional on several factors, such as future policy implementation, adoption rates, and the practical availability of mitigation options and practices for different farm landscapes. At the same time, the impacts and economic and environmental values attached to mitigation research cannot be overlooked and provide important insights to the benefits that public investments can make to the development of a more sustainable agricultural system for the country.

2 Introduction

New Zealand is the only country in the Organisation for Economic Co-operation and Development (OECD) where agriculture is the main contributor to the gross domestic product and the largest contributor to exports. National wellbeing is therefore quite dependent on the performance of its farms across the landscape. Within New Zealand agriculture, "dairy" and "sheep and beef" farm systems are the largest sectors in the industry, placing the country in the top producers of beef and dairy products worldwide. As a consequence of being a main contributor to the national economy, animal and pastoral sciences are the focus of large government resources to support research and innovation in these areas, including the mitigation of agricultural greenhouse gas (GHG) emissions.

Due to public and political concerns, climate change has emerged as an important topic for research worldwide, including agricultural science research. A simple analysis conducted using the academic search engine Scopus shows that published articles obtained by searching for "agriculture and climate change" have increased in the last fifteen years from 132 articles published worldwide in 2000 to 1,757 in 2015.[3] Within this field of research, in line with the importance of the agricultural industry for its national economy, New Zealand ranks as one of the top countries producing agricultural mitigation research, playing an important role in scientific research on biological GHG emissions (Knapp et al., 2014).

In this paper we compare the contribution of New Zealand in terms of scientific outputs (number of scientific publications) in the area of agricultural mitigation with the rest of the world, which shows how a small economy can make significant contributions to a globally important line of research. We also describe the main funding mechanisms supporting this research area, where public funding mechanisms have played an important role for the development of the country's agricultural mitigation research portfolio.

Finally, given the relative importance of public funding in the research focused on agricultural GHG mitigations in New Zealand, we evaluate the impacts and value of two research projects. Both are funded by the Sustainable Land Management and Climate Change (SLMACC) Programme, administered by the Ministry for Primary Industries (MPI), one of the main public sources of applied research funding in New Zealand.

The remainder of this paper is structured as follows:

- Section 2 takes a broad look at the international literature on agricultural mitigation options by analysing Scopus data on publications and citations across countries and over time.

[3] Scopus is a search engine from Elsevier that captures most peer-reviewed research published worldwide. For more details see https://www.scopus.com

- Section 3 scales down the world analysis to New Zealand, one of the most influential countries in the world in terms of this research, by introducing its main funding mechanisms for agricultural mitigation science projects.
- Section 4 briefly discusses the interconnections between economic values and publicly funded research and introduces a framework to evaluate the impact and value that research projects can have. We also describe our data methods and case study.
- Sections 5 and 6 analyse the impacts and value generated by our selected two SLMACC agricultural mitigation projects.
- Section 7 discusses the findings and concludes.

3 The International Agricultural GHG Mitigation Science

Animal production in agriculture represented approximately 10% of the total world GHG emitted in 2013.[4] Given this fact and the increasing public and political concern about climate change, the study of options to mitigate agricultural GHG emissions has grown considerably in the last 15 years. In order to better understand what this has meant in terms of publications and the citation impact of countries around the world, we use the platform Scopus – one of the largest international repositories of scientific papers – to extract and analyse publication data. We do this to contextualise the science outputs across the world and compare this with the research produced in New Zealand.

To conduct this analysis, data on all publications recorded in Scopus was retrieved during June 2018. The publications were captured for five main agricultural mitigation research clusters that encompass the broad range of science in this field. These research clusters are:

1. CH_4 inhibitors/vaccine,
2. Low GHG animals,
3. Low GHG feed,
4. Reduced N_2O from soil/plants,
5. Management interventions.

These clusters are described in detail in van der Weerden et al. (2018), but in general they refer to science looking at, respectively:

1. Options to reduce the generation of methane in the rumen of animals,
2. Options to breed animals that produce less methane emissions in a natural way,
3. Animal feed that fosters lower-emission animal digestion,

[4] www.c2es.org/content/international-emissions

4. Options to reduce or capture emissions from plants (study of plants better able to capture nitrogen, for example) and soil (after animal excretion, for example),
5. Farm practices that could reduce overall farm emissions (for instance practices that improve fertiliser management or animal health).

The papers for each of the five clusters were retrieved by searching the Scopus database in relation to specific word combinations in the title, abstract, or key words – the specific search queries used for each cluster are listed in Appendix Table A. The data retrieved included year of publication, journal title, number of citations, and information on the authors and their affiliations and countries.

After retrieving these data, we analysed the publications and citation impact for the five agricultural mitigation science clusters. The results of this analysis are presented in the following section. It is important to note that the analyses were performed with data that included papers from a wide range of journals and that do not necessarily focus specifically on technical aspects of agricultural GHG mitigation science but rather on broader scientific areas, and multidisciplinary outlets, relating to the different agricultural GHG mitigation clusters.

The tree maps in Figure 1 to Figure 5 show how different countries have contributed to the total number of publications across clusters.[5] As it could be expected, in most cases the United States is the country with the largest proportion, representing its dominant role in research across agricultural science. However, an important exception is the world-leading role that New Zealand appears to have for the cluster “Reduced N_2O from soil/plants”, as shown in Figure 5. In this category, New Zealand has the leading number of publications with at least one author from the country.

As seen in Figure 1 to Figure 5, New Zealand makes a relatively large contribution of publications compared to the rest of the world; its research contribution is always within the red and green boxes. This is remarkable considering that the treemaps drawn do not incorporate any per capita adjustments. Therefore, despite its relatively small size and population, New Zealand appears to have a world-leading role in agricultural GHG mitigation research even compared with much larger economies, such as the United States, China, Germany, and the United Kingdom. If we compare New Zealand to other countries with a similar population size, such as Ireland or Denmark, New Zealand’s contribution is greater in all cases.

[5] Data includes papers from 1997–2017. The size of the boxes reflects the number of publications within the cluster with at least one author from the respective country. Publications with authors from multiple countries are counted in multiple boxes.

Figure 1: Countries' share of publications in the "CH_4 inhibitors/vaccine" cluster. [Shares based on data from top 20 countries = 811 papers. Publications with researcher(s) from other countries = 133.]

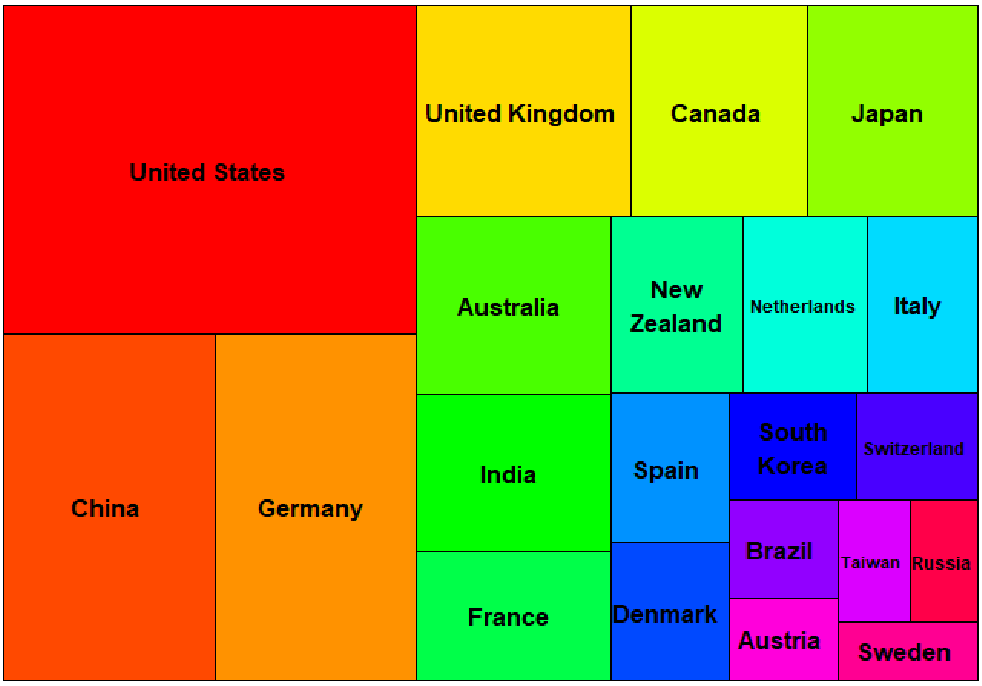


Figure 2: Countries' share of publications in the "Low GHG animals" cluster. [Shares based on data from top 20 countries = 701 papers. Publications with researcher(s) from other countries = 171.]

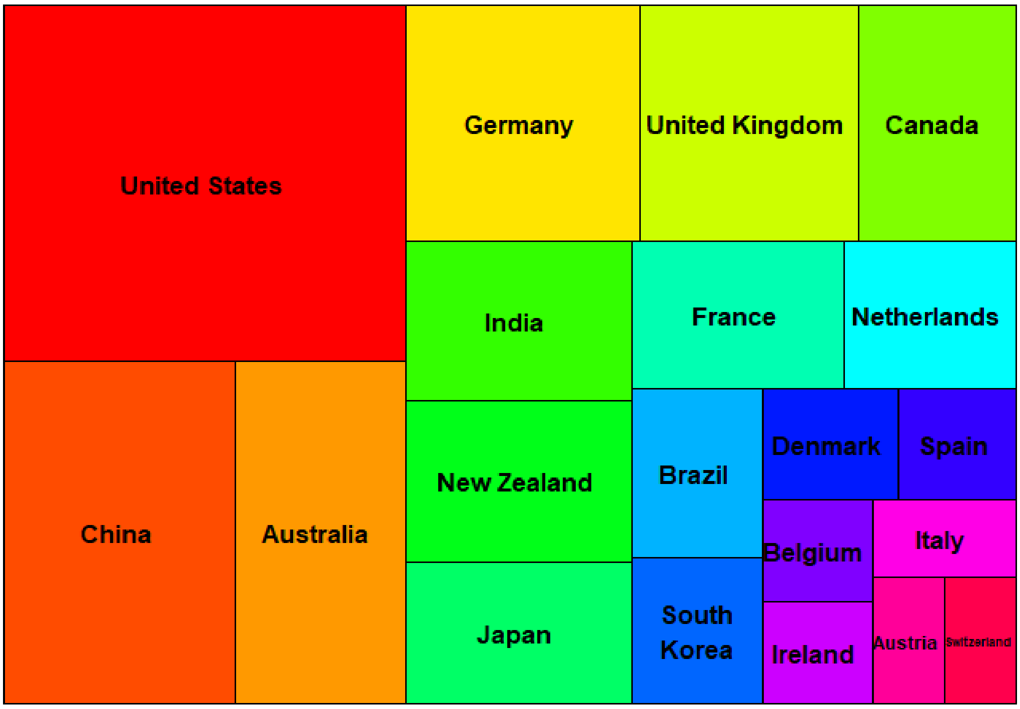


Figure 3: Countries' share of publications in the "Low GHG feed" cluster. [Shares based on data from top 20 countries = 746 papers. Publications with researcher(s) from other countries = 177.]

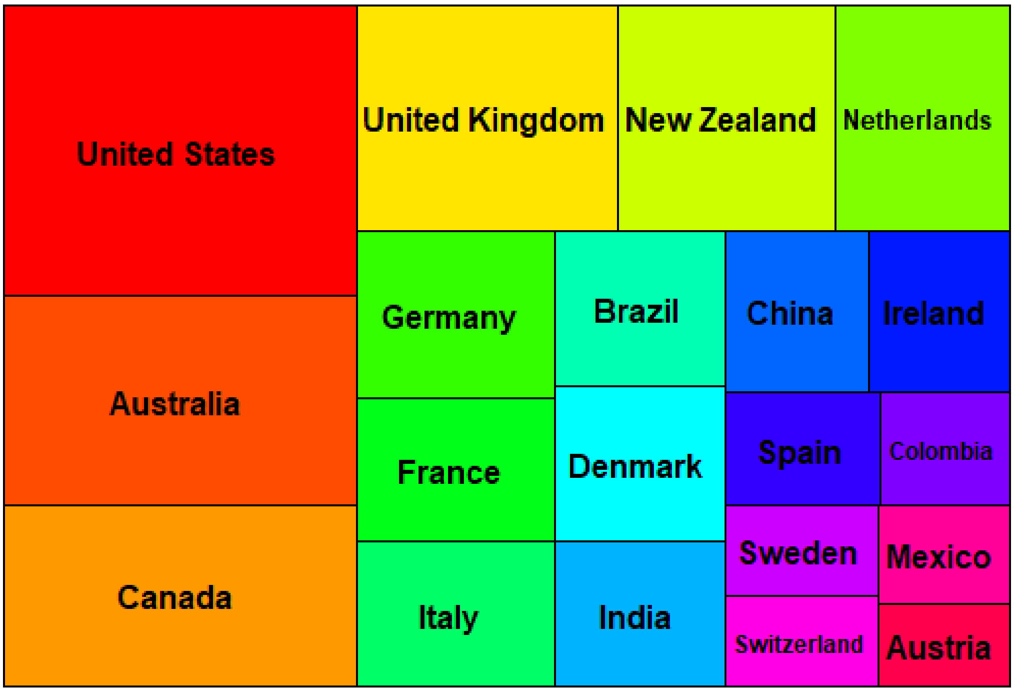


Figure 4: Countries' share of publications in the "Management interventions" cluster. [Shares based on data from top 20 countries = 2,060 papers. Publications with researcher(s) from other countries = 464.]

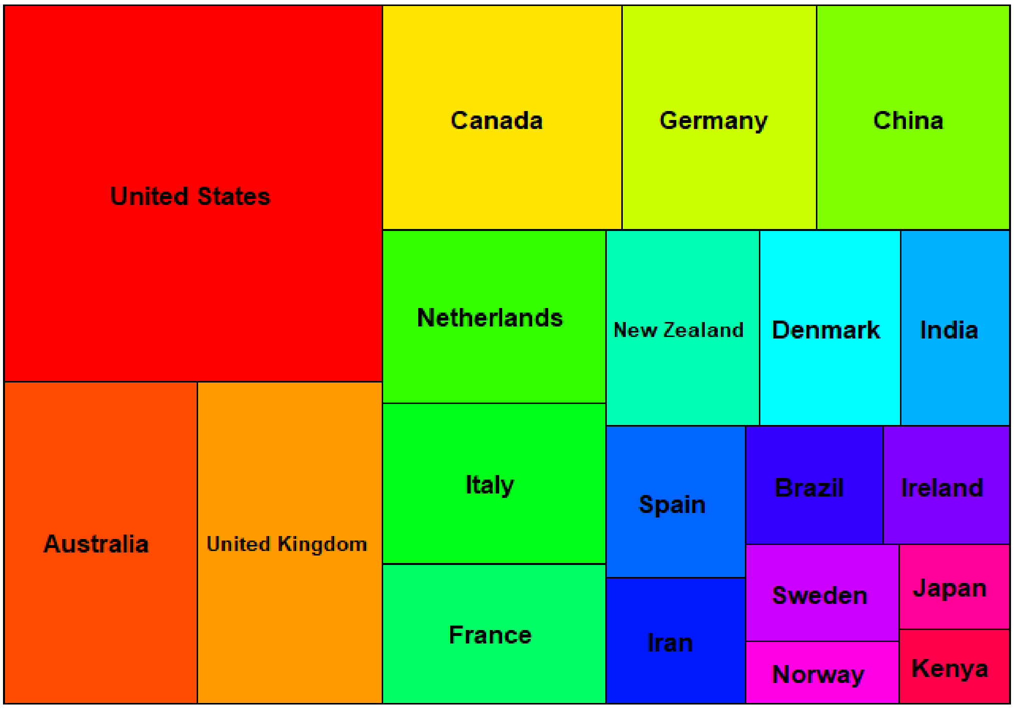
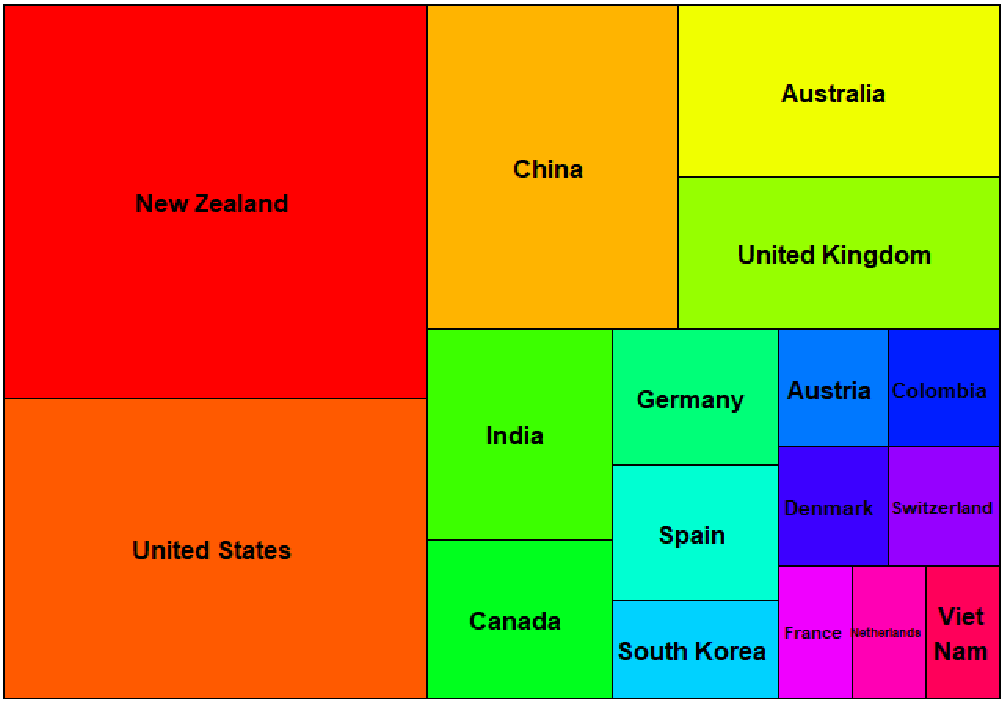


Figure 5: Countries' share of publications in the "Reduced N_2O from soil/plants" cluster. [Shares based on data from top 17 countries = 212 papers. Publications with researcher(s) from other countries = 43.]



3.1 Most Influential Agricultural Mitigation Research Organisation across the Globe

We looked next at the relative importance of different research organisations around the world; this is shown in Figure 6 to Figure 10. These figures show the most influential institutions in each cluster in terms of the number of publications with at least one author from each organisation.

A caveat on the publications data by organisation in Scopus is that some institutions like AgResearch are recorded under multiple names (e.g. AgResearch Grasslands Research Centre, AgResearch Ruakura Centre, etc.). Given that Figure 6 to Figure 10 reflect the number of publications for which at least one author is affiliated with each organisation, a publication with authors from two AgResearch units, for example, would be counted towards both organisations. Therefore, it is not possible to aggregate organisations in the figures above without double counting within categories.

Figure 6: Top 15 organisations, in terms of number of publications produced, in the cluster “CH_4 inhibitors/vaccine”. The orange bar shows New Zealand organisations.

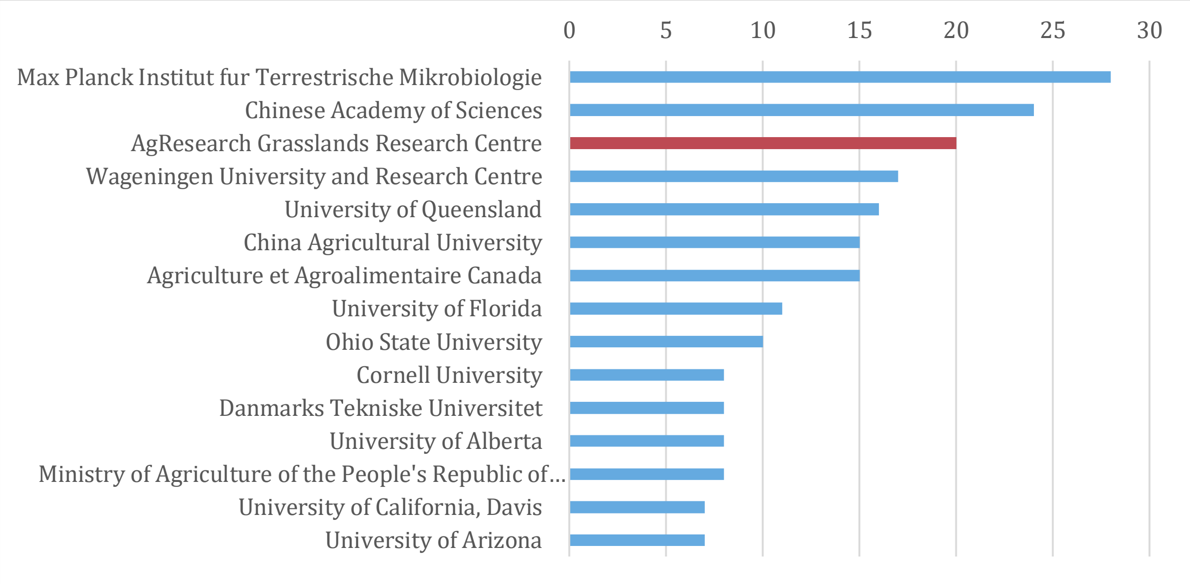


Figure 7: Top 15 organisations, in terms of number of publications produced, in the cluster “Low GHG animals”.

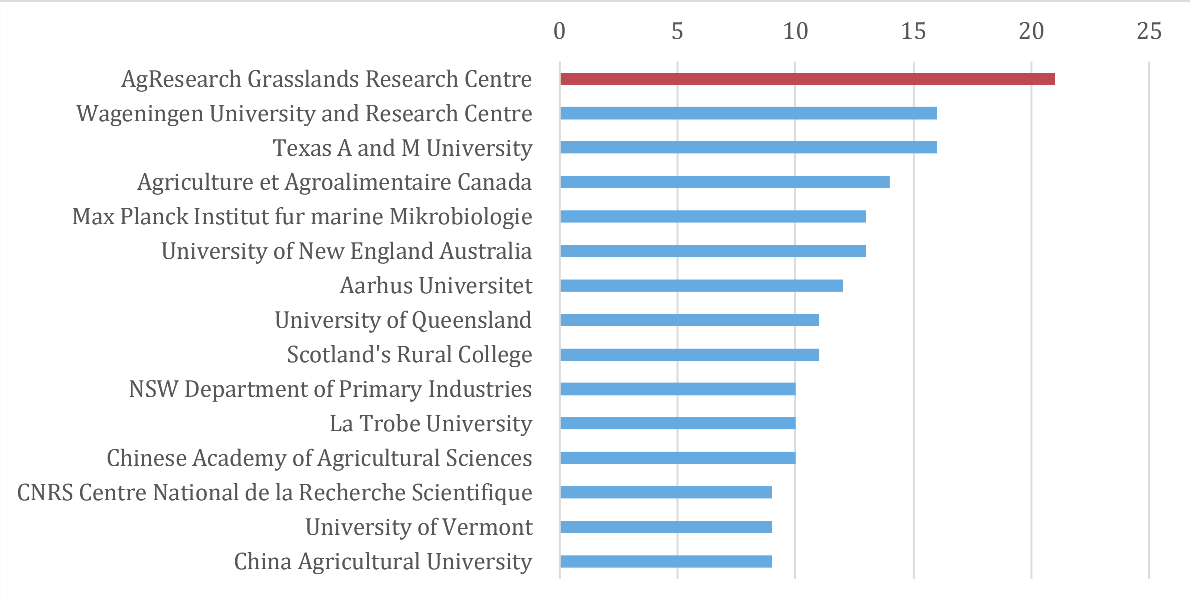


Figure 8 Top 15 organisations, in terms of number of publications produced, in the cluster "Low GHG feeds".

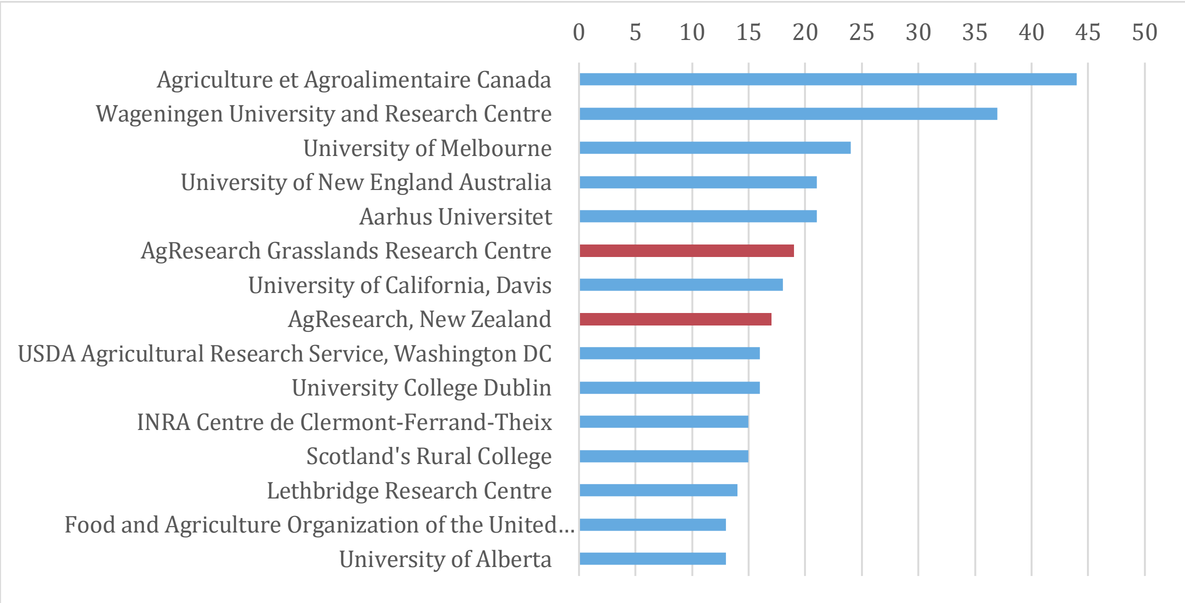


Figure 9: Top 14 organisations, in terms of number of publications produced, in the cluster "Management interventions".

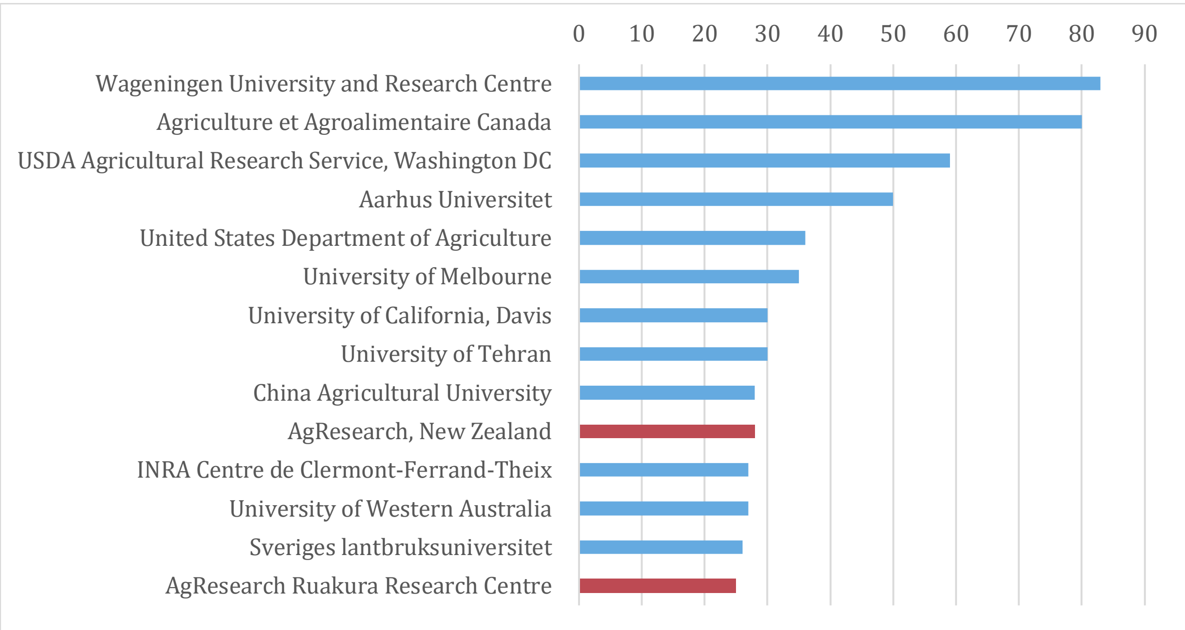
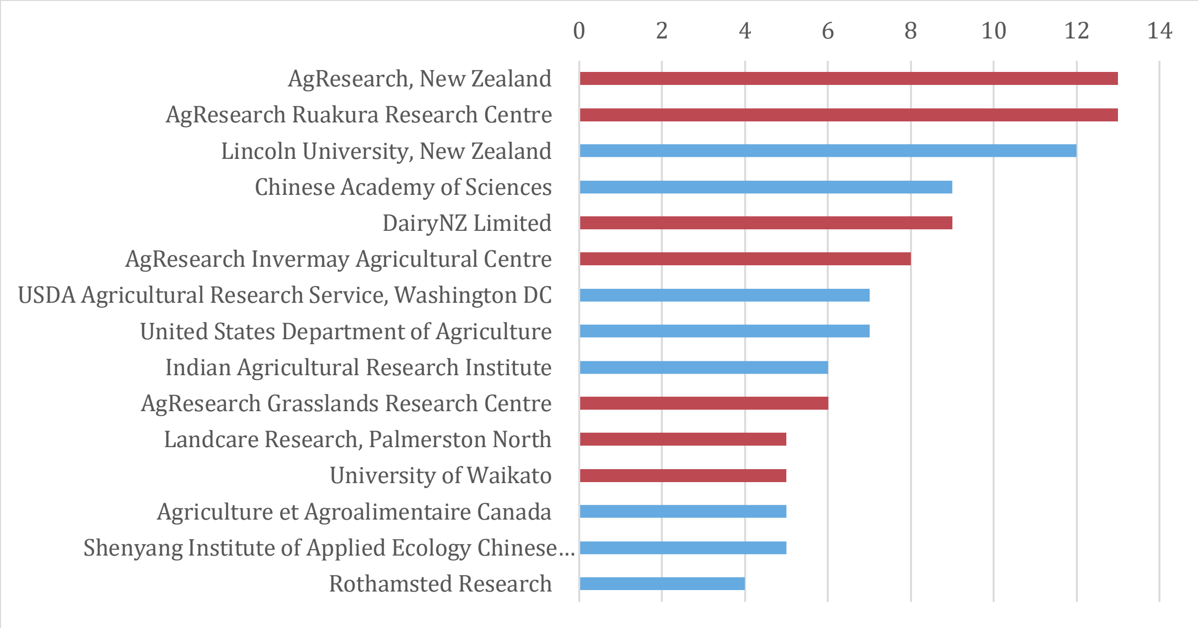


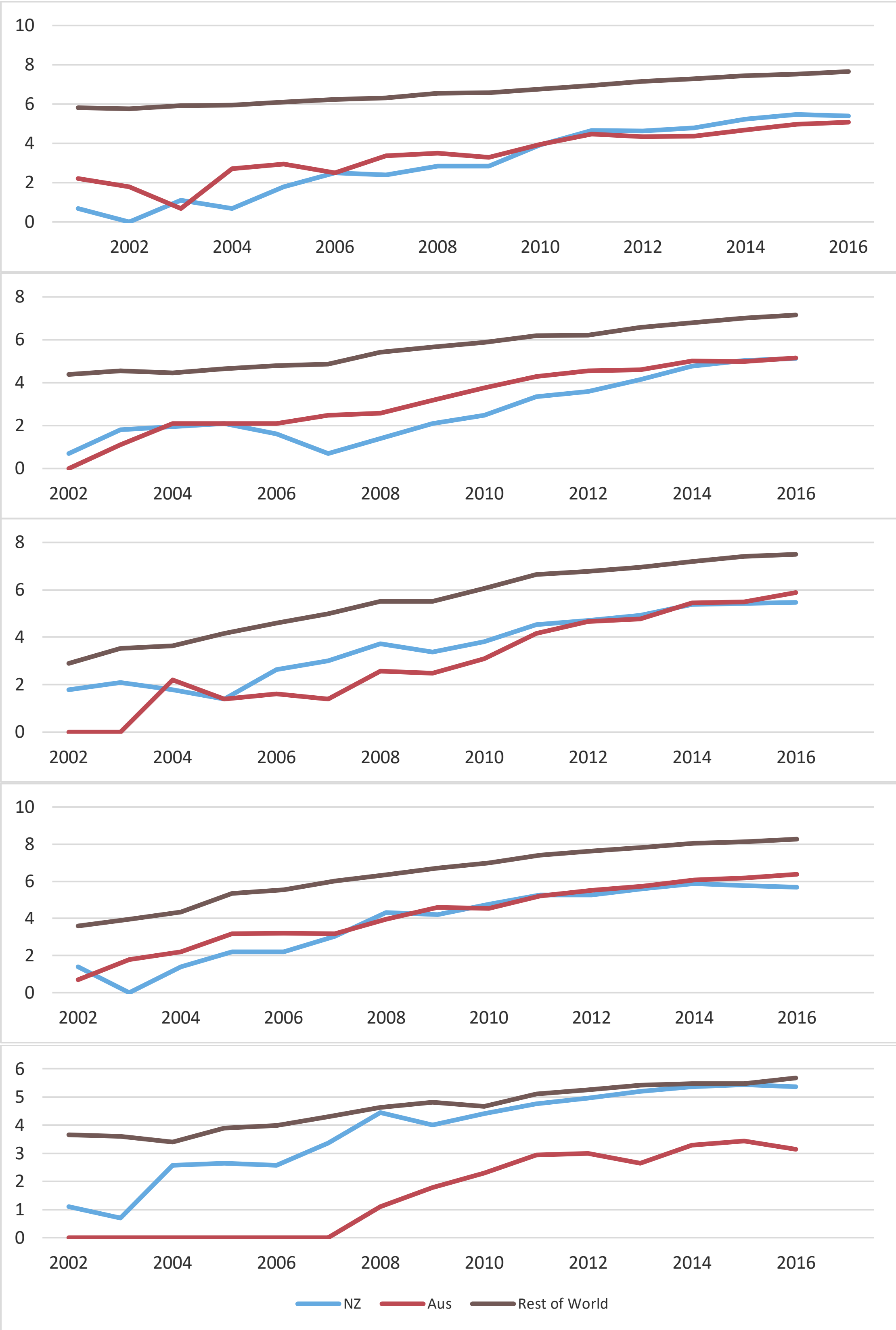
Figure 10: Top 15 organisations, in terms of number of publications produced, in the cluster "Reduced N_2O from soils/plants".



Considering the plotted data in Figure 6 to Figure 10, New Zealand organisations can be seen to have high international relevance, with AgResearch leading two out of the five clusters. The case of the "Reduced N_2O from soil/plants" cluster is particularly remarkable for New Zealand (Figure 10), in which four other New Zealand organisations – Dairy NZ, The University of Waikato, Lincoln University and Landcare Research – join AgResearch among the leading research organisations.

A different assessment of science impact is given by the magnitude and trend of citations. Citation measures are important in science because they signal the relevance that particular publications have had over other research. In Figure 11, we plot the trend that citations from all publications across clusters have received yearly since 2002. We plot three different trends: citations received by publications with New Zealand researchers, with Australian researchers and those from all the rest of the world – these last two are used to contrast New Zealand's impact. Given that in absolute terms the number of publications from the rest of the world is significantly higher that the number of publications in New Zealand or Australia, in Figure 11 we have transformed the citation data to natural logarithms, so the trend over time can be better appreciated.

Figure 11: Number of citations (transformed into natural logarithms to better contrast the trend of New Zealand and Australia to that of the rest of the world) received by year across clusters, from top down: CH_4 inhibitors/vaccine, Low GHG animals, Low GHG feed, Management interventions, and Reduced N_2O from soil/plants. Sourced from Scopus.



As seen in Figure 11, there is a general increasing trend in the number of citations per year, for both Australia and New Zealand and for the rest of the world. Interestingly, the growth in citations across New Zealand research in four of the five clusters resembles those for Australia, signalling the similar efforts made by both countries in developing this research. The only exception, in line to the findings of Figure 5 and Figure 10, is the cluster "Reduced N_2O from plants/soils", in which New Zealand has the leading presence, equalling in absolute terms the growth in citations in the rest of the world.

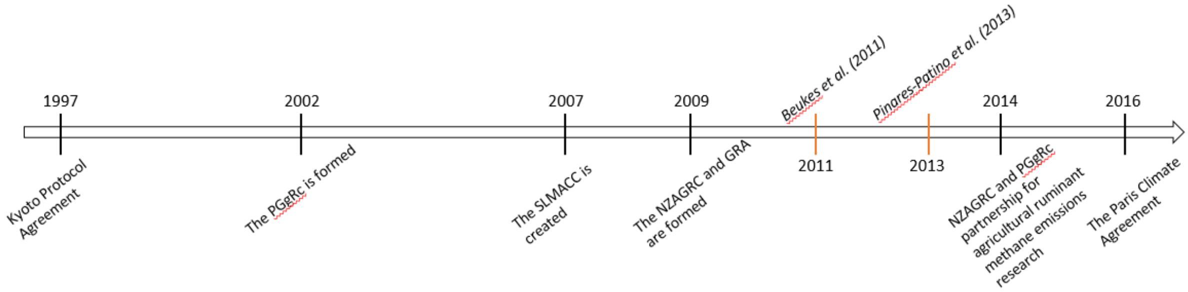
In summary, the data presented here show how agricultural mitigation research has grown in importance over recent years, with New Zealand standing out as a remarkable leader considering the size of its economy. It is expected that in the future, as climate change effects become more pronounced, more research efforts will be placed on improving the efficiency of animal systems across the world because demand for animal products is likely to keep increasing and there are many possibilities to keep reducing the emissions from ruminants (Reisinger et al., 2018). New Zealand and its research organisations will have an important role to play in this area, especially given the scientific capability developed in recent years (reflected in the number of the publications emanating from the country, as shown above) and the creation of organisations to financially support the development of this research (discussed below).

4 Funding for Agricultural Mitigation Research in New Zealand

Agricultural mitigation research funding in New Zealand has been in place since the early 2000s. The establishment of the Pastoral Greenhouse Gas Research Consortium (PGgRc) in 2002 was an important step. Since then, a number of organisations and programmes have emerged with funding to support the development of this research. The PGgRc is an organisation funded by both industry and the New Zealand government, and its main focus has been to support research into low-methane animal breeding and methane vaccine and inhibitors. Figure 12 summarises the timing of the creation of the main bodies that fund agricultural mitigation research in the country.

In 2007 a Plan of Action created by the Ministry for Primary Industries (MPI) included the creation of the Sustainable Land Management and Climate Change (SLMACC) programme. The aim of this programme was to provide dedicated funds for research related to climate change adaptation, GHG mitigation, forestry sinks, and cross-cutting issues relevant to agricultural and forestry industries. Two years later the New Zealand government decided to create a public entity to focus efforts on a wider range of agriculture mitigation options and science, creating the New Zealand Agricultural Greenhouse Gases Research Centre (NZAGRC). This happened almost simultaneously with the creation of the Global Research Alliance (GRA), a body aimed at funding international collaboration on agricultural mitigation research. In addition to these bodies, other sources of funding exist in the country, some from private resources and some from public funding. For more insights on the agricultural mitigation funding mechanisms in New Zealand, see NZAGRC-PGgRc (2016).

Figure 12: New Zealand agricultural mitigation research institutions timeline



Note: This figure only uses some of the institutes present in New Zealand and includes the data of publication of two papers (orange lines) discussed below.

In line with New Zealand's commitments under the Paris Climate Agreement, the government is likely to keep funding and supporting agricultural mitigation research in the future in order to reduce emissions. Given the time that has already passed since the inception of the organisations mentioned above and the international reputation of New Zealand's scientific capability in this area, we focus our attention in the next sections on the impact and value generated by two specific research projects in agricultural mitigation. Examining the country's success at a finer scale provides insights into the impact and value that two particular mitigation research projects have brought to New Zealand and the world.

We evaluate two research projects from the SLMACC Programme. We chose projects from SLMACC because pat of its role has been to fund agricultural mitigation research that complements the efforts of the PGgRc and NZAGRC. It therefore plays an important strategic role in supporting science in the area. Also, even though mitigation science is just one stream of the SLMACC fund, its investment in mitigation science is still relevant and an important fund to complement investments by other organisations, such as the NZAGRC.[6]

[6] Appendix Table C presents budget numbers to provide insights on the magnitude of SLMACC investments on mitigation research in comparison to the NZAGRC.

5 Evaluating (Valuing) Publicly Funded Research Projects

Privately funded research is undertaken to generate profits for firms, so it is focused on generating new commercial products and improving productivity. In contrast, publicly funded research is undertaken to advance social welfare more broadly, including seeking solutions to social challenges such as climate change. Regardless of the reason for funding research from public funds, it is generally expected that dollars invested will yield social benefits that could justify the initial investment. However, to estimate this in detail is commonly very hard and often practically impossible (Macilwain, 2010).

A common way to evaluate publicly funded investments is given by cost-benefit analysis (CBA) and similar techniques. However, benefits arising from public research can be difficult to quantify because of long and variable lags, and the complexity of causal chains from research to benefits. In addition, the aim of publicly funded research is generally to provide insight or solve issues that in many cases have economic values that are difficult to monetise, or that simply cannot be monetised (e.g. the value of the existence of a species), resulting in significant benefits that cannot be incorporated directly into a narrow economic CBA.

When CBAs or similar approaches are used, several types of economic values may be considered: [7]

- *Direct use value* is the value associated with increases in the use of new developments from the research, whether they are new products or services, or improved environmental conditions. Note that such use value may be uncertain and unrealised for a long period after the research is conducted; it is appropriate to include in a CBA a probability-weighted value associated with future use that may or may not eventually come to pass.
- *Indirect use values* are generated by spillovers from research. That is, in addition to its direct benefits, public research may generate benefits by creating new knowledge that can be picked up and built on by others, subsequently generating further benefits.
- *Option value* is value associated with the creation of options or flexibility. There would be, for example, value to society in the creation of tools or methods that we would use to mitigate harm if extreme but unlikely climate scenarios should come to pass.
- *Existence value* results because people derive utility from the knowledge that public goods exist, even if they have no intent of using the good themselves. Existence value, is typically very hard to assess because it is not connected to observable use, but that does not make it unimportant. In principle, because the entire population enjoys a public investment, its magnitude could be very large. For example, it is possible that the aggregate value placed

[7] The addition of these values is what is known as “total economic value” in CBAs (Sharp and Kerr, 2005).

by New Zealanders in total on knowing that Fiordland exists in a protected state is greater than the value associated with the enjoyment of the specific people who visit it.

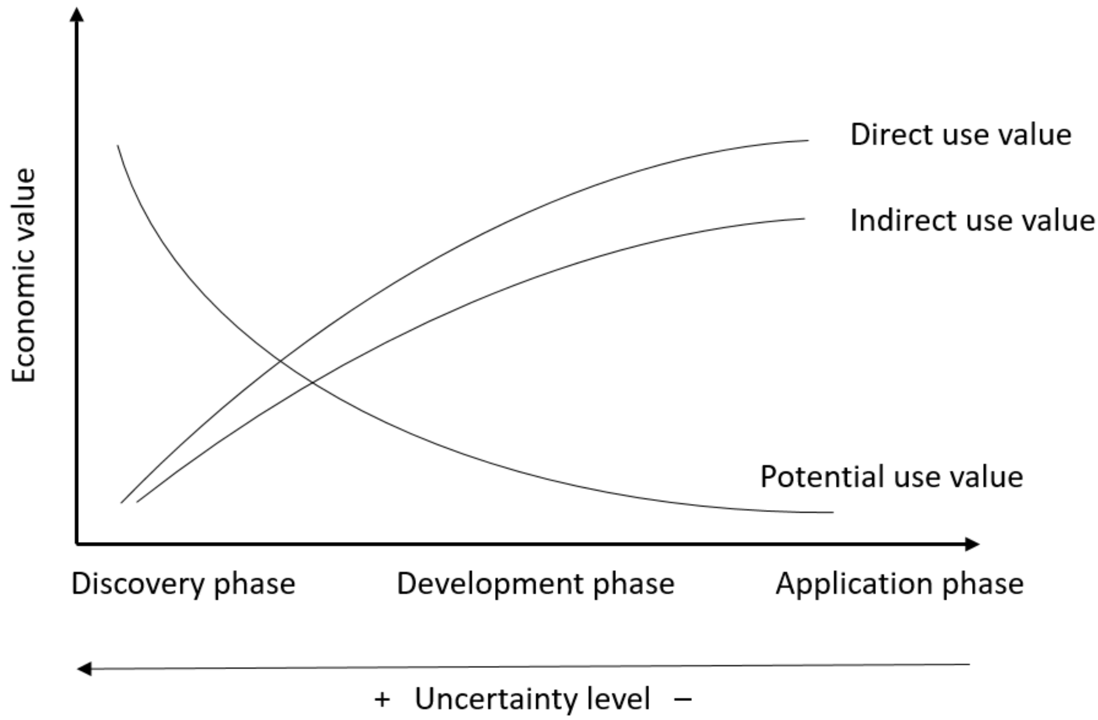
Note that a CBA of public investments should include benefits accruing to future generations. An economically appropriate discount rate should be used to add up benefits and costs across time (New Zealand Treasury, 2015).

Scientific research is generally subdivided into three phases: discovery, development, and application. The length of these phases varies by research project, with cases of long discovery periods (for instance, in the case of DNA coding or space exploration) or long application research phases (such as in cases of trial and error research to prove harmless doses of medication).[8] In the case of research looking at the development of a mitigation technique (as in our case), the use value of the researched technique will have a large uncertainty of realisation. This uncertainty is higher in the case of discovery research, where the technique does not exist at all and it is not known if the research would result in a practical usable product. In these cases, the value of research will be mainly driven by a *potential use value* – the economic value of the product or option is only potential and uncertainty is large. In Figure 13 we represent this, where in the early stages of research (discovery phase) uncertainty is large and potential use value dominates any type of other values. As research advances, the certainty of future use increases and so does its direct and/or indirect use value. Science, though, can also prove that a technique is impractical, in which case research would stop and the potential use value will never materialise. (In such a case there might still be indirect or spillover benefits, as other researchers might benefit from even negative research findings.)

In addition, research is generally characterised by slow investigation processes (in contrast to market activity, for instance) and slow application or uptake. Therefore, in an environment of uncertain and rapidly changing technology and knowledge, in many cases potential use values will dominate direct and indirect values in the discovery and development phases of public research. By contrast, in applied research it is likely that the number of potential users will grow as additional services and dissemination are added, so direct values are likely to be relatively more important as the certainty of utilisation arises.

[8] It's important to note that research, *per se*, of a particular topic or problem can be composed of several different independent projects across different research phases.

Figure 13: Representation of economic values and uncertainty levels across research phases



Note: In the initial phase of discovery, as uncertainty about the potential outcomes of the research is considerable, the potential use value of the option largely dominates the direct or indirect use values. As research moves through the phases (to development and to application phases), the direct and indirect use values increase as uncertainty decreases.

Publicly funded research can also be part of public-private alliances: as private research is generally targeted towards ventures that have an expected short- to medium-term profitability component, public funding can support endeavours that are expected to generate profits in the long term (therefore with higher uncertainty). Thus, it can be the case that research outcomes are profitable endeavours in the long term, but public intervention can be needed in order to initiate this research – public investment might be needed in cases where only potential use values are present. When industry only perceives potential use value with high uncertainty, it will have low incentives to finance a particular research project (for instance, because future regulation or polices are not clear) and public investment can be made to kick-off research.

Agricultural mitigation research is a clear example of these paradigms as the industry does not face a short-term financial incentive to reduce emissions, and there is uncertainty about when and how financial incentives will be implemented in the future. Public funding mechanisms can be efficient options to initiate the first steps of research that in the medium to long term can transform into profitable products to curb GHG emissions for farmers. This suggests that public research would be dominated by potential use values in a discovery-development phase. Once uncertainty is reduced, private funding may advance efforts in the application phases, which would be dominated by clearer future direct and indirect use economic values.

The importance of existence values and benefits that will accrue to future generations for climate change mitigation research is also clear, given that the benefits of the research protect important public goods and avoid potentially catastrophic harm in the future. However, the potentially large benefits that publicly funded climate change research might generate for the public at large in the distant future are often not a sufficient argument to assign resources to its development, as direct and indirect use values might be not evident and more short- to medium-term priorities may be targeted by policy makers.

5.1 Impacts and Non-economic Values

Because CBA and other approaches that measure benefits in monetary terms have difficulty reflecting the non-economic benefits of public research, there is a growing recognition that a broader multidimensional conception of research benefits is needed (European Science Foundation, 2012; Jaffe, 2015). The term "impact" in research evaluation generally refers to the influence that research outcomes produce in the science community (scientific impact) or among stakeholders (impact on stakeholders). Scientific impact generates influence in the form of knowledge, and is often assessed by the number of publications and the citation they accrue. On the other hand, impact on stakeholders refers to changes the research produces in the attitudes or decision-making of next- and/or end-users. These impacts do not necessarily need to be assessed in economic terms to be meaningful (though they can still relate to economic impacts and values) but rather in ways that explain how the change has happened for stakeholders.

5.2 The SLMACC Programme as Case study: Data and Considerations

During the last ten years the SLMACC Programme has funded more than 60 research projects related to agricultural GHG research. From these research projects, we chose the following two projects for our impacts and value evaluation:

1. Sheep, cattle, and methane predictors – MPI code: METH0901
2. Farm management and GHG for pastoral sector (also named: Systems analysis to quantify the role of farm management in GHG emissions and sinks for pastoral sector) – MPI code: C10X0902

We selected these two projects because they come from different mitigation research clusters – animal genetics and management – and because while one looks at a particular product (animals with low GHG emissions), the other looks at a set of management practices known by farmers.[9] In the next section we refer many times to these two projects as Project 1 and Project 2, or using an abbreviation of their names: methane predictors (for Project 1) and the farm management project (for Project 2).

Data for the evaluation of these projects came from different sources. Specifically, we gathered information from:

a. A list of all SLMACC projects and related funding, provided by the MPI
b. The official reports of these projects (provided by the MPI)
c. Scopus data on peer-reviewed indexed publications and citations
d. Published papers directly and indirectly related to these projects
e. Direct communication with agricultural mitigation scientists and stakeholders
f. Research reports related to climate change scenarios and mitigation in New Zealand (as referenced across the text).
g. Data, findings, and considerations reported in the review of van der Weerden et al. (2018)
h. Patent information from Lens.org.

Table 1 presents important information on projects 1 and 2, available from data from sources *a* and *b*, and from papers related to them (data sources *c* and *d*).

Table 1: Main projects' characteristics

Project	Year of initial funding	Main organisations involved	Number of peer-reviewed publications acknowledging SLMACC	Total number of authors across acknowledged SLMACC papers	Total SLMACC funding ($, nominal)*
Methane predictors (1)	2009–10	PGgRc, AgResearch, BIOSCIENCE	2	15	$150,000
Farm management (2)	2009–10	AgResearch, Dairy NZ, Landcare	6	26	$1,489,472

Notes: Details of papers counted in column 4 can be seen in Appendix Table C – these numbers of publications include non-formal peer-reviewed outlets, as shown in Appendix Table D. Column 5 denotes the total number of authors of the papers counted in column 4, i.e. papers directly acknowledging the SLMACC fund (see Appendix Table D). * Data provided directly by MPI.

[9] These projects were selected from a shortlist of projects drawn up after direct consultation with the MPI considering the relevance of their work across clusters.

These projects have resulted in different outputs and outcomes. In order to assess these and analyse their impacts and value, we perform three main activities: an analysis of scientific outputs using data from Scopus (data source *c*); a description of the projects' outcomes and use in followed-up research (generated by next-users) or outputs used by stakeholders (using data from sources *d* and *f*); and an analysis of potential values generated by the projects given climate projections, scenarios, policy and other considerations described by different policy and economic reports (source *e*).

6 Impact Analysis

In this section we look at the impact on science and on stakeholders defined as next- and end-users of projects 1 and 2. As mentioned above, impact on science and on stakeholders is generally understood differently. In science, the impact of a project is related to the influence of its generated knowledge, which is commonly assessed by its number of publications, the quality of the journal of publication, and the number (and significance) of citations accrued. On the other hand, impact on stakeholders relates to the changes that the research produced in next- or end-users. Thus, if research output(s) generates change in practices or influences decision-making, then stakeholder impact is generated.

6.1 Scientific Impacts of the SLMACC Projects

Both projects generated several research outputs in the form of publications, some of which were published in prestigious peer-reviewed journals. A list of papers generated by the two projects are presented in Appendix Table C. These papers were mainly identified as direct products of both projects.[10] However, it is important to note that in the case of Project 1, only two publications can be considered as direct products of this project. All of the other papers listed in Appendix Table C under Project 1 are actually the product of different research projects, but these directly used the data generated by Project 1. We list these papers here because they could have never been produced without the data generated from Project 1, so in relation its impact, these papers are denoted as "indirect" publications in Appendix Table C. For Project 2, as seen, many do not acknowledge the SLMACC funding in the publication, but they are listed here because they are claimed as products of Project 2 according to the final report presented to the MPI.

Appendix Table C also includes metrics relating to the papers' scientific impact in terms of citations. The second and fifth columns in Appendix Table C show the number of citations

[10] These papers were provided from direct communication with one of the main researchers involved in Project 1 and from the final SLMACC report of Project 2 (made available by AgResearch).

attributed to the paper in Scopus and Google Scholar, respectively. The number of citations in Google Scholar tends to be higher than those in Scopus because it covers a broader base of literature. In general, Scopus does not cover some important scientific publications, but Google Scholar also includes publications such as newspapers and blogs that do not correspond to scientific impact. Hence the number of citations corresponding to meaningful scientific impact likely falls between the Scopus and Google Scholar counts.

The number of citing countries shown in the third column is derived from citations tracked by Scopus, that is, citations coming from indexed, peer-reviewed literature. It is important to note that citations of different publications are not directly comparable because they may have had different amount of time to accrue citations and because citation patterns differ across fields. To address this, we include in Appendix Table C the Scopus field-weighted citation index (FWCI), which reflects the ratio of the citations accrued to the publication relative to the average citations of similar publications (of the same discipline, publication year, and publication type) over a three-year period. FWCI is comparable across the list of publications, and a FWCI score greater than one indicates that a publication is more highly cited than average. For example, an FWCI score of 2.5 indicates that the publication has 2.5 times the citations that we would expect given its discipline, publication year, and publication type.

Appendix Table C also provides information on the number of authors, their institutions, and the funding acknowledged in the paper. Where citation metrics are missing for a particular publication in Appendix Table C, the publication was not included in the relevant database.

To complement the information reported in Appendix Table C, in Appendix Table D we provide information relating to the journals in which the papers were published, including three measures of journal impact. Although journal impact does not directly measure the quality of the publication itself, it is indicative of quality because higher-impact journals are generally more selective.

The three journal impact measures in Appendix Table D are “CiteScore percentile”, “CiteScore” and “Source-normalised impact per paper” (SNIP), which are all sourced from Scopus. “CiteScore percentile” reflects the relative position of a source in its field in terms of average citations. Where a source spans multiple fields, we list the percentile for each field. For example, the first journal listed in Appendix Table D, the journal *Animal*, is in the 87th percentile for Animal Science and Zoology, implying that it is ranked as high or higher than 87 percent of all sources within this field. “CiteScore” is a measure of the average number of citations received in 2016 by all items published in the journal in the preceding three-year window. The SNIP is the ratio of the average number of citations per paper from the journal to the average number of citations of papers in the same field. Hence, the SNIP measure is corrected for differences in citation patterns that exist across fields. All journal metrics in Appendix Table D are calculated for 2016, and so may vary from the quality of the journal at the actual time the papers we are interested in were published.

Considering Appendix Table C, the only measure of citation impact that is comparable across the publications is the FWCI because it has been normalised. According to this metric, the publication with the greatest citation impact is Pinares-Patino et al. (2013A), one of the two direct publication outputs of Project 1. This paper's FWCI score of 11.18 suggests that it is more than 11 times more cited than the average of similar publications. This publication also had the highest number of authors, all of which were from New Zealand-based affiliations. All papers listed under Project 1, where they were included in Scopus, had above-average citations relative to similar publications (FWCI >1).

Publication outputs from Project 2 also had mostly above-average citations, but four of the twelve had a FWCI score below 1.00. The most impactful paper from Project 2, according to FWCI, is Beukes et al. (2010), with 5.28 times more citations than the average of all similar publications.

Similar to FWCI, CiteScore percentile and SNIP in Appendix Table D are calculated within fields and are therefore able to be compared across journals from different fields. CiteScore, on the other hand, is not adjusted for field differences. In general, all publications in Appendix Table D that are documented in Scopus are published in relatively high-impact journals in terms of their 2016 performance. Only one of those journals, *Nutrient Cycling in Agroecosystems*, has below-average citations relative to the fields covered. However, as mentioned above, measures in Appendix Table D are indicative of the performance of the journals and not of the quality of the individual publications under consideration. For example, Pinares-Patino et al. (2013A) had a much stronger citation impact (FWCI= 11.18) than the average publication within the same journal (SNIP=1.18). According to SNIP, the journal in Appendix Table D with the greatest performance is *Science of the Total Environment* (SNIP=1.849), in which Vogeler, Giltrap and Cichota (2013) from Project 2 was published. However, despite being published in a relatively high-quality journal, that publication has less than average citations for its field (FWCI=0.74).

For the (direct and indirect) publication outcomes of Projects 1 and 2, we also obtained their citation accrual in Scopus over time since their publication. These citation trends are shown in Figure 14 and Figure 15 below. It is important to note the difference in scale of the vertical axes across these two graphs. Data from 2018 has been dropped because the citation data were accessed in June 2018. It can be seen from Figure 14 that compared to other publications indirectly produced from Project 1, Pinares-Patino et al. (2013A) had a relatively rapid accrual of citations initially and have continued on an increasing path. Other publications from project 1 have taken a comparatively longer time to build up citations and have shown varied patterns over time. For Project 2, Figure 15 shows that Beukes et al. (2011) has persistently earned a high number of citations per year since publication, relative to other publications from the same project, in particular accruing a very high number of citations in its first year.

From the publications and citation metrics, it can be argued that both projects have had high impact in terms of scientific contributions: both produced publications in high-impact journals and with a high and increasing number of citations. Although we do not contrast these impacts to those of other papers generated in New Zealand or worldwide, the FWCI shows clearly that the papers have reached an impact beyond the average papers in their field.

Figure 14: Number of times (direct and indirect) papers of Project 1 were cited per year, based on Scopus data. Citations are recorded only until year 2017.

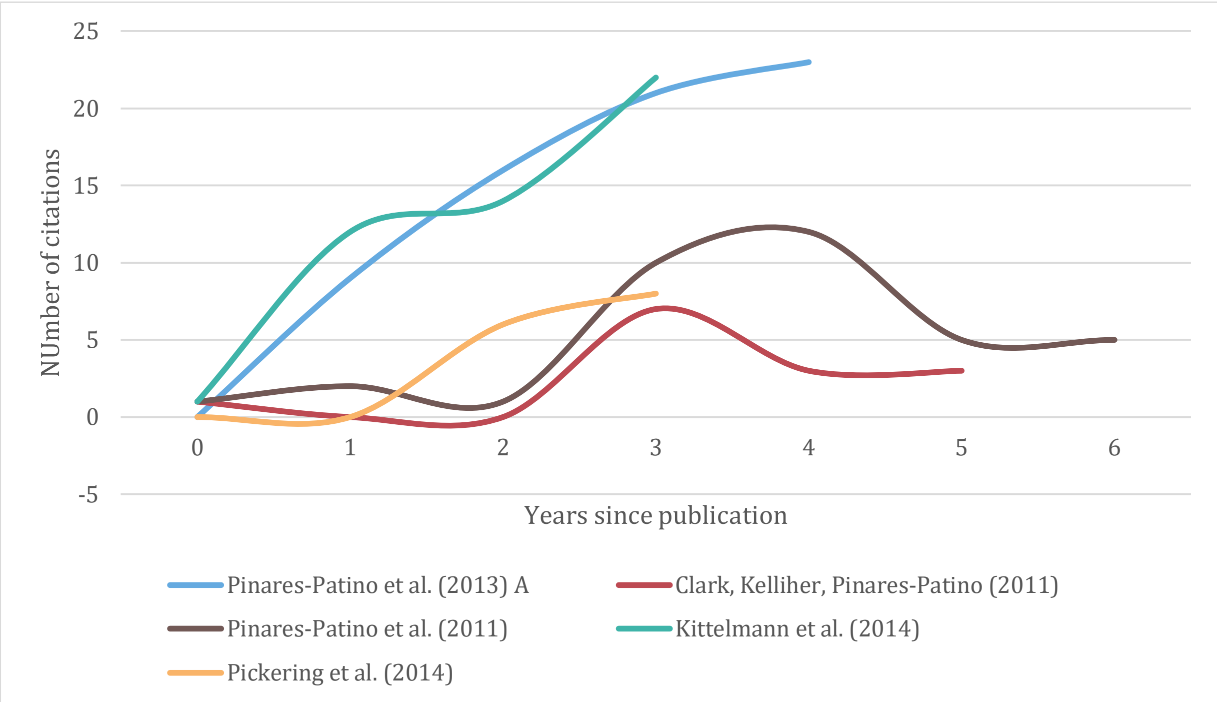
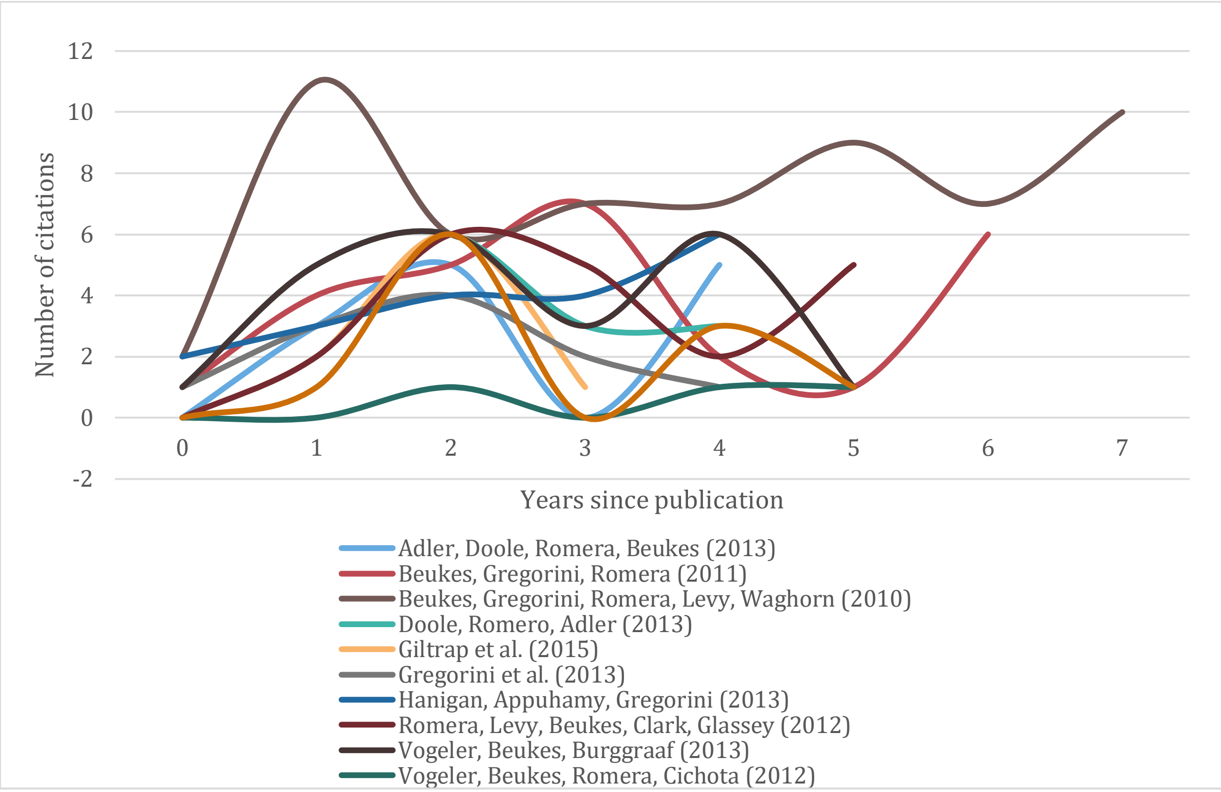


Figure 15: Number of times papers of Project 2 were cited per year, based on Scopus data. Citations are recorded only until year 2017.



The papers' findings and methods have not only been cited by other scientific work carried out in New Zealand research, but as seen in column 5 of Appendix Table D, they have also been used in publications in different countries. Figure 16 and Figure 17 show the country of origin of the affiliation of authors citing the works of Pinares-Patino (2013A) and Beukes et al. (2011), respectively. We choose to reflect the international impacts of these papers because they are the highest cited papers in both projects where SLMACC is acknowledged. As can be seen, countries in different continents have used the research generated by both projects, with a higher impact produced in the USA and the UK.

Figure 16: Number of papers citing the work of Pinares-Patino et al. (2013A) coming from the different countries of the affiliation of the authors.

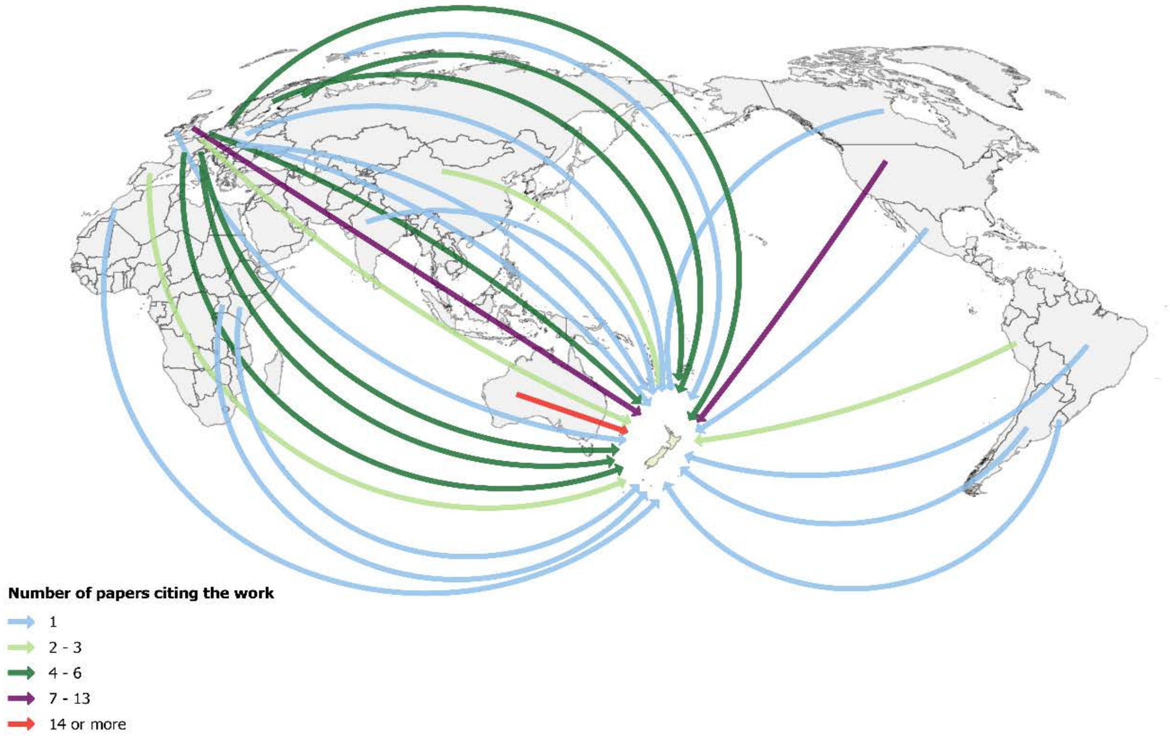
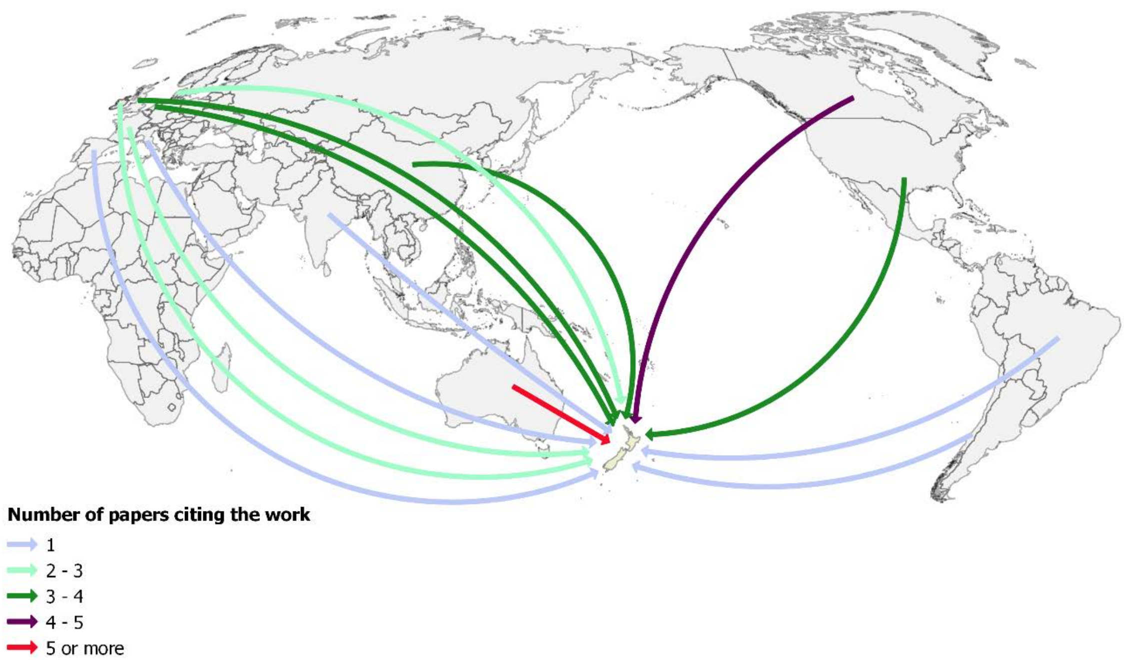


Figure 17: Number of papers citing the work of Beukes et al. (2011) coming from the different countries of the affiliation of the authors.



6.2 Stakeholder Impacts in the SLMACC Projects

To track the impact of the papers beyond the publications outputs, we first provide a brief description of what the projects' findings have meant. This description is not intended to provide a full or detailed technical description of the research but rather a general idea on the generated knowledge. We then summarise some of the impact generated in next- and end-users.

6.2.1 Main Research Objectives and Findings

Project 1, using artificial selection, focused on finding genomic markers to indirectly select for low CH_4 yield cattle and sheep. The main research result shows that heritability of CH_4 production and CH_4 yield in sheep were 0.29 and 0.13, respectively – meaning that low-methane traits are heritable and animals can be selected to keep improving their efficiency (van der Weerden et al., 2018). Little was achieved in cows because of the difficulties in studying GHG in large animals, which to date has been a challenge for researchers.

One positive finding from this research is that if the low CH_4 trait is in the selection index, it can be accumulative and integrated into pastoral systems. This is especially favourable in New Zealand, where a well-structured animal breeding system exists.

According to direct feedback from one researcher involved in this project, the main factor involved with low CH_4 animals is that they have a faster rate of passage than others. This means that the fibre eaten by these animals would be less effectively digested, which would affect the animal's productivity performance. Given this, low CH_4 yield animals will not be equally productive under lowering quality of pastures, which could result from climate change effects. Considering this point, it has been suggested that this option can be cost-effective only if high-quality feed is available.

On the other hand, for cows, given that dairy cattle are generally fed on high-quality diets in New Zealand but feeding level is not *ad libitum*, the reduction in emissions may not be significant due to the high rate of passage already operating. Given this, increasing the feed allowance might lead to reduced forage utilisation and hence affect quality and pasture yield. However, if the genotype of low-emitting cows is accurately identified, the inclusion of the trait in breeding programs can be relatively easy and can have a high impact.

Project 2 was one of the first overarching attempts to understand how different farm practices relate to GHG emissions, especially in dairy systems.

The most influential paper of Project 2, Beukes et al. (2011), based its methods on the DairyNZ Whole Farm Model with the objective of identifying practices that could reduce GHG emissions in dairy farms. The studied practices for decreasing GHG (CH_4 and N_2O) emissions included: fewer animals with higher genetic merit that are milked longer; lower replacement rates; standing cows off during autumn and winter; decreased fertiliser nitrogen inputs; and incorporating some low-nitrogen grain in the diet. The study found that milk production would increase by 15–20% and absolute GHG emissions would decrease by 15–20%. The changes to the system to address GHG emissions would also decrease nitrogen-leaching losses (Shepherd et al., 2016). Across their findings, Beukes et al. (2011) show that decreasing the stocking rate by 13% produced a 5% reduction in dry matter intake (DMI), which resulted in an 8% decrease in enteric CH_4 production.

Other important findings from Project 2 include:

- In dairy systems: the combination of lower replacement rates, increased body weight plus lower stocking rate, longer lactation, stand-off pad, replacing nitrogen fertiliser with low-nitrogen feed reduced GHG/kg milk solids (MS) by 15–20% and increased MS/ha by 15–20%. Total emissions per hectare reduced by 16–19% when all mitigation options were combined.
- Increasing the proportion of trading and dairy-heifer grazer cattle relative to breeding cows: for every 10% increase in dairy-heifer grazers, total GHG reduced by 0.5% and emissions intensity by 2.1%.
- In sheep and beef systems: increasing the breeding-ewe weaning percentage, decreasing the breeding-ewe replacement rates, and increasing the proportion of total cattle on farm was investigated. Every 10% increase in weaning reduced GHG by 1% and GHG intensity by 3%. Decreasing the replacement rate had minimal impact on GHG.

AgResearch was the leading organisation for Project 2, but several activities were conducted under the umbrella of Dairy NZ. The project relied importantly on the Dairy NZ Whole Farm Model and also developed new tools and models to analyse biological emissions in farms.

6.2.2 Impacts on Next-users

For Project 1**,** the results generated have been used several times across different follow-up projects, generally funded by the PGgRc. As mentioned by a researcher involved in this project, research in genetics commonly uses data collected in different years, so the data from Project 1 is still being used for current research and reanalysis or with further samples collected. In this sense, the technical contribution of Project 1 is an ongoing asset, as the knowledge generated from continues to be used directly to generate new research in animal genetics.

Internationally, the New Zealand research that has continued from this project has gained attention from media outlets and researchers in other countries, as evidenced by a news article recently published by the ABC in Australia.[11]

For cows, international studies have progressed this field, finding that cattle exhibit similar natural variation in emissions per unit of dry matter intake, and genomic markers for the trait have also been identified. Following the breeding work conducted on sheep, a cattle-breeding programme commenced at the end of 2015 in New Zealand, funded mainly by the NZAGRC-PGgRc and the New Zealand GRA (Reisinger et al., 2018).

For Project 2, part of the achieved results were used to feed the management practices developed for the large pastoral dairy farmlet trials and studies (aka P21) conducted in four different regions of New Zealand (De Klein and Dynes, 2017). Following the completion of the P21 study, a different study assessed the GHG footprint of the Canterbury farmlets (funded by SLMACC). This was then followed with a study assessing the GHG of the Waikato and South Otago farmlets (funded by NZAGRC) (van der Weerden et al., 2018).

Project 2 also led to the development of the farm optimisation model IDEA, which was the first optimisation model of a grazing system that considered different processes, such as post-grazing residual mass, which were previously not considered by national or international modellers. The project also improved the Molly enteric CH_4 sub-model of the Whole Farm Model (WFM) from Dairy NZ. Both of these models, IDEA and the WFM, have been subsequently used by different research.

The sheep and beef results were used to inform modelling and on-farm measurements in a subsequent project (funded by the NZAGRC) as well as informing several extension programmes (van der Weerden et al., 2018).

For both projects, it is important to mention that the funding coming from the SLMACC Programme supported an important initial movement into the research of these fields – ruminants methane genomics and modelling to better understand the link between management practices and biological GHG emissions in farms. However, one important question is whether such research, and the research that followed, would have been undertaken in the absence of the SLMACC Programme. This is of course hard to answer, as the counterfactual case (the non-existence of the SLMACC Programme) does not exist. In our opinion, the existence of the programme did influence the occurrence of these research areas, at least by accelerating the timing of their development. The SLMACC Programme in this sense provided resources for

[11] http://www.abc.net.au/news/rural/2018-06-07/new-zealand-scientists-breed-sheep-that-fart-and-burp-less/9841546

scientists to get "their foot in the water" at earlier stages in some of these initial research attempts, especially considering that at the time of funding, the NZAGRC was in early stages of operation.

6.2.3 Impact on End-users

Given that that the main aim of the evaluated research is to develop tools and options for on-farm mitigation, the end-users of the studied projects are farmers and the broader livestock sector, from both New Zealand (direct end-users) and overseas (indirect end-users).

<u>For Project 1</u>, given that the final product (low-GHG-emitting animals) is still not "formally" available, the uptake of this technology by farmers has not yet been observed. Most experts in the area agree that research into breeding values can be released to farmers in the short term and that this will be soon included in the New Zealand National Inventory. However, a challenge with using a breeding approach in sheep is that there is a relatively large number of rams used for breeding, hence diffusion of low-GHG-emitting animals into flocks is likely to take longer and will be hard to monitor and report (in the case of mixed parentage combining low-emission and "normal" animals), in contrast to dairy systems (Reisinger et al., 2018).

The market potential of this development is clear. Industry trials are under way to evaluate the benefits of incorporating the low methane trait into the current Sheep Improvement Selection Index (Reisinger et al., 2018), and many sheep are already in the national flock, so their reproduction should happen. However, the extent to which farmers will consider and use these low-emission animals in their herds is an unanswered question. In this sense, debate exists in terms of the rate of adoption that could be expected and what type of barriers might influence this adoption.

Even though it seems that, on average, the selected low-emission sheep have shown no important difference in their performance from the rest, the opportunity cost of having these animals could still be significant. Giving more weight to genetic GHG emissions in a selection index would mean lower weights for other, perhaps more economically relevant, traits, which will be the main target for farmers (Reisinger et al., 2018). This may be especially relevant for farmers in areas with, or facing, increasingly low pasture quality. In any case, this potential opportunity cost can be reduced over time with continued research and breeding (Reisinger et al., 2018).

<u>For Project 2</u>, even though most analysed options in the research correspond to practices that farmers are familiar with, the practices *per se* are still not seen as mitigation options by many (if

not most) farmers in the country. We particularly observed evidence of this in a set of interviews conducted with farmers of the North and South islands: practically all interviewed farmers and managers said they were unaware that many practices (like reducing stocking rate or reducing replacement rates) are positive drivers of reducing GHG emissions on the farm.

Reduction in the intensity of farms could also have a direct effect on the dairy industry, by decreasing volumes and trade competitiveness. Thus, even though the industry has signalled intentions to move towards a sector generating lower levels of GHG over time (as reflected in the Dairy Action for Climate Change, released in June 2017), actions are still in the early stages. Many farmers are still not aware that practices studied under Project 2 can indeed reduce their carbon footprint.

This issue of communication about mitigation options with farmers, which has been a barrier to the take-up of Project 2 outcomes, is also a threat to the potential impact of Project 1. In addition, a major concern about the potential of each of these projects to curb GHG across New Zealand regions is the extent to which the practices and options can be practically applied. Many farmers may face a variety of barriers in adopting these changes. Besides their perception of costs and potential effects on production and/or profits, several behavioural, industrial, market, and policy-type barriers might prevent farmers from moving towards more GHG-friendly practices, management, and/or options (such as low-emitting animals) (Jaffe 2017).[12] In particular, the uptake by farmers of any mitigation practices will be limited as long as New Zealand does not establish a formal incentive mechanism to reduce GHG emissions on the farm.

7 Value Analysis

In this section we attempt to estimate values related to the research outcomes generated by Projects 1 and 2. As these projects were mainly focused on advancing discovery and development research, it is not possible to evaluate them definitively in terms of a direct or indirect use value. However, abstracting from the complexities and interconnections between different types of related research projects that have occurred since the execution of Projects 1 and 2, we focus in the analysis below on estimating the potential use value of these projects. We do this by calculating what the incorporation of both farm strategies (low-emission animals and practices related to de-intensification) would mean in terms of savings for farmers in the case of a future carbon price imposed on agricultural emissions.

In order to assess the potential savings, we considered various predictions of the reduction in emissions that could result from the adoption of these methods (low-emission

[12] A list of studies looking at barriers to decision making in farming contexts in New Zealand is available here

animals and practices related to de-intensification) in 2030 and 2050, and interpreted the economic savings given a hypothetical carbon price in those years.

The New Zealand Government has asked several organisations to produce analyses of climate projections and the potential scenarios under specific policy changes and programmes to achieve the country's international commitments to GHG reductions under the Paris Agreement. Several of these studies have considered the application of agricultural mitigation options to reduce the GHG footprint generated by pastoral systems. For our valuation analysis, we based most of our calculation on two reports: Reisinger and Clark (2016) and on modelling conducted recently by the NZAGRC (Reisinger et al., 2018). These reports, and others also used (referenced below) in our analysis, considered various predictions of the emissions that could be saved by different mitigation options in 2030 and 2050. We use these predictions to estimate economic values based on a potential future carbon price imposed on agricultural emissions.

A final preliminary consideration is that the development of both low-emission animals and the linkages of management practices to lower emissions have been the coordinated efforts of several organisations and research products, as briefly summarised in section 5 above. This means that it is not possible to attribute the whole estimated economic value (or associated environmental or social values) to a particular entity such as the SLMACC Programme. Rather, the economic values estimated here need to be seen as a "whole package" of different contributions and efforts. Nevertheless, it can be argued that the SLMACC Programme has had an important role in envisioning the potential results shown here as consequence of its supporting early stages on both research streams. We are not attempting to estimate a proportion of the economic value to be assigned to the SLMACC work, but rather to state that part of it, if materialised in the future, would be achieved as direct contribution from this funding programme.[13]

7.1 Results for Project 1

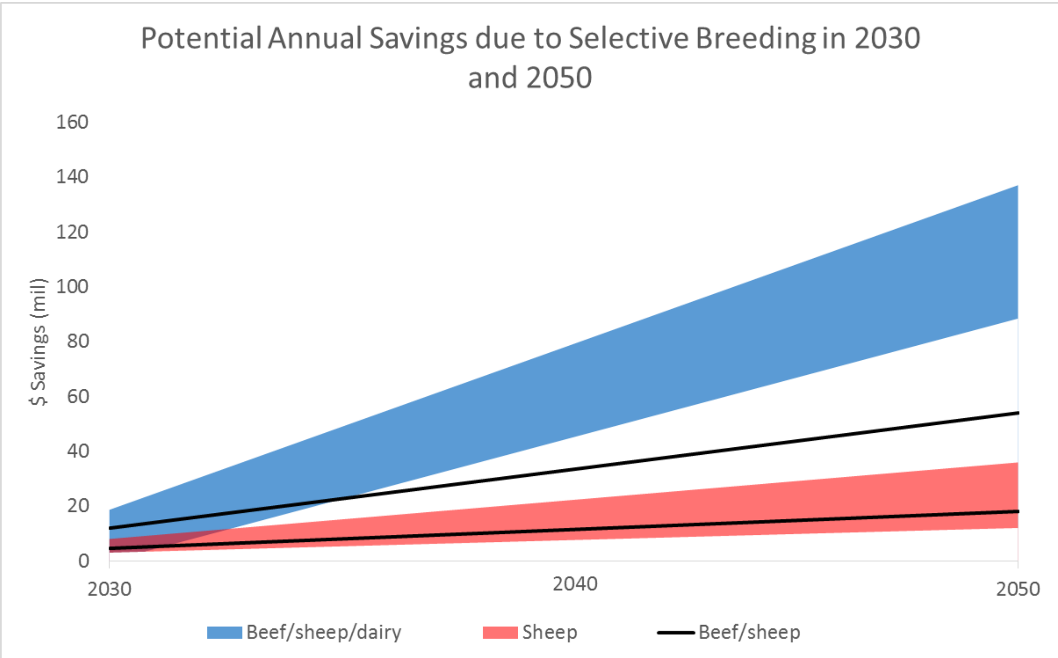
For the outcomes of selective breeding, we consider cases in which the mitigation option can be applied only to the sheep sector, to sheep and beef, or to sheep, beef and dairy. At the time of writing (August 2018), selective breeding for low-methane animals has mainly been developed in sheep, and so the extension to other sectors is not a feasible option at this stage. For each of these scenarios, we obtain a range of estimates of reduction in total GHG emissions across the agricultural sector for 2030 and 2050 under various assumptions, including the efficacy of

[13] As the SLMACC did importantly contribute to the benefits discussed here (not only the economic values estimated below, but also the environmental and social values and the impact generated in science and stakeholders from the projects), it can be said that the overall benefits of the research would not have been achieved without it. It is also true that if a rate of return were calculated, then all the costs of all related projects in both research areas (low GHG animals and farm practices) would need to be included in the denominator.

selective breeding and the rate at which it is adopted.[14] For the beef, sheep and dairy combined scenario, we use prediction ranges of GHG reduction from Reisinger et al. (2018), and for the sheep and beef sector, we use prediction ranges from Reisinger and Clark (2016).[15] We found no forecasts specific to the solely sheep industry, and so we derived this from the Reisinger and Clark (2016) predictions for sheep and beef, under the assumption that a sheep emits one quarter of the GHG volume of that generated by individual beef cattle. The assumptions and resulting predictions for each scenario are outlaid in Appendix Table E.

To put a price on the GHG reductions, we assume a carbon price of $25 per tonne of CO_2 in 2018 and increasing at a rate of 1.8% each year until 2050. At the subsequent carbon prices in 2030 and 2050, we extrapolate the minimum and maximum annual savings in 2030 and 2050 given the predicted ranges of emission savings in those years as shown in Reisinger and Clark (2016) and Reisinger et al. (2018). These potential annual savings are shown in Figure 18.

Figure 18: Potential savings from low-emission animals, based on simulations in Reisinger and Clark (2016) and Reisinger et al. (2018).



[14] Reisinger and Clark (2016) also compare maximum and minimum efficiency scenarios, where high (low) efficiency assumes a high (low) rate of conversion of land to dairy, and increasing (decreasing) animal efficiency. See Appendix Table E for more details on the assumptions across all reports used for our evaluation.
[15] Figures from Reisinger and Clark (2016) and Reisinger et al. (2018) were interpreted from charts and are therefore approximate.

For simplicity, we show a linear increase from 2030 to 2050, considering the assumed carbon prices in both 2030 and 2050, to give an indication of the increase in annual savings over time.[16] Results show that from 2030 to 2050, savings that farmers might accumulate from using low-emission sheep in their flock could lie between $159 and $462 million. If we consider the number of sheep farmers in 2012 of 13,512[17] (Statistics New Zealand 2012), this would amount to savings of $561–1,630 per farm per year – assuming no change in the number of farms over these years. Alternatively, considering projections in the number of sheep to 2050 described in Reisinger and Clark (2016), the value would amount to $5.70–19.30 per sheep over the period 2030–2050. These last amounts do not seem very high, especially over the long time period. However, if selective breeding for low-methane animals can be expanded to the beef and dairy sectors, the total annual savings to New Zealand by 2050 could be four to seven times greater than the savings with sheep only. Also, if the price on emissions increases to, say $100 per ton of CO_2eq by 2050, the savings would be between $13 and $44 per sheep.[18]

It is important to note that the implementation of selective breeding presents an indirect cost to farmers due to the reduction in the size of the gene pool available for achieving other breeding objectives (Reisinger and Clark, 2016) and the potential decrease in productivity in the case of lowering pasture quality. These costs are not accounted for in the savings predictions above.

7.2 Results for Project 2

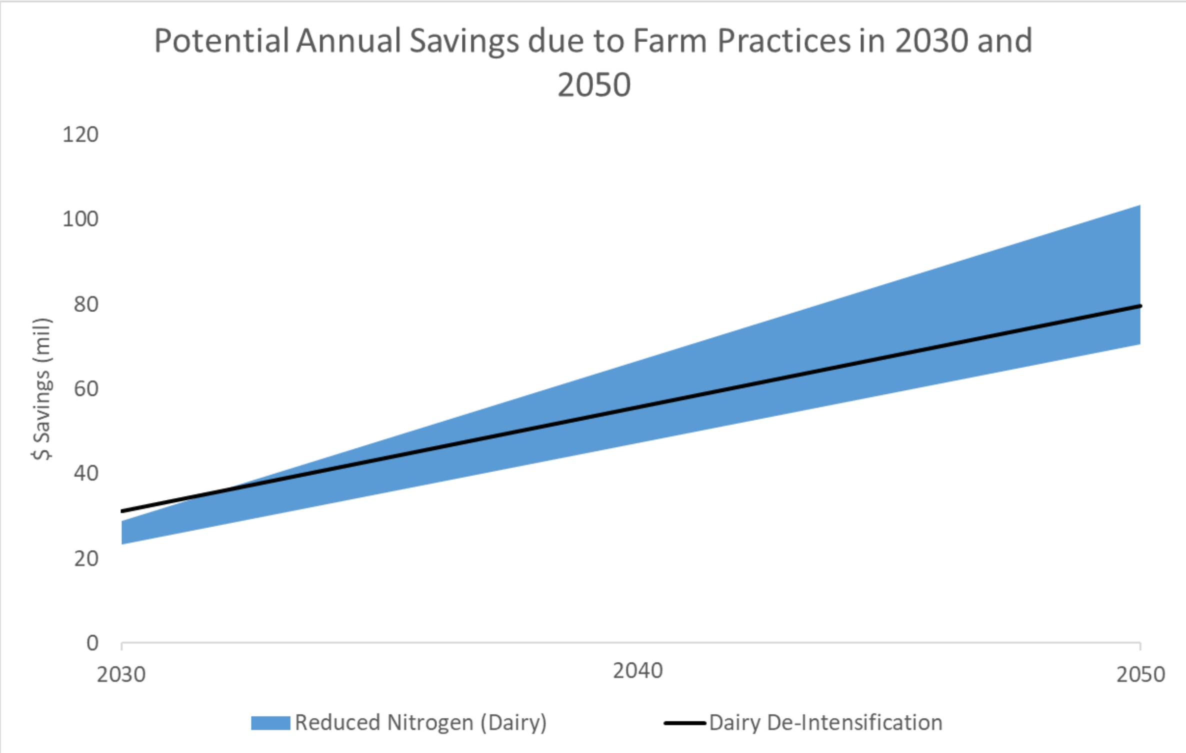
The research produced for Project 2 considered different types of practices and most of the generated outcomes related to the dairy sector. Therefore, for our valuation exercise, we consider two management-related dairy farm practice options from these papers: reduction of nitrogen inputs and dairy de-intensification. Predictions for reduced GHG from the reduction of nitrogen were taken from Reisinger and Clark (2016), while dairy de-intensification model estimates from Reisinger et al. (2018). The latter option is modelled as unwinding dairy systems back towards lower stocking rates and feed inputs, so consequently lower milk production and GHG emissions (Reisinger et al., 2018). The assumed adoption rates, baseline GHG emissions, and resulting emission reductions under each scenario are shown in Appendix Table E.

As above, we show potential savings in 2030 and 2050 in Figure 19. Only one scenario is available for dairy de-intensification, and so a single line is shown rather than a band. Again, we show a linear increase from 2030 to 2050 (see footnote 16). Cumulative savings over the period

[16] Given our assumption of compounding interest, the linear representation shown here is a close approximation to the yearly growth rate of the carbon price. The value for 2030 is $31.17 per ton of CO_2eq and for 2050 $44.23 per ton CO_2eq.
[17] This number includes sheep farms, sheep-beef cattle farms, and grain-sheep and grain-beef cattle farms.
[18] This last value of $44 per sheep is similar to the one mentioned by Dr Rowe in the news article referenced in footnote 11.

from 2030 to 2050 are predicted to lie between $984 and $1,389 million for dairy de-intensification and at $1,163 million for the reduction of nitrogen inputs. At the number of dairy cattle farms in New Zealand in 2012 – 12,150 (Statistics New Zealand 2012) – this implies a saving of $3,858–5,446 per farm per year for reduced nitrogen inputs and of $4,559 per farm for dairy de-intensification – assuming no change in the number of farms over these years. Alternatively, considering projections in the number of dairy cows to 2050 described in Reisinger and Clark (2016), the value would amount to $108–180 per cow for reduction in nitrogen and $127–151 per cow for de-intensification (over the 21-year period).

Figure 19: Potential savings from reduction in nitrogen and dairy de-intensification, based on simulations of Reisinger and Clark (2016) and Reisinger et al. (2018).



As with Project 1, it is important to re-emphasise that we do not model any sort of extra costs or loss of productivity associated with farmers' implementation of practices related to Project 2. Even though researchers claim that some of these practices can be characterised as "no-cost" (i.e. practices that should not negatively affect profits; de Klein and Dynes, 2017), some may still have effects on the level of profits across farms.

7.2.1 Alternative Carbon Price Scenarios

Alternative scenarios with different carbon prices under a potential future Agricultural ETS can also be imposed to the analyses performed above. These different scenarios can be considered by assuming higher or lower carbon price levels in 2030 or price variations to 2050 changing at higher or lower rates. As the number of scenarios possible to test is large, we do not provide alternative sets of values here. These alternatives can easily be pictured by proportional changes to carbon prices and consequent value estimates. The main point to consider here is that under an Agricultural ETS in the future, benefits from agricultural mitigation options or practices will be appraised, but undoubtedly they will vary according to the potential stringency of the carbon price market or regulation and how this changes over time.

Finally, an important point to consider in this analysis is that of a carbon price of zero, that is, a scenario in which there is no Agricultural ETS (or other agricultural GHG regulation that would produce a similar response that a carbon price). In the case of no Agricultural ETS, it can easily be claimed that most of the benefits generated by agricultural mitigation research will never materialise: as farmers will face no incentives to reduce their emissions, they will not take up options or practices to reduce GHG emissions. Under this scenario, the economic value estimated above will simply drop to zero. However, this "zero economic value" can be avoided under specific circumstances and scenarios. We highlight some potential cases here, but this is an area that could benefit from more research as it relates to the uptake of mitigation options given no Agricultural ETS framework. Two scenarios or circumstances to take into consideration include:[19]

1. New Zealand farming industry is capable of generating premium products that market commodities under a "low GHG footprint" label. Conditional on demand, this case will provide incentives to farmers (in the form or price premiums) for the voluntary uptake of agricultural mitigation options or practices, generating in this way an economic value to mitigation efforts.
2. Organic, or similar, farming philosophies are expanded across the country, such that farmers would voluntarily adopt low-emission practices and/or options. In 2016, only 0.7% of New Zealand agricultural land was under organic certification, which is relatively small compared to those in other OECD countries (for instance, in Australia, the share is 6.7%; FiBL & IFOAM – Organics International, 2018). Of course, the rate of adoption of mitigation options or practices in a small proportion of farms in New Zealand will not generate much value to mitigation research, but if the rate of "organic" farming could be improved with educational programmes or similar initiatives, more benefits accrue from the invested mitigation research.

[19] These scenarios can also happen in the case of an operating Agricultural ETS, in which they would contribute to the value generated by the policy.

7.3 Environmental Values

The analysis in the previous subsection evaluates the benefits associated with reduced GHG emissions in terms of a potential future carbon price to monetise the environmental improvement that would result. If monetisation of these benefits is not desired, they can be characterised simply in terms of the physical reductions in emissions. For Projects 1 and 2 the ranges of reduced annual emissions by 2050 are predicted to be 273–3,100 and 3,393-3,140 kt CO_2eq, respectively.[20] Although these amounts are a tiny fraction of all New Zealand emissions, let alone the world's, the difference could be more substantial if they were extended to other countries.

For the economic and environmental results discussed, caveats should be made for both cases in terms of the assumptions used (see Appendix Table E) and the consideration that farmers might face barriers to adopt these options or practices, including skills that might be needed to apply these into different contexts. For options related to Project 2, the GHG reduction potential is more limited to New Zealand pastoral systems and farming skills are more critical for their application. For Project 1, on the other hand, application could be achieved in more contexts, so environmental benefits in terms of lower GHG emissions internationally could be large given the potential of having sheep emitting 10% less methane through a tool used by sheep farms across the globe. In a back-of-the-envelope calculation, if we consider that total worldwide CH_4 emissions by sheep were approximately 177 million tonnes in 2010, the low-emission sheep trait originating from New Zealand could result in savings up to approximately 17 million tonnes of CH_4 annually(FAO, 2017).[21] Considering that CH_4 is approximately equivalent to 25 CO_2 in terms of warming potential, this hypothetical methane reduction is equal to 425 billion tonnes of CO_2eq less in a year, which is around 5 times all New Zealand gross CO_2eq emissions in 2013 (StatsNZ, 2017).[22] For Project 2, the mitigation options are more difficult to extrapolate to the world as they are much more dependent on the New Zealand context. However, the models developed under Project 2 can be used as base for different context, therefore also contributing to agricultural mitigation efforts in other countries.

[20] Ranges from various scenarios and assumptions as shown in Appendix Table E. The range for Project 2 assumes both reduction in nitrogen inputs and dairy de-intensification are adopted and that the resulting emission reductions are cumulative.

[21] Emissions based on milk and meat production from sheep in the reference year of 2010 and excludes fibre production.

[22] These are estimates done only as reference to a hypothetical use of low-emission sheep instead of all sheep grazing in the world. Such a hypothesis is, of course, implausible in current conditions.

7.4 Value from Intellectual Property: Patents

The protection of intellectual property is generally intended to protect the commercial value of research and products. In this way, the use of patents to protect intellectual property can be understood as a signal that the related research would have important direct and/or indirect use values. To explore the role of patents on our projects, we performed a search of patents citing the papers listed in Appendix Table C, using the online platform Lens.org.[23] We found Beukes et al. (2011) had been cited by the search reports of two patents, and Beukes et al. (2010) by the search report of one of those same patents. The search report of a patent application is carried out by the patent office to assist the decision of whether the application can be patented. In both cases the search report did not come from New Zealand, so value from patents for the country were not observed. The relevant patents citing in their search report the papers of Beukes et al. (2010, 2011) are presented in Appendix Table E. We found no matches to any of the other publications listed in Appendix Table C, therefore concluding that no patents were established as direct or indirect action of either Project 1 or 2.

8 Conclusion

Evaluating the benefits of publicly funded research is always a challenging task because of the long and uncertain lags between research and impact, the conditionality of impact on external factors, the difficulty of quantifying non-economic benefits, and the difficulty of knowing how possible impacts differ from the counterfactual of no public research. The current analysis faces all these challenges, and so we cannot produce air-tight quantification of the benefits of SLMACC research. We have, however, demonstrated that the key building blocks of significant impact have been obtained.

First, it is clear that public funding has contributed importantly to New Zealand's positioning itself as one of the leading global contributors to agricultural mitigation research. While this is not sufficient to prove significant broader benefits, it is certainly a necessary condition and a major accomplishment in and of itself. Second, the prominence of the research combined with the low likelihood of research occurring on this scale without public support suggests strongly that the results have been obtained through public funding. Finally, although the realisation of ultimate environmental and/or economic benefits will depend on the evolution of farming practices and climate change policy settings, the advances in genetic markers for low CH_4 animals and the identification of emission-reducing management practices have the *potential* for GHG emission reductions that would be significant in environmental

[23] Lens.org is a comprehensive online database of world patents.

terms and whose value at likely ETS pricing levels would be in the hundreds of millions of dollars.

We show and discuss in this work that with a potential future regulation of agricultural emissions, the use of on-farm mitigation options can generate important economic savings for the agricultural sector and importantly reduce the carbon footprint of farms. The results discussed are conditional on several factors, such as future policy implementation, adoption rates, and the practical availability of mitigation options and practices for different farm landscapes. Nevertheless, the impacts and economic and environmental values attached to mitigation research cannot be overlooked and provide important insights into the benefits that public investments can make in the development of a more sustainable agricultural system for the country.

9 References

Adler, Alfredo A., Graeme J. Doole, Alvaro J. Romera, and Pierre C. Beukes. 2012. "Identification of Cost-Effective Management Options for Reducing Greenhouse Gas Emissions by 10% on a Dairy Farm in Waikato, New Zealand." *Proceedings of the New Zealand Society of Animal Production,* 72, pp. 181–85.

Adler, Alfredo A., Graeme J. Doole, Alvaro J. Romera, and Pierre C. Beukes. 2013. "Cost-Effective Mitigation of Greenhouse Gas Emissions from Different Dairy Systems in the Waikato Region of New Zealand." *Journal of Environmental Management,* 131, pp. 33–43.

Beukes, P. C., P. Gregorini, and A. J. Romera. 2011. "Estimating Greenhouse Gas Emissions from New Zealand Dairy Systems Using a Mechanistic Whole Farm Model and Inventory Methodology." *Animal Feed Science and Technology,* 166, pp. 708–720.

Beukes, P. C., P. Gregorini, A. J. Romera, G. Levy, and G. C. Waghorn. 2010. "Improving Production Efficiency as a Strategy to Mitigate Greenhouse Gas Emissions on Pastoral Dairy Farms in New Zealand." *Agriculture, Ecosystems & Environment,* 136:3–4, pp. 358–65.

Bramble, Tyler Cole, James Dennison Johnston, Robin Alexander Johnston, and Karl A. Dawson. 2017. Systems and Methods for Estimating Feed Efficiency and Carbon Footprint for Meat Producing Animal. European Union EP3089595A4, filed December 31, 2014, and issued November 15, 2017. https://patents.google.com/patent/EP3089595A4/en/und.

Chiba, M. K., R. Cichota, and I. Vogeler. n.d. "Can We Improve Interpolation of N_2O Emission Measurements by Using Environmental Factors?", in *Advanced Nutrient Management: Gains from the Past – Goals for the Future,* L.D. Currie and C L. Christensen Eds.

Clark, H., F. Kelliher, and C. Pinares-Patino. 2011. "Reducing CH 4 Emissions from Grazing Ruminants in New Zealand: Challenges and Opportunities." *Asian-Australasian Journal of Animal Sciences,* 24:2, pp. 295–302.

De Klein, C. and R. Dynes. 2017. "Analysis of a New Zealand-specific No-cost Option to Reduce Greenhouse Gas Emissions from Dairy Farms". Paper prepared for Motu. Available soon.

Doole, Graeme J., Alvaro J. Romera, and Alfredo A. Adler. 2012. "A Mathematical Optimisation Model of a New Zealand Dairy Farm: The Integrated Dairy Enterprise (IDEA) Framework."

———. 2013. "An Optimization Model of a New Zealand Dairy Farm." *Journal of Dairy Science,* 96:4, pp. 2147–60.

Dorner, Z., Djanibekov, U., Soliman, T., Stroombergen, A., Kerr, S., Fleming, D., Cortes-Acosta, S. and S. Greenhalgh. 2018. "Land-Use Change as a Mitigation for Climate Change." Motu Report to the Biological Emissions Reference Group.

Elmes, S. N., W. E. Bain, G. J. Greer, S. M. Hickey, E. A. Young, N. K. Pickering, S. J. Rowe, K. J. Knowler, C. S. Pinares-Patino, and J. C. McEwan. 2014. "An Exploratory Investigation of the Effects of Selection for Divergence in Methane Emissions on Rumen Digesta and Carcass Traits in Eight-Month-Old Sheep." In *Proc. NZ Soc. Anim. Prod.*, 74, pp. 142–4.

European Science Foundation (2012). "A Guide to Evaluation Activities in Funding Agencies." A report by the ESF MO Forum on Evaluation of Publicly Funded Research. Available at: http://archives.esf.org/coordinating-research/mo-fora/evaluation-of-publicly-funded-research.html

FAO. 2017. "FAO – GLEAM Global Greenhouse Gas Emissions from Livestock Summary Data." http://www.fao.org/fileadmin/user_upload/gleam/docs/GLEAM_Data_public_release.xlsx.

FiBL & IFOAM – Organics International. 208AD. "The World of Organic Agriculture Statistics & Emerging Trends 2018." Available at: https://shop.fibl.org/CHen/mwdownloads/download/link/id/1093/?ref=1

Giltrap, D. L., I. Vogeler, R. Cichota, J. Luo, T. J. van der Weerden, and C. A. M. de Klein. 2015. "Comparison between APSIM and NZ-DNDC Models when Describing N-Dynamics under Urine Patches." *New Zealand Journal of Agricultural Research,* 58:2, pp. 131–55.

Gregorini, P., P. C. Beukes, M. D. Hanigan, G. Waghorn, S. Muetzel, and J. P. McNamara. 2013. "Comparison of Updates to the Molly Cow Model to Predict Methane Production from Dairy Cows Fed Pasture." *Journal of Dairy Science,* 96:8, pp. 5046–52.

Hanigan, M. D., J.A.D.R.N. Appuhamy, and P. Gregorini. 2013. "Revised Digestive Parameter Estimates for the Molly Cow Model." *Journal of Dairy Science,* 96:6, pp.3867–85.

Jaffe, A. 2015. "A Framework for Evaluating the Beneficial Impacts of Publicly Funded Research." *Motu Note 15*, Motu Economic and Public Policy Research Trust, Wellington, New Zealand

Jaffe, Adam B. 2017. "Barriers to Adoption of No-Cost Options for Mitigation of Agricultural Emissions: A Typology." *Motu Note 24.* Motu Economic and Public Policy Research, Wellington, New Zealand.

Kaiser, Roger, Paul Silverman, and Jim Wargo. 2016. Methods to Increase Silage Quality in Crops. European Union EP2950663A4, filed January 30, 2014, and issued August 31, 2016. Available at: https://patents.google.com/patent/EP2950663A4/en.

Kittelmann, Sandra, Cesar S. Pinares-Patino, Henning Seedorf, Michelle R. Kirk, Siva Ganesh, John C. McEwan, and Peter H. Janssen. 2014. "Two Different Bacterial Community Types Are Linked with the Low-Methane Emission Trait in Sheep." *PLoS One,* 9:7, e103171.

Macilwain, C. (2010). "What Science Is Really Worth." *Nature,* 465, pp. 681–4.

New Zealand Treasury, 2015. "Guide to Social Cost Benefit Analysis", https://treasury.govt.nz/publications/guide/guide-social-cost-benefit-analysis

NZAGRC-PGgRC. 2016. "The Structure of the Agricultural Greenhouse Gas Research Funding in New Zealand." Available at: https://www.pggrc.co.nz/files/1500851649628.pdf

Pickering, N. K., V. H. Oddy, J. Basarab, K. Cammack, B. Hayes, R. S. Hegarty, Jan Lassen, J. C. McEwan, S. Miller, and C. S. Pinares-Patino. 2015. "Animal Board Invited Review: Genetic Possibilities to Reduce Enteric Methane Emissions from Ruminants." *Animal,* 9:9, pp. 1431–40.

Pinares-Patino, C. S., Seyed Hadi Ebrahimi, J. C. McEwan, K. G. Dodds, H. Clark, and D. Luo. 2011. "Is Rumen Retention Time Implicated in Sheep Differences in Methane Emission?" In *Proceedings of the New Zealand Society of Animal Production*, 71, pp. 219–22.

Pinares-Patino, C. S., S. M. Hickey, E. A. Young, K. G. Dodds, S. MacLean, G. Molano, E. Sandoval, H. Kjestrup, R. Harland, and C. Hunt. 2013. "Heritability Estimates of Methane Emissions from Sheep." *Animal,* 7: suppl 2, pp. 316–21.

Pinares-Patino, C. S., J. C. McEwan, K. G. Dodds, E. A. Cárdenas, R. S. Hegarty, J. P. Koolaard, and H. Clark. 2011. "Repeatability of Methane Emissions from Sheep." *Animal Feed Science and Technology,* 166, pp. 210–8.

Reisinger, A. and H. Clark. 2016. "Modelling Agriculture's Contribution to New Zealand's Contribution to the Post-2020 Agreement." *MPI Information Paper* No: 2016/02.

Reisinger, A., et al. 2018. "Future Options to Reduce Biological GHG Emissions On-farm: Critical Assumptions and National-scale Impact." Report prepared by the New Zealand Agricultural Greenhouse Gas Research Centre.

Sanderson, T., Reeson, A. and P. Box. 2017. "Understanding and Unlocking the Value of Public Research Data – OzNome Social Architecture Report." CSIRO, Australia.

Sharp, B. and Kerr, G. 2005. "Option and Existence Values for the Waitaki Catchment." Report prepared for the Ministry of the Environment. Wellington, New Zealand.

Shepherd et al. 2016. "An Assessment of Climate Mitigation Co-Benefits Arising from the Freshwater Reforms." Report produced for the MPI, New Zealand. Available at: https://www.mpi.govt.nz/dmsdocument/16849/loggedIn

Stats NZ. 2017. "New Zealand Greenhouse Gas Emissions". Available at: http://archive.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Atmosphere-and-climate/nz-greenhouse-gas-emissions/nz-greenhouse-gas-emissions-archived-19-10-2017.aspx

Romera, Alvaro J., Gil Levy, Pierre C. Beukes, Dave A. Clark, and Chris B. Glassey. 2012. "A Urine Patch Framework to Simulate Nitrogen Leaching on New Zealand Dairy Farms." *Nutrient Cycling in Agroecosystems,* 92:3, pp. 329–46.

Rowe, S., J. C. McEwan, S. M. Hickey, R. A. Anderson, D. Hyndman, E. Young, H. Baird, K. G. Dodds, C. S. Pinares-Patino, and N. K. Pickering. 2014. "Genomic Selection as a Tool to Decrease Greenhouse Gas Emission from Dual Purpose New Zealand Sheep." In *Proceedings of the 10th World Congress of Genetics Applied to Livestock Production*, pp. 17–22.

Van der Weerden, Tony, Arjan Jonker, David Fleming, Kate Preston, Cecile de Klein, and David Pacheco. 2018. "A Review of SLMACC-funded Agricultural Greenhouse Gas Mitigation Research in New Zealand." Report to the MPI, Wellington, New Zealand. (Forthcoming).

Vogeler, I., P. Beukes, and V. Burggraaf. 2013. "Evaluation of Mitigation Strategies for Nitrate Leaching on Pasture-Based Dairy Systems." *Agricultural Systems,* 115, pp. 21–8.

Vogeler, Iris, Donna Giltrap, Frank Li, and Val Snow. 2011. "Comparison of Models for Predicting Nitrification, Denitrification and Nitrous Oxide Emissions in Pastoral Systems." In *19th International Congress on Modelling and Simulation, Perth, Australia*, pp. 12–6.

Vogeler, Iris, Pierre Beukes, Alvaro Romera, and Rogerio Cichota. 2012. "Estimating Nitrous Oxide Emissions from a Dairy Farm Using a Mechanistic, Whole Farm Model and Segregated Emission Factors for New Zealand." *Soil Research,* 50:3, pp. 188–94.

Appendix

Keywords Used in Scopus Queries Search

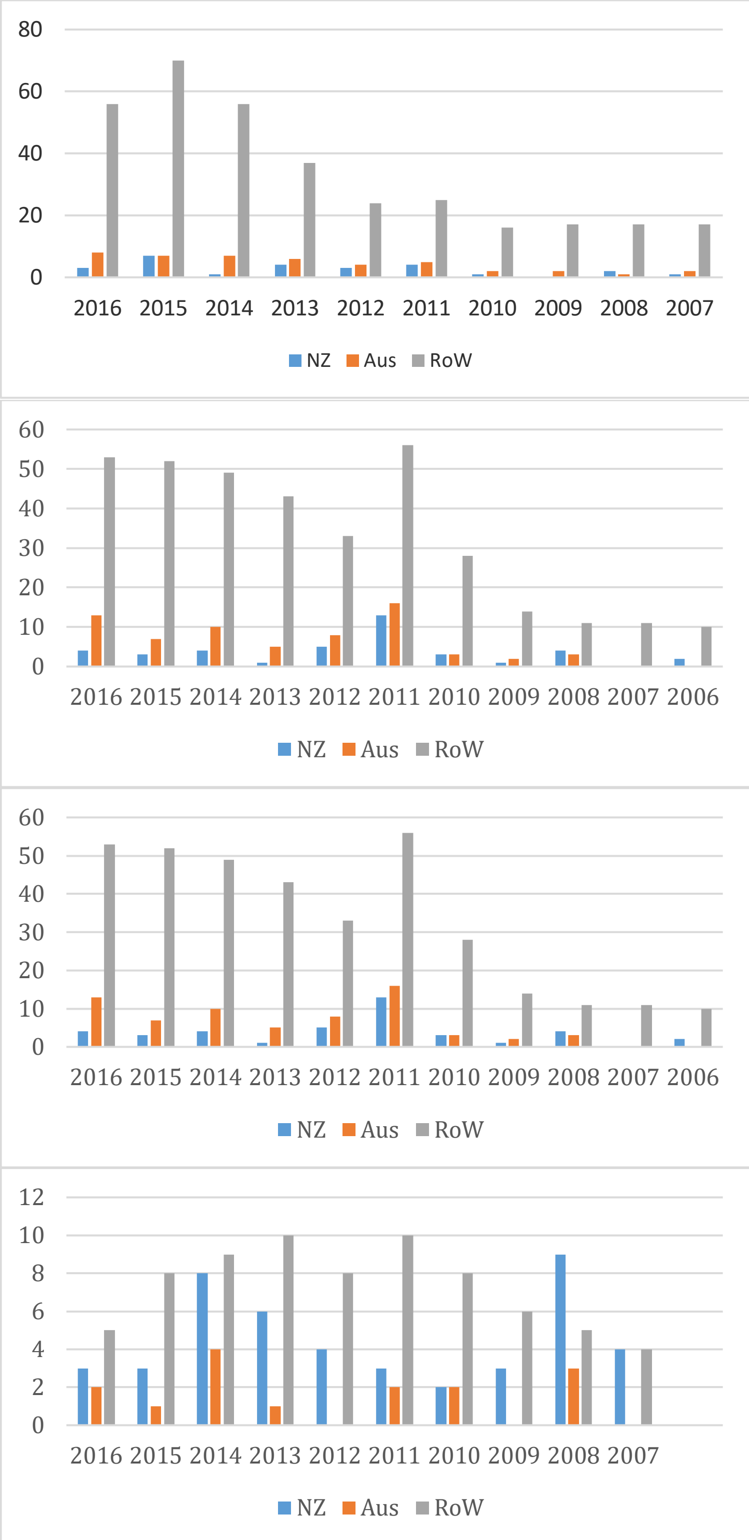
Appendix Table A: Keywords used in Scopus queries search

Mitigation option cluster	Scopus query used	Number of papers obtained
CH_4 inhibitors/vaccine	TITLE-ABS-KEY (methanogen AND inhibitors) OR TITLE-ABS-KEY (methane AND vaccine) OR TITLE-ABS-KEY (anti-methanogen) OR TITLE-ABS-KEY (methanogen AND inhibitors) OR TITLE-ABS-KEY (methanogenesis AND agric*)	723
Low GHG animals	TITLE-ABS-KEY (methane AND ((animal AND genetics) OR (ruminants AND genetics) OR (breeding AND value))) OR TITLE-ABS-KEY (animal AND genetics AND greenhouse AND gases)	
Low GHG feed	TITLE-ABS-KEY (greenhouse AND gases AND feed AND ((forage AND rape) OR pasture OR ryegrass OR (animal AND diet) OR biochar OR (urine AND additives) OR (soil AND additives) OR (forage AND crop) OR brassica OR supplement OR concentrate OR (plant AND secondary AND compound) OR silage OR starch OR excreta OR lipid OR fat OR tannin OR (essential AND oil) OR silage OR (urine AND dung)))	621
Management interventions	TITLE-ABS-KEY (greenhouse AND gases AND farm AND (model OR (irrigation AND management) OR (Farm systems) OR (Life cycle analysis) OR (management AND (pasture OR grazing OR feeding OR fertiliser OR manure OR effluent))))	1,849
Reduced N_2O from soil/plants	TITLE-ABS-KEY (farm AND (Urease inhibitor) OR (nitrification inhibitor) OR (biochar AND greenhouse gases) OR (DCD) OR (process inhibitors))	198

Note: This search was conducted on June 2018.

Number of Publications over Time for the Five Clusters

Appendix Figure 1: Publication numbers for period 2007–16. From top to down: Low GHG animals, Low GHG feed, Management interventions, and Reduced N_2O from Soil/plants clusters. Sourced from Scopus.



Funding Overview of Mitigation Organisations

Here we present funding invested by NZAGRC and SLMACC on agricultural mitigation research. As seen in Table A3 the NZAGRC has invested considerable part of its total core research funding Methane research. Part of this has gone to fund low-emitting animals' research, which has complemented the initial investment of SLMACC on project METH901.

On the other hand, in 10 years (2007-2017), the SLMACC Programme has invested approximately $25 million dollars in agricultural mitigation research, of which $17 million has been focused in mitigation options science (van der Weerden et al. 2018). Of these $17 million, as seen in table 1, $150,000 were invested in project 1 and $1.5 million in project 2.

Appendix Table B: NZAGRC research spending by financial year (nominal NZ$).

Financial Year	Methane	Integrated Systems	Total Core Research
2009/2010	$671,600	$102,200	1,460,000
2010/2011	$1,142,000	$480,000	3,762,000
2011/2012	$1,023,269	$480,000	3,874,383
2012/2013	$1,087,692	$480,000	3,755,407
2013/2014	$1,379,797	$0	3,352,505
2014/2015	$1,627,395	$742,075	4,837,310
2015/2016	$964,224	$993,430	4,079,041

Source: NZAGRC annual reports, retrieved from https://www.nzagrc.org.nz/annualreport.html

Publication Outputs of Projects 1 and 2

Appendix Table C: Publication outputs of Projects 1 and 2

	Citations in Scopus	No. citing countries	FWCI	Citations in Google Scholar	No. Authors	No. of institutions (international)	Funding acknowledged (SLMACC highlighted)
Project 1 (METH0901)							
Pinares-Patino et al. (2013A)	74	29	11.18	94	12	1	PGgRc, SLMACC & NZAGRC
Clark, Kelliher and Pinares-Patino (2011)*	19	18	1.56	45	3	3	PGgRc, MAF, and the NZ Foundation for Res. Sc. and Tec.
Pinares-Patino et al. (2011A)*	37	19	3.35	60	7	3 (2)	PGgRc
Pinares-Patino et al. (2011B)*	N/A	N/A	N/A	21	6	2	PGgRc
Elmes et al. (2014)*	N/A	N/A	N/A	6	10	2	PGgRc and AGgRc
Kittelmann et al. (2014)*	53	37	6.40	69	7	2	
Pickering et al. (2015)*	17	21	2.68	29	11	3 (2)	
Rowe et al. (2014)	N/A	N/A	N/A	3	10	3	PGgRc, SLMACC, Beef + Lamb NZ, NZ Government
Pinares-Patino et al. (2013B)*	N/A	N/A	N/A	3	12	2	PGgRc
Project 2 (C10X0902)							
Adler, Doole, Romera, Beukes (2013)	14	6	0.96	18	4	2 (1)	

Beukes, Gregorini, Romera (2011)	29	15	4.07	44	3	1	FRST/SLMACC Farm Systems Project No. C10X0902
Beukes, Gregorini, Romera, Levy, Waghorn (2010)	62	19	5.28	108	5	1	PGgRc
Chiba, Cichota, Vogeler	N/A	N/A	N/A	0	3	2 (1)	NZAGRC under a LEARN fellowship, NZ MAF
Doole, Romero, Adler (2012)	N/A	N/A	N/A	2	3	3 (1)	
Doole, Romero, Adler (2013)	18	7	2.40	25	3	3 (1)	
Giltrap et al. (2015)	9	8	2.06	8	6	4	NZAGRC and SLMACC
Gregorini et al. (2013)	11	10	1.60	14	6	4 (2)	SLMACC project C1OXO902 and Dairy NZ
Hanigan, Appuhamy, Gregorini (2013)	20	9	2.08	26	3	2 (1)	Virginia State Dairymen's Assoc. and College of Ag. & Life Sc. at Virginia Tech. Salary support from Dairy NZ
Romera, Levy, Beukes, Clark, Glassey (2012)	21	9	2.36	29	5	1	Dairy NZ and the Ministry of Science and Innovation – Dairy Systems for Environmental Protection (DRCX0802)
Vogeler, Beukes, Burggraaf (2013)	22	10	3.24	30	3	3	MBIE Rural Futures Programme and the DairySystems for Env. Protection
Vogeler, Beukes, Romera, Cichota (2012)	3	2	0.13	3	4	2	NZAGRC and SLMACC.
Vogeler, Giltrap, Cichota (2013)	11	8	0.74	17	3	2	NZAGRC and SLMACC.
Vogeler, Giltrap, Li, Snow (2011)	2	2	0	4	4	3	NZAGRC and SLMACC.

Note: all papers are available online. *denotes papers indirectly related to the SLMACC funding as explained in the text. Papers with N/A means they are not published in Scopus-indexed journals. FWCI = Field-weighted citation index

Journal Metrics of Publication Outputs of Projects 1 and 2

Appendix Table D: Journal metrics of publication outputs of Projects 1 and 2

	Journal name	CiteScore percentile	Journal impact Factor	
			CiteScore	SNIP
Project 1 (METH0901)				
Pinares-Patino et al. (2013A)	*Animal*	87th (Animal Sc. and Zoology)	1.94	1.180
Clark, Kelliher, Pinares-Patino (2011)	*Asian-Australian Journal of Animal Sciences*	71st; 61st (Animal Sc. and Zoology; Food Sc.)	1.28	0.905
Pinares-Patino et al. (2011A)	*Animal Feed Science and Technology*	90th (Animal Sc. and Zoology)	2.11	1.425
Pinares-Patino et al. (2011B)	*Proceedings of the New Zealand Society of Animal Production*	N/A	N/A	N/A
Elmes et al. (2014)	*Proceedings of the New Zealand Society of Animal Production*	N/A	N/A	N/A
Kittelmann et al. (2014)	*PloS ONE*	92nd; 91st; 82nd (General Ag. and Biological Sc.; Medicine; General Biochem, Genetics and Molecular Biology	3.11	1.092
Pickering et al. (2015)	*Animal*	87th (Animal Sc. and Zoology)	1.94	1.180
Rowe et al. (2014)	*Proceedings of World Congress of Genetics Ap. to Livestock Production*	N/A	N/A	N/A
Pinares-Patino et al. (2013B)	*Book chapter*	N/A	N/A	N/A
Project 2 (C10X0901)				
Adler, Doole, Romera, Beukes (2012)	*Proceedings of the New Zealand Society of Animal Production*	N/A	N/A	N/A
Adler, Doole, Romera, Beukes (2013)	*Journal of Environmental Management*	96th; 95th; 91st, 88th (Medicine; Manag., Monitoring, Policy and Law (Env. Sc.); Env. Eng.; Waste Manag. and Disposal)	4.28	1.779
Beukes, Gregorini, Romera (2011)	*Animal Feed Science and Technology*	90th (Animal Science and Zoology)	2.11	1.425
Beukes, Gregorini, Romera, Levy, Waghorn (2010)	*Agriculture, Ecosystems and Environment*	99th; 96th; 95th (Animal Sc. and Zoology; Agronomy and Crop Sc.; Ecology)	4.41	1.828

Doole, Romero, Adler (2012)	Working Papers in Economics, University of Waikato	N/A	N/A	N/A
Doole, Romero, Adler (2013)	*Journal of Dairy Science*	94th; 86th; 62nd (Animal Sc. and Zoology; Food Science; Genetics)	2.66	1.464
Giltrap et al. (2015)	*New Zealand Journal of Agricultural Research*	72nd, 69th, 61st, 54th (Animal Sc. and Zoology; Agronomy and Crop Sc.; Plant Sc.; Soil Science)	1.33	1.096
Gregorini et al. (2013)	*Journal of Dairy Science*	94th; 86th; 62nd (Animal Sc. and Zoology; Food Sc.; Genetics)	2.66	1.464
Hanigan, Appuhamy, Gregorini (2013)	*Journal of Dairy Science*	94th; 86th; 62nd (Animal Sc. and Zoology; Food Sc.; Genetics)	2.66	1.464
Romera, Levy, Beukes, Clark, Glassey (2012)	*Nutrient Cycling in Agroecosystems*	79th; 65th (Agronomy and Crop Sc.; Soil Sc.)	1.84	0.867
Vogeler, Beukes, Burggraaf (2013)	*Agricultural Systems*	97th; 89th (Animal Sc. and Zoology; Agronomy and Crop Sc.)	2.90	1.370
Vogeler, Beukes, Romera, Cichota (2012)	*Soil Research*	75th; 72nd; 70th (Env. Sc. (miscellaneous); Earth-Surface Processes; Soil Sc.)	1.97	1.038
Vogeler, Giltrap, Cichota (2013)	*Science of the Total Environment*	95th; 91st; 91st; 88th (Env. Eng.; Waste Manag. and Disposal; Pollution; Env. Chemistry)	5.09	1.849
Vogeler, Giltrap, Li, Snow (2011)	*19th International Congress on Modelling and Simulation*	N/A	N/A	N/A

Note: Papers with N/A data means they are published in journals not indexed by Scopus.

Assumptions and Other Considerations for R16 and R18

Appendix Table E: Assumptions and other considerations for R16 and R18

Assumptions and Calculations Savings from Selective breeding (emissions in kt CO_2-eq per year)													
Scenario	**Sector**	**Methane mitigation efficacy**	**Adoption**	**Baseline emissions (total agriculture)**		**Baseline emissions (sheep/beef)**		**% reduction from sheep/beef baseline**		**Emissions reduced**		**Savings under assumed carbon price**	
				2030	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
R16 Max efficiency/High adoption	sheep/beef	10%	Starting 2020, increasing linearly until 80% in 2050	43,500	50,300	18,500	20,000	2.10%	6.10%	389	1,220	$12,109,545	$53,960,600
R16 Min efficiency/High adoption	sheep/beef	10%	Starting 2020, increasing linearly until 80% in 2050	40,500	44,500	18,500	17,800	2.10%	6.20%	389	1,104	$12,109,545	$48,812,228
R16 Max efficiency/Low adoption	sheep/beef	10%	Starting 2020, increasing linearly until 30% in 2050	43,500	50,300	18,500	20,000	0.80%	2.30%	148	460	$4,613,160	$20,345,800
R16 Min efficiency/Low adoption	sheep/beef	10%	Starting 2020, increasing linearly until 30% in 2050	40,500	44,500	18,500	17,800	0.80%	2.30%	148	409	$4,613,160	$18,107,762
Sheep Max efficiency/High adoption	sheep	10%	Starting in 2020, increasing linearly until 80% in 2050	43,500	50,300	18,500	20,000	1.40%	4.07%	259	813	$8,073,030	$35,973,733
Sheep Min efficiency/High adoption	sheep	10%	Starting in 2020, increasing linearly until 80% in 2050	40,500	44,500	18,500	17,800	1.40%	4.13%	259	736	$8,073,030	$32,541,485
Sheep Max efficiency/Low adoption	sheep	10%	Starting 2020, increasing linearly until 30% in 2050	43,500	50,300	18,500	20,000	0.53%	1.53%	99	307	$3,075,440	$13,563,867
Sheep Min efficiency/Low adoption	sheep	10%	Starting 2020, increasing linearly until 30% in 2050	40,500	44,500	18,500	17,800	0.53%	1.53%	99	273	$3,075,440	$12,071,841
R18 High efficacy/ adoption	sheep/beef /dairy	Starting in 2020/2025, rising to 3-7% in 2030, 15% in 2050	0% in 2030, 30% (beef/sheep) and 50% dairy in 2050	38,800	40,000			38,200	36,900	600	3,100	$18,702,000	$137,113,000

R18 Low efficacy/ adoption	sheep/beef /dairy	Starting in 2020/2025, rising to 3-7% in 2030, 15% in 2050	5% beef, 10% dairy, 20% sheep in 2030, 50% beef/sheep, 90% dairy in 2050	38,800	40,000			38,800	38,800	0	1,200	$0	$53,076,000
Assumptions and Calculations for Savings from Reduction in Nitrogen Inputs (Dairy)													
		Adoption				**Baseline emissions (dairy)**		**% reduction from dairy baseline**		**Emissions reduced**		**Savings under assumed carbon price**	
	Sector					**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
R16 Max efficiency	Dairy	Beginning 2016, increasing linearly until 100% in 2035				25,000	32,500	3.70 %	7.20 %	925	2,340	$28,832,250	$103,498,200
R16 Min efficiency	Dairy	Beginning 2016, increasing linearly until 100% in 2035				22,000	24,500	3.40 %	6.50 %	748	1,593	$23,315,160	$70,436,275
Assumptions and Calculations for Savings from Dairy De-intensification													
	Sector	**Adoption**		**Baseline emissions (total agriculture)**				**Emissions with mitigation (total agriculture)**		**Emissions reduced**		**Savings under assumed carbon price**	
				2030	**2050**			**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
R18	Dairy	High-intensity farms fall systematically from 25% to 10% in both 2030 and 2050, and low-intensity farms increase systematically from 35% to 50% in 2030 and 70% in 2050.		38,800	40,000			37,800	38,200	1,000	1,800	$31,170,000	$79,614,000

Notes: R16 = Reisinger and Clark (2016); R18 = Reisinger et al. (2018).

Patents Information

The relevant patents citing the Beukes papers are discussed below.

EP2950663A4: Methods to Increase Silage Quality in Crops (Kaiser, Silverman, and Wargo 2016)

Kaiser, Silverman, and Wargo (2016) is also an application to the European Patent Office and claims methods for improving the quality of crop plant silage consumed by animals used for milk and meat production. In particular, the process involved treating plants with a gibberellin, producing silage from the plants, and then feeding the silage to the animals. The methods resulted in higher quality meat and increased milk production.

It is indicated in the search report of Kaiser, Silverman, and Wargo that the Beukes, Gregorini, and Romera (2011) paper was considered relevant to the patent application. This study modelled five mitigation options, one of which was replacing some of nitrogen fertiliser with nitrification inhibitors and the gibberellins (plant growth stimulant). The patent search report made particular reference to the following paragraph from Beukes, Gregorini and Romera (p. 716):

> "When the strategies were implemented individually, none achieved both goals. Increased genetic merit with a lower stocking rate and longer lactations resulted in a substantial increase in milk production/ha, but with very little impact on GHG emissions. Lower N fertilizer use with nitrification inhibitors and gibberellins resulted in 5–10% lower GHG emissions, but with lower milk production compared to the baseline farm. However, when all five mitigations were combined, DM intake decreased by 5–10%, milk production/ha increased by 15–20%, CH4 decreased by 7–12%, urinary N deposited onto pasture decreased by 33–42%, and total GHG emissions decreased by 15–20% compared with the baseline farm. This confirms the conclusion of del Prado et al. (2010) that effectiveness of combined GHG mitigations cannot be assessed by adding the effectiveness of each strategy. These findings have important implications for agricultural GHG mitigation. A Memorandum of Understanding between the New Zealand government and the agricultural sector is focusing on delivery of technologies that would mitigate N_2O and CH_4 emissions by 20% relative to 'business as usual' (i.e., the baseline farm in this study) by the end of the first Kyoto commitment period (2012; Ministry for the Environment, 2008).

EP3089595A4: Systems and Methods for Estimating Feed Efficiency and Carbon Footprint for Meat Producing Animal (Bramble et al. 2017)

Bramble et al. (2017) is an application to the European Patent Office and claims methods for estimating meat-producing animal feed conversion efficiency and carbon footprint. In particular, a digestion model of an animal feed is integrated with weight gain efficiency and carbon footprint. The model allows different feed supplements, or amounts of them, to be chosen in order to reach the desired trade-off in weight-gain efficiency and carbon footprint.

It is indicated in the search report of Bramble et al. (2017) that both Beukes, Gregorini and Romera (2011) and Beukes, Gregorini, Levy, and Waghorn (2010) concern the invention of a method for estimating the impact on carbon footprint of multiple meat-producing animals. In addition, Beukes, Gregorini, Levy, and Waghorn (2010) is concerned with an equivalent invention, but for a single meat-producing animal. The two publications are attributed with providing information on systems for harvesting data from feed compositions and animal conditions and using this to calculate a carbon footprint. Both papers implemented modelling with the Molly cow model in Dairy NZ's Whole Farm Model and Overseer.

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18-08 Sin, Isabelle, Kabir Dasgupt, and Gail Pacheco. 2018. "Parenthood and labour market outcomes." (also a Ministry for Women Report)

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18-03 Sin, Isabelle, Eyal Apatov and David C. Maré. 2018. "How did removing student allowances for postgraduate study affect students' choices?"

18-02 Jaffe, Adam B., and Nathan Chappell. 2018. "Worker flows, entry, and productivity in New Zealand's construction industry."

18-01 Harris, Richard, and Trinh Le. 2018. "Absorptive capacity in New Zealand firms: Measurement and importance."

17-15 Sin, Isabelle, Steven Stillman and Richard Fabling. 2017. "What drives the gender wage gap? Examining the roles of sorting, productivity differences, and discrimination."

17-14 MacCulloch, Robert. 2017. "Political systems, social welfare policies, income security and unemployment."

17-13 Fleming, David A., Arthur Grimes, Laurent Lebreton, David C. Maré and Peter Nunns. 2017. "Valuing sunshine."

17-12 Hyslop, Dean, and Wilbur Townsend. 2017. "The longer term impacts of job displacement on labour market outcomes."

17-11 Carver, Thomas, Patrick Dawson and Suzi Kerr. 2017. "Including forestry in an Emissions Trading Scheme: Lessons from New Zealand."

17-10 Daigneault, Adam, Sandy Elliott, Suzie Greenhalgh, Suzi Kerr, Edmund Lou, Leah Murphy, Levente Timar, and Sanjay Wadhwa. 2017. "Modelling the potential impact of New Zealand's freshwater reforms on land-based Greenhouse Gas emissions"

17-09 Coleman, Andrew. 2017. "Housing, the 'Great Income Tax Experiment', and the intergenerational consequences of the lease"

17-08 Preston, Kate, and Arthur Grimes. 2017. "Migration and Gender: Who Gains and in Which Ways?"

17-07 Grimes, Arthur, Judd Ormsby and Kate Preston. 2017. "Wages, Wellbeing and Location: Slaving Away in Sydney or Cruising on the Gold Coast."

17-06 Leining, Catherine, Judd Ormsby and Suzi Kerr. 2017. "Evolution of the New Zealand Emissions Trading Scheme: Linking."

17-05 Leining, Catherine, Corey Allan and Suzi Kerr. 2017. "Evolution of the NZ ETS: Sectoral Coverage and Points of Obligation."

17-04 Maré, David C., Trinh Le, Richard Fabling and Nathan Chappell. 2017. "Productivity and the Allocation of Skills."

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