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A marginal abatement cost analysis of practice options related to the NLMP program

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Abstract

This research compares expected GHG mitigation and financial returns for practice options examined as part of the NLMP that appear to be financially viable or have the potential to be financially viable. A total of 13 mitigation strategies were analysed for abatement potential and financial outcomes.

Financial outcomes were estimated using representative case studies from eight different farming systems. This project developed a marginal abatement cost curve (MACC) for each of these representative case study farms. The results of case study analysis were then scaled up to estimate the national potential for each of the mitigation strategies examined.

The results suggest that, when all farming systems are considered at national scale, the practice options with the greatest potential to reduce Australia's greenhouse gas emissions inventory are algae, NOP, plant bioactives, vaccination and biochar. However it should be noted that the outputs from these analyses depend greatly on the assumptions made. Some of the assumptions are based on sound scientific evidence, but many do not yet have sufficient experimental results. Further, the cost of implementation would need to be reduced for algae, NOP and plant bioactives to become financially viable.

Executive Summary

Meat and Livestock Australia (MLA) commissioned the Australian Centre for Sustainable Business and Development, University of Southern Queensland (USQ) in collaboration with John L Black Consulting to evaluate and compare abatement potential and financial outcomes for a range of GHG mitigation practice options, including those examined as part of the National Livestock Methane Program (NLMP). A major objective of NLMP was to identify strategies that may reduce the emission of methane without impairing productivity. Only limited previous research has been carried out on the financial implications of the adoption of these mitigation strategies.

The mitigation practice options included management practice changes that improve production efficiency and reduce methane emissions, strategies resulting from NLMP project research and strategies considered potentially valuable for reducing methane emissions resulting from research conducted outside NLMP. The management strategies were included in the analyses to demonstrate the relative impact of direct methane mitigation interventions compared with what can be achieved by adopting existing livestock and/or nutrition management options. The practice options analysed were:

- Increased production efficiency
- Phosphorus Supplementation
- Flock type change
- Increased conception and lamb survival
- Genetics
- Vaccination against methanogenic archaea
- Leucaena
- Algae as a feed supplement
- Plant bioactive compounds
- Wheat feeding at high rates to dairy cows
- Grape marc
- Nitrate supplements
- NOP as a feed supplement
- Biochar as a feed supplement

Abatement potential and financial outcomes were estimated utilizing representative case studies from eight different farming systems across the beef, sheep and dairy industries. A marginal abatement cost curve (MACC) was constructed for each of the case studies to identify those mitigation strategies with the greatest potential to both reduce emissions and increase farm profitability. Many methane abatement strategies were evaluated across all farming systems, but some applied only to specific systems.

FarmGAS and *DGAS* were used to estimate emissions reductions and productivity changes, providing a standardised measurement approach across the broad range of methane mitigation practice options examined. These modelling outputs were then used to estimate cash flows related to productivity changes and carbon credits for the investment analysis. Financial modelling was carried out which involved identifying all incremental capital and operating costs associated with the implementation of each practice option on farm. Carbon prices of $0, $14 and $50 per tonne were modelled to reflect the current uncertainty around future carbon prices under the Emissions Reduction Fund.

The results of the case study analysis were then scaled up to estimate the national potential for each of the mitigation strategies under investigation.

The results indicate that the practice options showing the greatest potential for methane abatement across the range of farming systems examined, in order of potential, are algae as a feed supplement, NOP as a feed supplement, plant bioactive compounds, vaccinations against methanogenic archaea, and biochar as a feed supplement. Adoption of some of these strategies by the Australian ruminant industries would provide potential to significantly decrease greenhouse gas emissions from enteric methane. For example, with 10% adoption, algae, NOP and plant bioactives were predicted to reduce methane emissions as CO_2 equivalents by up to 2,4, 1.2 and 1 million tonnes for the Australian beef industry and 660,000, 330,000 and 275,000 for the sheep industry respectively.

In addition, wheat feeding at high rates for dairy cows shows emissions reduction potential for that particular farming system while Leucaena demonstrates potential but is limited to the northern coastal beef regions. Both of these practice options, along with biochar, showed potential to be profitable due to increased productivity, however the cost to establish Leucaena pastures is at least $250/ha making it a long-term investment.

On the other hand, our results indicate that some of the practice options examined show only limited potential for significant emissions reductions. These are genetic selection for industries other than dairy, nitrate supplements, and the two management practices examined for sheep - flock type change and increased lamb survival and conception.

The remaining options examined – increased production efficiency, phosphorus supplementation and grape marc - show moderate potential for emissions reductions. Increased production efficiency and phosphorus supplementation are profitable for some beef farming systems, while grape marc and genetics are expected to be profitable for the dairy industry, potentially making them attractive practice options for some livestock producers.

Several assumptions were made as part of the analysis, and it is important to acknowledge the potential impact of these assumptions on the interpretation of the results. Estimated emissions reductions are based on the research results available at time of writing this report. Some of this research should be considered preliminary and the estimated emissions reductions are therefore expected to be revised as further research is completed.

The financial viability of some of the practice options demonstrating the greatest abatement potential will depend on a significant reduction in the cost of implementation. This is particularly the case for algae, NOP and plant bioactives. The costs of implementation for some of the mitigation strategies were difficult to estimate since the products are either not currently available or require further investment and development to determine a price at which they could be produced at scale. The cost estimates used are based on discussions with industry experts and prices for comparable products from overseas. For example, the current cost of wild-harvest *Asparagopsis* in Australia is approximately $200/kg, while an imported algae is available for $1.50/kg. Our analysis indicates that if *Asparagopsis* can be produced at scale for $1.50/kg and a reasonable proportion of the energy retained is converted to increased growth, this mitigation strategy has the potential to become financially viable and significantly reduce methane emissions across the Australian livestock herd. Vaccination is a low cost, high emissions reduction strategy that has potential to become financially viable if sufficient income can be earned from carbon credits.

Estimated financial outcomes are also closely related to the potential for productivity gains. Those practice options identified above as showing the greatest prospects for methane abatement across the range of farming systems also have potential to provide productivity benefits that would increase their financial viability. However, our ability to model estimated productivity gains was restricted by the availability of research results confirming these gains. For example, while estimated productivity gains are available and have been included in the financial evaluation for biochar, these estimates are based on very preliminary research and are likely to be revised as further research is completed. Confirmed growth rate increases for energy saved were not available from current research for many of the emissions reduction options examined including algae, NOP, plant bioactives and vaccination. Preliminary analysis with vaccination and algae feeding suggest that increasing the energy from methane mitigation that is utilised for productive purposes markedly changed the potential profitability of these mitigation strategies.

The analysis presented in this report shows clearly that the greatest economic benefits come from those methane mitigation strategies that increase animal productivity and have low costs for implementation. The price paid for carbon credits has an impact on profitability, but the effect is generally smaller than the impact of a strategy on animal productivity.

Consequently, adoption of existing livestock and/or nutrition management options generally results in the greatest profitability due to improved productivity, despite relatively low savings in methane emissions. However a word of caution is needed in regard to interpretation of results for management practice options. Simplifying assumptions were used in the extrapolation of prior case study results to our representative case study farms and the national herd. The results achieved in these previous case studies do not fully account for indirect costs and are unlikely to be able to be achieved across all regions. They are included as examples of what might be possible rather than what could generally be expected. Full whole farm modelling is needed when assessing the potential benefit to an individual property. Nevertheless, adoption of productivity and profitability increasing management options that also reduce emissions should be encouraged.

Results from this study can be used to help identify areas of research that are suitable for further investment. Priority areas that have been identified include development of a dose response curve for Leucaena, preliminary research into enhancing the ability of ruminants to capture digested energy, development and cultivation of algae, and plant bioactive compound dose response experiments in sheep and cattle.

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1 Background

1.1 National Livestock Methane Program (NLMP)

Approximately 16% of Australia's greenhouse gas (GHG) equivalent (CO_{2e}) emissions come from agriculture and around 65% of those emissions are derived from livestock digestion, primarily as methane from the stomach (rumen) of cattle, sheep and goats (Wiedemann et al. 2013).Cattle are responsible for about 70% of methane emission from ruminants in Australia.

Methane is 21-times more potent as a GHG than carbon dioxide. Methane loss from ruminants represents from 2-12% of dietary energy they consume depending on their diet and environment, with the higher losses occurring when the animals are consuming lower quality forages.

A major objective of NLMP was to identify strategies that may reduce the emission of methane without impairing productivity. Whilst a reduction in methane output from ruminants could theoretically enhance energy use by the animal improve productivity, for this to occur, any methane mitigation strategies must involve an alternative use for the hydrogen released. Although there appears not to be an accepted value in the literature, a calculation has been undertaken for this project to predict the amount of methane energy saved by inhibiting methane emissions that could be retained for animal productive purposes. Based on knowledge of control by rumen hydrogen concentration of the relative rates of the five pathways for the conversion of glucose from either starch or cellulose fermentation by rumen microbes to volatile fatty acids (Janssen, 2010) it is predicted that around 40% of the energy not lost in methane could be used by the animal. An outline of the calculations used to predict the saving in energy from methane not emitted is provided in Section 4.3 of the report.

The NLMP began on 1 July 2012 with six themes across sixteen individual projects plus a coordination project. The program focused on achieving three main objectives

- Practical on farm options that will achieve significant reductions in methane emissions from livestock;
- Quantify the level of abatement achieved while maintaining productivity; and
- Develop the science to underpin methodologies developed for the Emission Reduction Fund.

In terms of this economic evaluation, outcomes from the sixteen projects were assessed in consultation with the national coordination team to determine the options to be evaluated. The individual projects were:

1. Measuring methane in the rumen under different production systems as a predictor of methane emissions;
2. Development of gas selective membranes (for intra ruminal capsules);
3. Evaluation and optimisation of Greenfeed Emission Monitoring units for measuring methane emissions from sheep and cattle;
4. Genetic technologies to reduce methane emissions from Australian beef cattle;
5. Understanding methane reducing tannins in enteric fermentation using grape marc as a model tannin source;
6. Development of algae based functional foods for reducing enteric methane emissions from cattle;
7. Supplementation with tea saponins and statins to reduce methane emissions from ruminants;

8. Strategic science to develop dietary nitrate and defaunation as mitigation methodologies for grazing ruminants;
9. Practical and sustainable considerations for the mitigation of methane emissions in the northern Australian beef herd using nitrate supplements;
10. Enteric methane mitigation strategies through manipulation of feeding systems for ruminant production in southern Australia;
11. Impacts of Leucaena plantations on greenhouse gas emissions and carbon sequestration in northern Australian cattle production systems;
12. Best choice shrub and inter-row species for reducing emissions and emissions intensity;
13. The mechanism of antimethanogenic effects of bioactive plants and products on methane production in the rumen;
14. Efficient Livestock and Low Emissions from southern grazing systems;
15. Culture independent metagenomic approaches for understanding the functional metabolic potential of methanogen communities in ruminant livestock; and
16. Comparative analyses of rumen microbiomes to mitigate methane and improve feed utilization.

Projects or reports external to the NLMP that have potential to reduce methane emissions from ruminants were also evaluated. These included efficient farm management practices and compounds studied by other scientists:

1. The potential for using improvements in production efficiency to abate greenhouse gas emissions in extensive beef production systems in northern Australia (Eady, 2011)
2. Research & Extension Opportunities to Reduce Emissions and Emissions Intensity from Broadacre Sheep Enterprises (Young, 2013)
3. 3-nitrooxypropanol (NOP) a chemical synthesised by DSM, a global nutrition supply company.
4. Biochar
5. Antimethanogenic vaccination

The non-NLMP research options were included to help identify most promising areas for future R&D funding. Although no research was conducted within NLMP on developing a vaccine, research was directed towards identifying unique *Archaea* surface peptides not found in other rumen microorganisms for use as vaccine antigens. In addition, a review was commissioned to identify ways of using novel synthetic virus like particles and alternative vaccination routes.

This report has been commissioned within three months of the end of the NLMP. The evaluation of the science surrounding the program has been conducted without the final reports from each of the 16 projects and some assumptions made may change as the projects are completed.

1.2 Emissions Reduction Fund

Australia accounts for its emissions by sector including energy, industrial processes, agriculture, land use, land-use change, forestry and waste (Department of Environment 2015) (Table 1). Agriculture accounted for 16% of Australia's emissions in 2012 with little change in total emissions since 1990. Australian farmers are also the largest contributor of emissions to land use, land use change and forestry. These land use emissions have fallen from 25% to 2% or (i.e. a 125.5 million tonne pa reduction) since 1990.

Table 1 Australia's emissions by sector

Sector	Total Emissions '000 2012	Percentage 2012	Total Emissions '000 1990	Percentage 1990
Energy	413,358.85	75%	286,420.00	52%
Industrial Processes	31,205.77	6%	24,141.44	4%
Agriculture	87,360.56	16%	86,832.12	16%
Land Use, Land-Use Change and Forestry	10,920.39	2%	136,492.36	25%
Waste	11,723.27	2%	18,761.77	3%
Total Emissions	554,568.84		552,647.69	

Source –Department of Environment (2015)

Australian governments, both Coalition and Labour, have introduced a suite of legislation since 2001 to underpin Australia's commitment to international emissions targets under the Kyoto Protocol. The legislation includes:

- Emissions Reduction Fund – Carbon Farming Initiative Amendment Bill – 25 Nov 2014;
- Clean Energy Legislative Package – 8 Nov 2011 – repealed 17 Jul 2014;
- Australian National Registry of Emissions Units — 8 Nov 2011;
- Carbon Farming Initiative — 23 August 2011 and 8 November 2011;
- National Greenhouse and Energy Reporting scheme — 28 Sep 2007; and
- Renewable Energy Target — 21 Dec 2000, 07 Sep 2009, 27 Jun 2011, 04 Aug 2011, 18 Nov 2011.

The Emissions Reduction Fund is a program to support board scale emissions reduction within the Australian economy. The Emissions Reduction Fund has superseded the Carbon Farming Initiative and includes the Renewable Energy Target and Energy Efficiency Opportunities. Eligible activities under the Emission Reduction Fund include (Department of Environment, 2015):

- upgrading commercial buildings;
- improving energy efficiency of industrial facilities and houses;
- reducing electricity generator emissions;
- capturing landfill gas;
- reducing waste coal mine gas;
- reforesting and revegetating marginal lands;
- improving Australia's agricultural soils;
- upgrading vehicles and improving transport logistics; and
- managing fires in savannah grasslands.

The Carbon Farming Initiative allowed for projects to be registered in the sectors for agriculture, land use, land-use change and forestry and waste. The broadening of the allowable project base increases the eligible activities to all sectors. Successful bidders or lowest cost projects will be paid a price on the tonnes of carbon equivalents emissions reductions. Under this system, projects will be assessed for risk and commercial readiness upon registration in Emissions Reduction Fund auctions.

This philosophy mirrors the project development under the Clean Development Mechanisms (CDM) under the United Nations Conventions on Climate Change (UNFCCC., 2015). The projects under the CDM are developed for all sectors including large scale project savings in gasses such as sulphur hexafluoride and other industrial gasses.

Table 2 CDM registered projects 2015

	CDM Projects	
Energy	6,822	77%
Industrial Processes	840	9%
Agriculture	219	2%
Land Use, Land-Use Change and Forestry	952	11%
Waste	55	1%
Total Emissions	8,888	

Under this program, emissions savings methodologies are first developed. An application of the methodology or "project" is then developed by an individual or organisation. If approved, the project is implemented and offsets in carbon dioxide equivalent reductions are measured and verified. Under the CDM program (Table 2) there are 8,888 projects registered in 2015 with 219 projects (2%) from the agriculture sector and 952 projects from land use, land-use change and forestry (11%). In assessing the likely success of projects under the Emissions Reduction Fund, we can look to the success of projects under the CDM. Agricultural methodologies have not delivered a large number of projects under the CDM with only 219 of the total of 8,888 projects.

2 Project Objectives

2.1 NLMP practice options research question

Research Question – what is the comparison of expected GHG mitigation and financial returns for practice options examined as part of the NLMP that appear to be financially viable or have the potential to be financially viable.

The research team, in conjunction with the MLA NLMP coordination team, proposed a range of mitigation strategies to be analysed for abatement potential and financial outcomes. These options included management practices that improve production efficiency and reduce methane emissions, strategies resulting from NLMP project research and strategies considered potentially valuable for reducing methane emissions resulting from research conducted outside NLMP. The management strategies were included in the analyses to demonstrate the relative impact of direct methane mitigation interventions compared with what can be achieved by adopting existing livestock and/or nutrition management options. The non-NLMP research options were included to help identify most promising areas for future R&D funding.

The strategies analysed to develop the marginal abatement cost curves were:

- Production efficiency
- Phosphorus Supplementation
- Flock type
- Conception and lamb survival
- Genetics
- Vaccination
- Leucaena
- Algae as a feed supplement

- Plant bioactive compounds
- Wheat feeding at high rates to dairy cows
- Grape marc
- Nitrate supplements
- NOP as a feed supplement
- Biochar as a feed supplement

2.2 NLMP Investment analysis research question

Research question – what are the estimated financial outcomes for a range of possible scenarios for those mitigation options demonstrating the greatest potential

The analyses compared the GHG mitigation options utilizing case studies from a number of farming systems including:

- Northern Coastal Beef (NCB)
- Northern Rangeland Beef (NRB)
- Temperate/Sub-Tropical Beef (TSTB)
- Fine Sheep (FS)
- Medium Sheep (MS)
- Pastoral Sheep (PS)
- Dairy (D)
- Feedlot Beef (FB)

Many methane abatement strategies were evaluated across all farming systems, but some applied only to specific systems. The abatement strategies evaluated for each farming system are shown in Table 3.

The results of the case study analysis were then scaled up to estimate the national potential for each of the mitigation strategies under investigation.

3 Methods

3.1 NLMP practice options

Table 3 Farming systems - modelled methane mitigation strategies

	1	2	3	4	5	6	7	8	9	10
Northern Coastal Beef (NCB)	Production Efficiency	Phosphorus Supplementation	Genetics	Vaccination	Leucaena	Algae	Plant bioactives	Nitrates	NOP	Biochar
Northern Rangeland Beef (NRB)	Production Efficiency	Phosphorus Supplementation	Genetics	Vaccination	Algae	Plant bioactives	Nitrates	NOP	Biochar	
Temperate/Sub-Tropical Beef (TSTB)	Production Efficiency	Genetics	Vaccination	Algae	Plant bioactives	Nitrates	NOP	Biochar		
Fine Sheep (FS)	Conception and Lamb Survival	Flock Type	Genetics	Vaccination	Algae	Plant bioactives	Nitrates	Grape marc	NOP	Biochar
Medium Sheep (MS)	Conception and Lamb Survival	Flock Type	Genetics	Vaccination	Algae	Plant bioactives	Nitrates	Grape marc	NOP	Biochar
Pastoral Sheep (PS)	Conception and Lamb Survival	Flock Type	Genetics	Vaccination	Algae	Plant bioactives	NOP	Biochar		
Dairy (D)	Wheat Feeding	Genetics	Vaccination	Algae	Plant bioactives	Nitrates	Grape marc	NOP	Biochar	
Feedlot Beef (FB)	Genetics	Vaccination	Leucaena	Algae	Plant bioactives	Nitrates	Grape marc	NOP	Biochar	

3.1.1 Increased production efficiency

Production efficiency is one of the two management practice change options modelled for the beef farming system. This scenario serves to highlight the effect that practice change can have on overall emissions reduction and importantly improves GHG emissions intensity (g/kg product) for beef farming systems. Livestock producers ultimately control their individual farming systems and these scenario's serve to demonstrate what can be achieved by practice change. The scenario is based on work by Mr Peter Whip with the practice option measured for emissions and on farm economic improvements (Meat & Livestock Australia, 2015). It is assumed that no two farming systems are the same and so these results may not translate to other farming systems.

Increase in production efficiency through mating earlier has three main outcomes for the this farming system, firstly by mating heifers 12 months earlier there is a reduction in pressure on pastures. Secondly initial mating weights are reduced from 500kg to 450kg with a further reduction in pasture pressure. Lastly this scenario is contingent on lower calf birth weights with improved management on farm leading to improved calving rates and maintaining wiener target weights.

With no adjustment in cow herd numbers, resulting in the total stocking rate (in Adult Equivalents) reducing for the property and turn-off increasing. Any abatement from a system that increases absolute levels of GHG emissions within the project is reliant on > 0% "reverse" leakage, i.e. the increase in production must result in a price signal that causes a marginal producer (with a higher GHG intensity) to reduce production.

Cost of implementation

The modelled emissions savings and profit increases for this scenario were based on Peter Whip's case study results and extrapolated to our case study farms for Australia's three beef farming systems. He achieved increases in gross margin averaging $120 per head. It should be noted that the cost of change within the individual properties is significant in producer time, operational and financial changes including changes to the farming system. The analysis of the scenario for the purposes of this project has been simplistic with significant whole farm analysis required to accurately model changes to an individual farming system.

3.1.2 Wet season phosphorus supplementation

Phosphorus supplementation is the second management practice change option modelled for beef farming systems. There are significant advantages in supplementing animals during the wet season on phosphorus (P) deficient country. The addition of P is likely to have commercial effect and maximise the long term return on investment due to reducing the limitation placed on growth and metabolism by the P deficiency (Eady, 2011). The use of the supplement has multiple effects including:

- Increased nutrient digestibility and increase voluntary feed intake;
- Faster growth rates and higher survival of young cattle;
- Heavier liveweights of heifers at first mating;
- More rapid recovery of body condition for 1st and 2nd calf heifers hence a higher conception rate for the following pregnancy; and
- More body reserves for mature cows leading to better lactation performance and higher rates of conception for the following pregnancy.

Cost of implementation

The P supplement analysis has been simplistic with significant whole farm analysis required to accurately model changes to an individual farming system. The emissions and profitability results have been extrapolated from research by Eady (2011)and adapted to the case studies in this study. The average increase in gross margin per head is $47.

3.1.3 Flock type change

Flock type change is the first management practice option modelled for sheep farming systems. The production efficiency associated with changes in flock type from wool to meat is a key driver for increased profitability and return on investment for producers. The scenario merino ewes are no longer mated with merino rams but as described by Young (2013) with "a terminal sire and surplus merino ewes in the self-replacing flock are also mated to the terminal sires with all ewes producing first cost prime lambs". The improvement in emissions per kilo of meat does not translate to emissions savings in kilos of wool.

Cost of implementation

The modelled emissions savings and profit increases for this scenario were based on research by Young and extrapolated to our case study farms for Australia's three sheep farming systems. The analysis of the scenario for the purposes of this project has been simplistic with significant whole farm analysis required to accurately model changes to an individual farming system. Average savings are applied at the rate of $4.29 per DSE.

3.1.4 Increased lamb conception and survival

The second management practice option modelled for sheep farming systems was increased lamb conception and survival. As described by Young (2013) "increase lamb survival by 10% and increase conception by 10% then the improvement in EI and profit would be slightly greater than 12% and 17% because as on-farm techniques conception and survival are more than additive".

Cost of implementation

The modelled emissions savings, increases to conception rates and profit for this scenario were based research by Young and extrapolated to our case study farms for Australia's three sheep farming systems. The analysis of the scenario for the purposes of this project has been simplistic with significant whole farm analysis required to accurately model changes to an individual farming system. Average savings are applied at the rate of $2.04 per DSE.

3.1.5 Genetics

Genetic variability is inherent between animals of the Australian red meat industry and is known to apply to methane emissions. The variation in methane emissions is due to a lower feed intake for the same growth rate (known as low residual feed intake, RFI) and/or a lower methane production for the same feed intake (known as residual methane production, RMP). Research within NLMP and related sheep projects, funded under Filling the Research Gap 2 program, have demonstrated that methane emissions(expressed as methane per unit of feed intake – methane yield, which is equivalent to RMP) has a moderate heritability of about 0.2 in both cattle and sheep.

Results from NLMP project 91200; B.CCH.6310 and summarised in the CFI scoping document[1] suggest that bulls with low RFI can have an 8% lower feed intake for the same growth rate. Similarly, it was shown that bulls with a low RMP can produce about 7.7% lower methane output for the same feed intake (Cohn et al 2014, see footnote below). However, such bulls need to be identified and selected for breeding so their genetic contributions realised in the commercial herd over time. The rate of genetic progress will depend on the heritability, the magnitude of the difference in methane emissions between the selected bulls and the herd average, the accuracy of measurement of the traits and on the generation interval(average age of the parents when progeny are born in the bull breeding herd) of the animals. There is also a lag from the time that the traits are introduced into the bull breeding herd and their realisation in the commercial herd where bulls are used.

Estimated values for annual changes in RMP based on observed heritability, generation intervals and structure for moving genes throughout an animal class are provided in Table 4 for the different animal classes. BREEDPLAN is developing a new index which includes RFI for southern beef breeds but this has not yet been released to bull breeders. There is a clear need to define the relationship between RFI and methane emissions. The central question relates to the scale of the reduction in methane emissions with the reduction in food intake. There is unlikely to be a tool in the medium term for estimating breeding values for RFI for northern cattle or for sheep.

The models have also been developed to include RMP but there are insufficient data at present to incorporate RMP within a commercial bull breeding program. Hence the application of RMP will require more data to be collected on animals (bulls with a wide genetic influence) that are important contributors to the Southern beef herd. The reality is that it will be some time (5 years or more) before sufficient data are likely to be available to make robust estimates of the genetic merit of a sufficiently large proportion of the contributors to the genetics of the Southern beef herd to make sound recommendations to the industry re selection for RMP. Implementation will also require the use of genomic selection methodology which is under development but is critically dependent on two factors: high quality phenotypes that are collected on important genetic contributors (bulls and bull breeding herds).

While genetic approaches will be effective in reducing methane emissions, there are three fundamental issues to consider with respect to the implementation of such approaches: firstly, what is the likely penalty in terms of the rate of genetic gain in productivity traits (weight gain, fertility) that directly influence profitability due to diverting selection pressure away from productivity towards reducing methane; secondly the requirement that genomic selection approaches are being implemented within the bull breeding herds; and thirdly the monetary value (contribution to profitability) of methane reduction (compared with the value of other traits).

Table 4 Estimates of annual reductions in methane emissions based on heritability, generation interval and traditional methods for spreading genes within an animal class and r RMP

Stock type	RMP (% annual difference)

Southern beef[1]	0.4% per year; 8% after 20 years
Feedlot cattle	0.4% per year; 8% after 20 years
Northern beef[2]	0.4% per year; 8% after 20 years
Sheep[3]	0.4% per year; 8% after 20 years
Dairy cows[4]	16% per year after 10 years

Due to the nature of variation within farming systems, different approaches need to be taken for southern beef cattle, northern beef cattle, sheep and dairy cows. Feedlot cattle are assumed to be similar to southern beef cattle. The annual rate of progress is higher in dairy cows because of the greater efficiency with which new genes are spread across herds through more intense selection of animals and the use of artificial insemination. Although selecting for RFI may reduce animal body fat content and fertility, this is not likely in southern beef cattle, feedlot cattle or dairy cows because intakes and body condition scores are usually maintained at higher levels than for animals in other regions. RFI is assumed to be not applicable for northern cattle and sheep.

The MACC analyses presented in Section 4.1 assume the impact of genetic selection has been applied across all animal classes. However, the time for this to be achieved will vary widely between classes because of the structure of the industries. Estimates for time to application are 2-3 years for dairy cattle, 4-5 years for southern beef and feedlot cattle and 10-20 years for northern beef cattle and sheep.

Adoption of technology

The assessment of adoption is based on the sire requirement (which requires an estimate of the effective life of sires in commercial flocks and herds) and an estimate of production capacity (and estimated sales of sires) in the seed stock sector. The data for beef cattle in Table 4 indicate that after allowing for the lag from the time that bull breeders first incorporate EBVs for methane emissions to the time that the changes are being realised in the commercial herd will mean that after 20 years of selection that the net change in methane emissions will be around 8% at 100% adoption.

Therefore the rate of uptake (adoption) of improved genetics via sires used in the commercial sector is required. This has been taken from a recent report to MLA[5] (Table 5). This table provides the estimates based on numbers of sires generated from recorded herds/flocks (proxy for adoption rate) from 2001/02 to 2011/12 together with estimates of lifetime coverage (females per male lifetime) – that is, the capacity of the seed stock sector to directly supply the commercial sector needs for breeding sires. Therefore Table 5presents an estimate of the number of sires required to service the various industry sectors in 2012. We ask the question '*how many sires would be required to be purchased each year to mate X million females to a defined sire type given typical joining rates*?'

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[1]Fennessy, Byrne & Proctor2015 - Estimating the potential impact of different mitigation strategies to reduce methane output from beef cattle (B.CCH.6133); Draft Report to MLA, May 2015

[2]Assumed the same as southern beef. Although lower adoption expected for northern beef.

[3] Heritability similar to cattle - FRG2 project 7310. Although lower adoption expected for sheep.

[4]Heritabilities approximately double beef cattle - Bell et al (2014) Breeding dairy cows to reduce greenhouse gas emissions. http://dx.doi.org/10.5772/50395.

[5]Table from Fennessy, Byrne, Amer & Martin; Evaluating the impact of animal genetics and genomics RD&E investment, Report to MLA July 2014 (B.EVA.0001 & B.EVA.0002)

Table 5 Estimates of sire requirement and the capacity to generate recorded sires in 2012

	Estimated requirement for sires in 2012		Estimated capacity to generate sires		Estimated adoption rate
	Number of females mated	Total sires required	Number of recorded females mated	Sire generation capacity	
Sheep (38 M ewes to be mated, at 150 joinings per ram lifetime)					
Merino rams	20.6 M	137,500	102,000	24,200	18%
Terminal rams	9.4 M	63,000	131,000	42,600	68%
Maternal rams	8.0 M	53,600	74,000	22,200	41%
Southern Beef (3.2 M cows to be mated at 95 joinings per bull lifetime)					
Terminal bulls	0.58 M	6,100	21,000	25,700 (plus 3,900 to Northern)	75%
Maternal bulls	2.65 M	27,900	90,000		
Northern Beef (6.0 M cows to be mated at 115 joinings per bull lifetime)					
Bostaurus bulls	1.0 M	8,700	21,000	3,900 ex Southern *(plus 500 local)*	50%
Maternal (*Bosindicus*) bulls	5.0 M	43,300	23,000	5,300 (plus 3,300 local)	20%

These data provide estimates of the impact of the use of genetically-improved sires in the national herd/flock in 2012 where for sheep (at 150 joinings per ram lifetime) 50% of all recorded rams weaned are sold as sires:

- LAMBPLAN flocks are supplying about 68% of terminal sires, and 41% of maternal sires; and
- MERINOSELECT flocks are supplying about 18% of Merino sires in use (including rams that are sold with EBVs and those sold with Rampower estimates).

Table 6 Key parameters for genetics

Effect of genetics on feed intake	RFI feed intake reduced for the same growth rate
Effect of genetics on growth rate	Growth rate unaffected by selecting for RMP
Effect of genetics FarmGas simulations	For each animal group as calculated from data in Table 4 assuming the simulation are after 10 years cumulative gain for dairy cows and 20 years cumulative gain for all other animal classes

Whereas for cattle (at 95 joinings per bull lifetime for Southern Beef – bulls retained for 3.15 years and used at a rate of 1 per 30 cows, and 115 joinings per bull lifetime for Northern Beef, bulls are retained for 3.85 years and used at a rate of 1 per 30 cows):

Bulls from BREEDPLAN recorded herds are meeting around 75% of demand for *Bostaurus* bulls (say 25,700 'sold' to meet Southern needs and Northern use of about 3,900), while there is the capacity for BREEDPLAN recorded herd *Bosindicus* bulls to meet about 12% of demand. The northern use of *Bostaurus* bulls is taken as supplying about 50% of the need for bulls for non-*indicus* matings (1 million of a total of 6 million cows mated); in the case of Northern Beef, it is estimated that within-herd breeding (*'local'* in Table 5) provides the remainder of bulls to meet the estimated adoption rates.

Cost of implementation

The cost of implementing genetic selection is assumed to be zero on the basis that many producers already use systems such as BREEDPLAN or LAMBPLAN that incorporate emissions reductions and the cost of purchasing livestock based on this genetic trait is not materially different to selection based on other traits. Nevertheless, there will be large costs to stud breeders identifying low methane emitting animals. The project life is one year since the research has calculated a percentage annual change to derive project outcomes.

3.1.6 Vaccination

Vaccination against rumen methanogens (microbes called *Archaea*) offers farmers potentially a cost effect option to reduce methane emissions in sheep and cattle. If successful, this option is particularly attractive because, under a best case scenario, it would require only a few early animal treatments for a lifetime effect. Research within the NLMP project 01200.038; B.CCH.6610 is directed partially towards identifying cell surface proteins that are unique to methanogens and do not occur on other microbes within the rumen. These specific surface proteins could be ideal for a vaccine target.

From previous research, it appears that there is potential for a 10% reduction in methane emissions through vaccination against methanogenic organisms in the rumen. A7.7% reduction has already been reported with a crude vaccine which did not include all *Archaea* genetic lines (Wright et al., 2004b). Wedlock et al (2013) suggested a 20% reduction in methane emissions is highly probable when the 'entire genetic repertoire' of *Archaea* is examined to identify motifs common to all Archaea but not to rumen bacteria.

Wright et al (2004b) measured feed intake in vaccinated and non-vaccinated sheep for 5 days prior to methane measurements in chambers and found no effect of vaccination on feed intake. It is considered unlikely that vaccination against rumen methanogenic organisms will have a negative effect on intake. However, it would be expected that hydrogen concentrations within the rumen would rise as a result of vaccination and that a proportion of the energy saved from reducing methane emissions would be captured for animal productive purposes. See discussion on energy retained in Section 4.3 regarding prevention of acidosis.

Table 7 Key parameters for vaccination

Effect of vaccination on feed intake	No effect on feed intake
Effect of vaccination on growth rate	Assume 40% of energy saved from methane inhibition is available for growth
Effect of vaccination FarmGas simulations	Two simulations: 10% and 20% reduction in methane emissions

Cost of implementation

It is assumed that a vaccination cost of $4.50 for cattle and $2.00 for sheep. These figures have been derived following an analysis of Australian vaccines. It is assumed that the vaccination frequency will be an annual single shot.

3.1.7 Leucaena

Leucaena applications are applied only to Northern Coastal Beef and Feedlots industry sectors. Leucaena can only be grown in the northern coastal environment and can be harvested then dried and potentially made available for inclusion in mixed rations for feedlot cattle.

Northern Coastal Beef

Results from project 01200.035; B.CC.H.6510 in NLMP, where cattle grazed either irrigated Leucaena plantations or non-irrigated plantations planted in rows in Rhodes grass or naturalised pasture, respectively, showed a substantial increase in growth rate and a reduction in methane emitted compared with cattle grazing pasture alone. At Belmont, with irrigated Leucaena and pasture, mean growth rate over the cattle growing period from 325 to approximately 600 kg liveweight, was 0.87 and 0.67 kg/day, respectively, for the Leucaena based and Rhodes grass pastures. The growth rate was approximately 23% faster for the cattle consuming Leucaena. Average methane output (g/kg LWTG) was 28% less for the Leucaena group than for the Rhodes grass group. The mean digestibility of dry matter in the plant material eaten by the Leucaena grazing cattle was estimated to be 61.5% and, for the Rhodes grass grazing cattle, 58.5%. Feed intake was estimated using a marker to be 8.7 kg/d for the cattle consuming Rhodes grass and 7.6 kg/d for cattle consuming Leucaena and Rhodes grass.

Table 8 Key parameters for Leucaena in northern coastal regions

Effect of Leucaena on feed intake of northern coastal cattle	Feed intake reduced because of the higher DMD (61.5 vs. 58.5)
Effect of Leucaena on growth rate of northern coastal cattle	Assume 23% improvement in growth rate
Effect of Leucaena FarmGas simulations	One simulation assuming a 28% reductions in methane emissions

Feedlot cattle

Several Leucaena growers in Queensland are considering harvesting leaf material from Leucaena plantations, drying and pelleting the product for feeding to livestock, including feedlot cattle. Leucaena appears not to have been added to feedlot diets as a replacement for traditional protein sources and fibre. However, the harvesting and drying of the plant leaves and small stems may provide an alternative to silage or cotton seed. Freshly harvested Leucaena has been fed at 22% and 44% with Rhodes grass and methane output measured from cattle in respiration chambers(Kennedy and Charmley, 2012). It was assumed that drying would not reduce the methane mitigation properties of Leucaena, but this needs evaluation. The experiment showed that methane emissions declined from 19.4 g/kg DMI to 17.8 g/kg DMI. Using these results and extrapolating to zero Leucaena in the diet, methane emissions for any Leucaena proportion in the diet could be calculated from the following equation:

Methane emissions (g/kg DMI) = 21 - 0.07273 * Leucaena % in diet

Des Rinehart, the MLA Feedlot research manager, arranged for Feedlot nutrition consultant, Rob Lawrence, to formulate diets including Leucaena with the composition of the plant material used by Kennedy and Charmley (2012).

Table 9 Composition of harvested Leucaena based on Kennedy and Charmley (2012)

OM	NDF	ADF	ADL	N	NDF-N	C	GE	OMD	RUP

g/kg DM	g/kg DM	g/kg DM	g/kg DM	g/kg DM	g/kg DM	g/kg DM	MJ/kg DM	%	%
921	336	230	89	37.8	2.2	447	19.7	66	73

Feedlot ration calculations were based on tempered wheat (best reflect energy density of a number of grain processing methods with some moisture required). All rations include whole cottonseed as the cheapest form of protein & effective fibre, but it is also a high energy source because of its lipid content. Roughage sources include corn silage and have also included straw as Leucaena lacks effective fibre. Leucaena NDF and ADF values are lower than whole cottonseed when consisting of mainly leaf and small particle size means effective fibre is limited to an assumed value of 5%. Crude protein was assumed to be 23.6% (3.78% Nitrogen x 6.25) and other nutrients were used within energy equations to reflect a similar gross energy value of 19.7 MJ/kg DM. These assumptions provided a digestible energy (DE) value of 14.7MJ/kg, a metabolisable energy (ME) value of 11.8MJ/kg, a net energy for growth (NEg) of 1.24Mcal/kg and a net energy for maintenance (NEm) of 1.88Mcal/kg. These net energy values were used in the performance prediction.

Performance comparison based on four rations finishing cattle for export (100 DOF (days on feed), 340kg HSCW), based on the assumption that Leucaena does not affect feed intake and an amount consumed of 11.4 kg/head/day. In the following table, Leucaena was balanced against silage and grain.

Table 10 Predicted effects of increasing Leucaena inclusion in a feedlot diet on diet and performance variables

	Leucaena Inclusion %			
	0	10	15	20
DM%	73.6	77.1	78.9	79.3
CP%	13.7	15.0	15.5	16.1
NEgMcal/kg	1.41	1.38	1.37	1.35
eNDF%	9.2	8.8	9.0	9.2
Daily gain kg/hd	2.0	1.94	1.91	1.88
FCE	5.72	5.89	5.96	6.08
DOF	100	103	104	106

The analysis suggests that growth rate would fall by 6% (2.0 to 1.88 kg/day) and days on feed (DOF) would be extended by 6 days if there were no positive effects of Leucaena on feed intake because the net energy content of the diet fell from 1.41 to 1.35 Mcal/kg with the inclusion of 20% Leucaena.

A 20% inclusion of Leucaena leaf and small stem in a feedlot diet based on the results from Kennedy and Charmley (2012) is predicted to reduce methane emissions by 7% at the same feed intake.

An experiment adding Leucaena to a feedlot diet is required to evaluate the accuracy of the above assumptions.

Table 11 Key parameters for Leucaena in feedlots

Effect of Leucaena on feed intake of feedlot cattle	Assume no effect of Leucaena in feedlot diets
Effect of Leucaena on growth rate of northern coastal cattle	Assume 6% decline in growth rate when 20% Leucaena inclusion
Effect of Leucaena in FarmGas simulations	One simulation assuming a 20% inclusion in the feedlot diet and a 7% reduction in methane emissions

Cost of implementation of Leucaena strategies

The Leucaena stands grazed at both sites were established stands at the full production rate. Normally full grazing cannot commence until 18 months to 2 years after establishment. The cost of establishing Leucaena is $250-$350/ha if undertaken by the farmer and $450/ha when established under contract. There is also a carbon sequestration in soil resulting from Leucaena plantations. Estimates as high as 37.4 t C/year have been made for this sequestration (Conrad, 2014), but these high values have been queried by others (pers com).

For the purposes of feeding Leucaena in a feedlot the price of $450 per tonne was assumed. This is the price of its competitor Lucerne pellets and Leucaena would have to achieve this price to be competitive. Since Leucaena would replace existing rations, no additional cost is included for rations. Transport costs are included at $5 per tonne per kilometre for an 800km trip required.

3.1.8 Algae

NLPM project 01200.035; B.CCH.6510 showed that the red marine alga, *Asparagopsistaxiformis*, when collected by wild-harvest in the filamentous tetrasporophyte phase, dried and ground, reduced methane emissions *in vitro* by up to 99% without depressing substrate digestibility or volatile fatty acid production when included at up to 2% of total substrate organic matter. Subsequently, an experiment funded outside NLMP with rumen cannulated tropical cattle fed Flinders grass hay showed an average 14% reduction in methane emissions per unit of feed intake over a period from 21-29 days after 2% OM intake of *Asparagopsis* was administered daily into the rumen. There was no evidence of microbial adaption to the alga over the 29 day period. Feed intake was not depressed and in fact rose by 6% (approaching significance) compared with the controls during the last methane measurement period in respiration chambers.

A more extensive experiment funded outside NLMP has recently been conducted with adult wether sheep. The sheep were fed a typical export shipping pellet with 0, 0.5, 1.0, 2.0 or 3.0 % of organic matter provided as dried, ground *Asparagopsis* mixed with crushed lupins. The intake of red alga was approximately 0, 13, 26, 58 and 80 g/d, respectively for the 5 treatments. The sheep were fed at 1.2 times maintenance energy intake and methane emissions were measured in chambers on days 30, 51 and 72 after introduction to the algal supplement. There was no indication of adaption of the microbes to the algae over the 72 day period and feed intake was not significantly affected. Methane emissions were reduced linearly (R^2 = 0.82) as the amount of alga in the diet was increased. When 3.0% of organic matter was included as alga, there was a reduction of 80% in methane emissions per unit of feed intake. At the last methane measurement period, there was a 0.86% fall in methane emissions for every gram of alga included in the diet. At the last methane measurement period, there was a 0.86% fall in methane emissions for every gram of alga included in the diet. There was a trend for increased liveweight, but full statistical analyses are not yet available.

The mechanism for reduction of methane is presumed for some algae. The red alga used in the sheep experiment contained 0.22 mg/g DM of halogenated metabolites. Halogenated methane analogues, such as bromochloromethane (BCM), inhibit methane production by reacting with reduced vitamin B12 which inhibits the cobamide-dependent enzyme methyl-coenzyme (CoM) reductase step in methanogenesis. *Asparagopsis* produces more than 100 low molecular weight metabolites containing bromine, iodine and chlorine that have antimicrobial activity. Bromoform is a secondary metabolite produced by *Asparagopsis* and inhibits methanogenesis by also reacting with a vitamin B12 cofactor, CoM reductase, in a similar way to NOP.

A provisional patent relating to the use of algae for reducing methane emissions (Method for reducing total gas production and/or methane production in a ruminant animal) was lodged on 21 January 2014 and updated to an international patent, PCT/AU2015/000030, on 21 January 2015. The information quoted above comes from that patent application.

Several studies have used BCM to inhibit methane emissions in ruminants (McCrabb et al., 1997, Tomkins and Hunter, 2004, Mitsumori et al., 2012). These studies show that BCM can reduce methane production in cattle and goats by more than 90%. Although high doses of BCM (0.6 g/100 kg liveweight) were shown to reduce feed intake, doses that depressed methane production by around 60% had no significant effect on intake. Similarly, several experiments (Goel et al., 2009, Mitsumori et al., 2012) showed no effect of BCM on digestibility or efficiency of microbial growth. McCrabb et al. (1997) showed that BCM significantly increased the efficiency of feed use in tropical cattle.

If the results from the BCM studies are assumed to be similar to those obtained with *Asparagopsis*, a reduction in methane emission of 50-60% would seem practical without any negative effect on feed intake. However, the resulting increase in hydrogen concentration within the rumen would be expected to increase the proportion of propionate produced and increase productivity.

It is assumed that the algae scenario can be applied to all production circumstances, because the effective dose rate for cattle appears to be less than 100 g/d so it could be provided in lick or block form to grazing animals.

Table 12 Key parameters for algae

Effect of algae on feed intake	No effect of algae on feed intake
Effect of algae on growth rate	Assume 40% of energy saved from methane inhibition is available for growth
Effect of algae FarmGas simulations	Two simulations undertaken for all production regions assuming either 30% or 60% reduction in methane emissions

Cost of implementation

Currently the cost of wild-harvest is approximately $200/kg of *Asparagopsis*. However, Ridley Agriproducts are working with JCU to establish a marine macroalgae production system. A production system would need to be developed to supply macroalgae at scale and at a low cost. The cost adopted for the project is based on $1.50 per kilo for imported algae with 100gm per head per day fed for 365 days. To test the sensitivity of results to the assumption that a low cost system can be developed, analysis is also undertaken based on a price of $5.00 per kilo.

3.1.9 Plant bioactives compounds

Research within NLMP project 01200.021; B.CCH.6530 has shown that several plant species, specifically the Tar Bush shrub, *Eremophilaglabra* and the legume pasture plant, Biserrula, reduce methane emissions from *in vitro* fermentation cultures (batch and longer term Rusitec) and from sheep compared with control diets (Banik *et al*. 2013; Li 2013; Li *et* al. 2014; table below). When *E. glabra* was included at 15%, 25% and 40% with oaten chaff and lupins for 33 days in a Rusitec fermentation system, methane emissions were reduced linearly with dose to be 45% less than the controls (Li *et* al. 2014). Other bioactive compounds, called C and L, have been have been extracted from native Australian plants and shown to substantially reduce methane emissions *in vitro*, but have not yet been tested in animals. The compound L, when included in a batch culture fermentation assay reduced methane emissions substantially with a 97% reduction occurring when added at the rate of 250 µL/g dry matter incubated. Subsequent studies over 10 days using the Rusitec long-term *in vitro* fermentation assay showed approximately 85% reduction in methane emissions when C was included at a rate of 25 µL/g dry matter incubated or L included at a rate of 50 µL/g dry matter incubated (NLMP Progress Report October 2014).

An estimate of the likely reduction in methane emissions when C or L are provided as a supplement to animals was obtained by comparing the reduction in methane emissions when the bioactive plants Eremophila and Biserrrula were assayed *in vitro* (batch and Rusitec) with the reduction when fed to sheep. The results of this comparison are presented in Table 13 below.

Table 13 Comparison of methane reduction from in vitro assays and in vivo feeding to sheep

Treatment	Dose	% inhibition *in vitro*	Testing type	% inhibition *in vivo*	Scale of effect# (*in vitro/in vivo*)	Authors*
Bioactive plants						
E. glabra	15 % E. glabra/ 85% oaten chaff	37.0	rusitec	14.7	2.5	(Li et al., 2014)
Biserrula	100% biserrula	13.2	rusitec	20.0	0.7	(Hutton et al., 2010, Banik et al., 2013)
Biserrula	50% biserrula/50% subclover	45.4	rusitec	*10.0*	4.5	(Hutton et al., 2010, Banik et al., 2013)

Biserrula	50% biserrula/50% subclover	51.0	batch	*10.0*	5.1	(Hutton et al., 2010, Banik et al., 2013)
Biserrula	100% biserrula	*80.0*	batch	20.0	4.0	(Hutton et al., 2010, Banik et al., 2013)
ESEF[$]					3.4	
C and L						
C	25 µL/g DMi	86	rusitec	*25.3*	3.4	(García-González et al., 2006)
L	25 µL/g DMi	59	rusitec	*17.2*	3.4	(García-González et al., 2006)
L	50 µL/g DMi	85	rusitec	*25.1*	3.4	(García-González et al., 2006)

[#]Scale of effect = % methane inhibition *in vitro*/% methane inhibition in *vivo*; *manuscripts in preparation, [$]Average Scale of effect for all treatments.

The average Scale of effect for the experiments with both *in vitro* and *in vivo* results was used to estimate the likely reduction in methane emissions when compounds C or L are included as supplements for ruminants. The comparison suggests that both compounds C and L when included at the rate of 25 ml/kg DM and 50 ml/kg DM, respectively, would reduce methane emissions by approximately 25%.

There is no information on the likely effect of C and L supplementation on the intake of ruminants. Thus, it is assumed there will be no positive or negative effect of these compounds when fed as supplements on the intake of ruminants. An effect of plant bioactives on energy utilisation would be expected due to the inhibition of methane and rise in H_2 concentration within the rumen. One FarmGas simulation was undertaken for all production regions, because the small amounts required for a methane inhibiting effect could be provided in lick or block form to grazing animals.

Table 14 Key parameters for plant bioactive compounds

Effect of plant bioactive compounds on feed intake	No effect of plant bioactives on feed intake
Effect of plant bioactive compounds on growth rate	Assume 40% of energy saved from methane inhibition is available for growth
Effect of plant bioactive compounds in FarmGas simulations	One simulation for each production region assuming a 25% reduction in methane emissions

Cost of implementation

The approximate cost based on using high purity Sigma compounds would be for L $6 per head per day to achieve 25% reduction, and about $18 per head per day with C to achieve 25% reduction. However, there are also bulk suppliers of these compounds, mostly from China, and much lower prices would be anticipated. A cost of 50c per head per day for 365 days per year is assumed.

3.1.10 Wheat feeding to dairy cows

Two experiments have been conducted within project 01200.017; B.CCH.6460 to show that when crushed wheat grain is fed at a rate of approximately 9 kg in two daily feeds with either freshly cut ryegrass pasture or chopped Lucerne hay, methane production per kg DMI was reduced by 30% to greater than 50%, respectively, compared to the pasture alone or a diets providing the same amount of crushed maize grain (Moate et al., 2012, Moate et al., 2014b). Milk yield was significantly higher by 21% in the experiment comparing fresh pasture with pasture plus wheat. However, there were no significant differences in milk yield when wheat was compared with maize.

The composition or energy value of the wheat samples used in these experiments was not determined. The last experiment in the project compared 9 kg/d of crushed wheat with 9 kg/d of crushed maize fed with longer cut Lucerne hay. The wheat sample used in the last experiment was of extremely poor quality, with pinched grains, low starch content and many grains not crushed during processing. Milk yield was lower for the cows consuming crushed maize than for those consuming wheat. However, there were no differences in methane emissions between the two treatments. These results suggest that normal, high starch content wheat with a rapid rate of fermentation in the rumen results in substantially lower methane emissions when fed twice daily at rates of approximately 9 kg/d to dairy cows.

Table 15 Key parameters for feeding wheat at 9 kg/day to lactating dairy cows at pasture

Effect of 9 kg/d wheat on feed intake of dairy cows	No effect of wheat on feed intake
Effect of 9 kg/d wheat on milk yield	Assume milk yield is increased by 20% when wheat is fed with pasture
Effect of 9/kg/d of wheat in FarmGas simulations	One simulation for lactating dairy cows assuming a 40% reduction in methane emissions

Cost of implementation

As per the scenario above the 9kg of wheat has replaced half the pasture costs for 300 days per year. The cost of wheat is assumed to be $250 tonne, compared to pasture silage at $92 tonne.

3.1.11 Grape marc

Grape marc consists of the skins, seeds, stalks and stems remaining after grapes have been pressed to make wine. It can be dried and made into pellets, ensiled or remain fresh before being used as an animal feed or as a fertiliser. Grape marc contains condensed tannins with a range of compositions, high concentrations of oils and tartaric acid (NLMP project 01200.007; B.CCH.6410). All these compounds have the potential to reduce methane emissions in ruminants (Moate et al., 2014a). Grape marc can have a relatively high fibre and low metabolisable energy content because of its high stalk and stem content. Three experiments within NLMP have been conducted feeding grape marc to dairy cows and sheep and one experiment was conducted within the Action on the Ground (AOG) program where grape marc was fed to beef cattle under feedlot conditions.

The effectiveness of grape marc for reducing methane production without a negative impact on animal productivity appears to depend on the relative energy content of the control diet compared with the grape marc sample included in the diet. Dried grape marc provided greater benefit than ensiled grape marc in one experiment with dairy cows, but this may have been related to the higher fibre and lignin content of the ensiled product (Moate et al., 2014c). Brahman cattle appear to better maintain productivity when fed grape marc than Angus cattle which may reflect their superior ability to digest high fibre diets.

In the first dairy cow experiment conducted in project 01200.017; B.CCH.6460, either dried/pelleted or ensiled grape marc replaced approximately 5 kg of 13 kg of Lucerne hay per day in a diet providing 4 kg/day concentrate. The cows were in the late lactation phase of production. The fibre (neutral detergent fibre, NDF, and acid detergent fibre, ADF) content of the Lucerne hay and dried/pellet grape marc were similar and lower than for the ensiled grape marc. Milk yield from cows offered the control diet or the diet containing dried/pelleted grape marc was not significantly different, but methane emissions expressed as g/day, g/kg DMI or g/kg milk were 20-25% lower for the grape marc diet. Methane emissions expressed in g/day were also significantly lower for the cows consuming the ensiled grape marc product, but methane emissions expressed as g/kg milk were similar to the control cows.

In the second dairy cow experiment, either red or white ensiled grape marc replaced approximately 4.5 kg of freshly cut pasture in a daily diet containing 5 kg maize. The ADF content of the grape marc was about 35% higher than for the pasture. Although methane emissions expressed as g/day were reduced by approximately 14% for the cows consuming grape marc, milk yield was depressed and there were no differences between treatments in methane emissions expressed as g/kg milk. This result reflects the lower energy content of grape marc compared with the fresh pasture.

In the sheep experiment in project B.CCH.6460, either crimped or ensiled grape marc was used to replace an oaten hay of similar metabolisable energy content in diets offered to the animals in sufficient quantity to maintain liveweight. Although intake was similar and there was a trend for reduced methane emissions in the sheep offered the diets containing grape, variation in methane emissions measured by face mask was too great for these differences to be significant. However, based on the trend in results, a 30% inclusion of grape marc when the energy content of the diets was similar to grape marc suggests that methane emissions could be reduced by 10% without affecting animal performance.

In the AOG project with feedlot cattle either 10% or 20% of the diet was grape marc which replaced the 10% maize silage and some barley. Inclusion of 20% grape marc in the diets of Angus cattle in a feedlot did not significantly reduce feed intake, but reduced methane emissions expressed as g/d by around 10%. However, growth rate was reduced by 30% in the cattle consuming 20% grape marc in the diet and methane emissions expressed as g/kg liveweight gain increased by 25%. Adding 20% grape marc to the diet for Brahman cattle did not alter growth rate and reduced methane production expressed as g/d by approximately 25%. However, there was a reduction in feed intake. Methane production expressed as g/kg DMI was reduced by only around 5%. Grape marc is not a likely practical option for northern cattle because of the distance from grape growing regions.

The results from experiments with grape marc suggest that it has a place for feeding mainly as a replacement to low quality diets. However, three MACC analyses were undertaken: i) dairy cows in late lactation where energy content of the grape marc and forage it replaces are similar; ii) sheep fed low quality diets near maintenance; and iii) feedlot cattle where methane emissions and performance are both reduced.

Dairy cows

Assume 40% of diet forage is replaced by grape marc of similar ME (digestibility, 60%) and the diet contains 25% concentrate (digestibility 90%). Hence DMD for the diet is assumed to be 68%. Assume there is a 20% reduction in methane production when grape marc replaces approximately one third of the forage of similar ME content. Addition of grape marc is assumed not to alter feed intake of dairy cows if the ME content of the forage and grape marc are the same. Although methane is assumed to be reduced, no saving of energy for productive purposes was included in the calculations because of the observed lack of effect on milk yield.

Table 16 Key parameters for feeding grape marc to lactating dairy cows consuming a diet of similar ME content

Effect of grape marc on feed intake of lactating dairy cows	No effect of grape marc on feed intake
Effect of grape marc on milk production	Assume there is no effect
Effect of grape marc in FarmGas simulations	One simulation for lactating dairy cows assuming a 20% reduction in methane emissions when diet and grape marc ME are equal

Cost of implementation

Marc sourced directly from the winery has no cost except for loading and transport. Processed marc is around $12/t when steam distilled, $40-$50/t when crimped (roller mill to crush seed) and$100/t when dried. On-farm use is best made into bunker silage for longer-term storage.

It has been assumed that crimped grape marc is fed as per the scenario with on farm cost of $73.33 per tonne, including loading and transportation. It is assumed there are no further costs once landed on farm.

Sheep at maintenance

Grape marc is assumed to be used only in southern Australia and in the late summer-autumn feed-gap period for 3 months when standing forage quality is low. It could be offered as a supplement to or replacement for the low quality forage. Intake would not need to be controlled since grape marc has a low ME content. Methane production is assumed to be reduced by 10% when grape marc is fed as a supplement to low quality forage or is used as a drought feed for maintaining body weight. Addition of grape marc is assumed not to alter feed intake of sheep eating low quality forage during the summer-autumn feed-gap period because of the low ME content of available forage. The dry matter digestibility of the forage on offer and grape marc was assumed to be 60%. There was considered to be no saving of energy for productive purposed due to reduced methane.

Table 17 Key parameters for feeding grape marc to sheep fed low quality forage

Effect of grape marc on feed intake of sheep during the feed gap	No effect of grape marc on feed intake
Effect of grape marc on growth rate of sheep at maintenance	Assume there is no effect as ME of forage and marc are similar
Effect of grape marc in FarmGas simulations for sheep	Simulations for all classes of sheep assuming a 10% reduction

	in methane emissions when energy intake is near maintenance

Cost of implementation

As for dairy.

<u>Feedlot cattle</u>

The analyses were considered only for feedlot cattle in southern Australia with the Angus breed. No effect of grape marc on feed intake was assumed because it is replacing other forms of effective fibre. However, there was a trend that replacing maize silage with grape marc reduced feed intake of both Angus and Brahman cattle, but the effect was not significant. Growth rate of cattle in feedlots was assumed to be reduced by 25% because of the decrease in diet energy content and digestibility. Assume dry matter digestibility of the diet is reduced from 80% to 75% when 20% grape marc is added to the feedlot diet. Methane production is assumed to be reduced by 10%.

Table 18 Key parameters for feeding grape marc to feedlot cattle at 20% of the diet

Effect of grape marc on feed intake of feedlot cattle	No effect of grape marc on feed intake
Effect of grape marc on growth rate of feedlot cattle	Assume growth rate reduced by 25%
Effect of grape marc in FarmGas simulations for feedlot cattle	Simulations for feedlot cattle a 10% reduction in methane emissions when energy intake is near maintenance

Cost of implementation

As for dairy.

3.1.12 Nitrate as a feed supplement

Adding nitrates as a supplement to sheep and cattle has been examined in two NLMP projects, 01200.031; B.CCH.6440 and 01200.048; B.CCH.6450.Non-protein nitrogen sources are fed to ruminants to increase microbial growth, feed digestibility, feed intake and productivity when crude protein concentration in the diet is less than about 60g/kg dry matter (Minson, 1990) or 2 g N/MJ metabolisable energy (Nolan et al., 2015). Typically urea has been used as the non-protein nitrogen source in dairy and feedlot diets and in lick-blocks available to sheep and cattle grazing dry, low quality pastures. However, if the non-protein nitrogen is provided from nitrates, hydrogen is used in the conversion of nitrate to nitrite and then to ammonia. These nitrate reduction reactions have a lower free energy change than reactions utilising hydrogen for methane production within the rumen and therefore have a competitive advantage. Consequently, adding nitrate to diets reduces methane emissions, while providing non-protein nitrogen for microbial growth (Leng and Preston, 2010, Van Zijderveld et al., 2010). However, if the concentration of nitrite in the rumen rises and nitrite is absorbed into the blood, nitrite poisoning created by excess methaemoglobin in the blood can occur. Methaemoglobin reduces the oxygen carrying capacity of the blood and can result in animal death.

There have been numerous experiments and reviews of the effect of nitrate feeding on methane emissions from ruminants (Van Zijderveld et al., 2011, Lee and Beauchemin, 2014, Nolan et al., 2015). The general consensus is that adding nitrate to the diet of ruminants linearly reduces methane production (to a maximum of approx. 50%) as the amount eaten increases, with little further reduction in methane emission as nitrate intake continues to increase (Van Zijderveld et al., 2011, Lee and Beauchemin, 2014). Theoretically, 1 g of nitrate reduces methane production by 258 mg. However, complete efficiency of hydrogen uptake by nitrate is not observed, with an average efficiency of hydrogen uptake being around 90% (Nolan et al., 2010, Van Zijderveld et al., 2011, Lee, 2012, Callaghan et al., 2014). A rounded estimate is that 10 g nitrate/kg DMI can reduce methane emissions by up to 10%. However, feeding more than 7 g nitrate/kg DMI is not recommended for grazing cattle in the Energy Reduction Fund methodology because of the risk of nitrite poisoning (Commonwealth of Australia, 2014).

A review of the literature by Lee and Beauchemin (2014) suggests that across many experiments feed intake and growth rate of cattle is not negatively affected by nitrate feeding and will increase if the rumen microbes respond to non-protein nitrogen. However, nitrate would normally be fed to ruminants as a replacement for urea when providing non-protein nitrogen. There is wide variation across experiments in the effects of nitrate supplementation on feed intake and animal performance when it is fed in the place of urea. Recent studies suggest that cattle fed diets containing nitrate under total mixed ration conditions have a reduced feed intake of 7-15% compared with diets containing isonitrogenous amounts of urea (Hulshof et al., 2012, Hegarty et al., 2013, Velazco et al., 2014). However, experiments where nitrate has been provided at isonitrogenous rates and compared with urea in cattle fed low quality tropical forage suggest that intake of nitrate and urea supplemented animals is similar (Callaghan et al., 2014). Similarly, there is little evidence nitrate supplementation reduces intake or productivity of lactating dairy cows when compared with urea supplementation (Van Zijderveld et al., 2010, Van Zijderveld et al., 2011). Adding nitrate to feeds or lick-blocks appears to change the feeding behaviour of cattle, resulting in smaller and more frequent meals when total mixed rations are fed and lower intake of lick-blocks under dry-season tropical pasture conditions (Velazco et al., 2014, Callaghan et al., 2014).

Experiments with sheep indicate similar responses to cattle when nitrates are included in either total mixed rations or supplements with lower quality forage diets (Nolan et al., 2010, Li et al., 2013, de Raphélis-Soissan et al., 2014). However, there appears to be a consistent increase in wool growth from 12-37% when nitrates are fed to sheep (Li et al., 2013, de Raphélis-Soissan et al., 2014). The increase in wool growth is thought to be caused by nitric oxide formed from nitrite causing dilation of blood vessels and increasing blood flow to the skin.

The literature suggests that nitrate can at least partially replace urea in circumstances where ruminant animals respond to the addition of non-protein nitrogen sources. The following MACC analyses are undertaken: i) cattle in northern Australia for the period of the year when pasture crude protein content has declined to less than 6% dry matter; ii) sheep in southern Australia for periods of the year when pasture crude protein content is less than 6% dry matter; iii) feedlot cattle where methane emission and feed intake are reduced; iv) dairy cows where methane emissions are reduced, but intake and milk yield are unaffected.

<u>Northern beef cattle</u>

Nitrate is assumed to be included in lick-blocks with urea and fed to cattle under rangeland conditions when the crude protein content of the pasture is less than 6% dry matter. Research from NLMP project 01200.031; B.CCH.6440 suggests that the maximum intake of nitrate from lick-blocks under rangeland conditions is around 20 g/animal/day. Callaghan (2014) showed that feeding 50 g nitrate/day to tropical cattle eating a low protein pasture reduced methane production by 11.6 g/day, which was a reduction of 16% compared with urea supplemented cattle and represented an efficiency of hydrogen uptake by nitrate of 89%. Using this relationship, if maximum intake of nitrate is assumed to be 20 g/d, methane emissions are calculated to be reduced by approximately 6.5%. Evidence from project 01200.031; B.CCH.6440 suggests that when non-protein nitrogen supply is adequate for rumen microbial metabolism of cattle grazing low protein tropical forages, feed intake of cattle consuming up to 50 g/d nitrate is not affected.

Table 19 Key parameters for feeding 20 g/d nitrate as a replacement to urea in northern cattle consuming low protein forage

Effect of 20 g/day nitrate replacing urea on feed intake of northern cattle	No effect of nitrate on feed intake
Effect of 20 g/day nitrate replacing urea on growth rate of northern cattle	Assume no effect on growth rate
Effect of 20 g/day nitrate replacing urea in FarmGas simulations for northern cattle	Simulations for northern cattle when forage protein < 6% and assume a 6.5% reduction in methane emissions

Cost of implementation

It has been assumed that nitrate has been applied for 182 days at a cost of 25c per day. The analysis has not taken into account the feeding issues associated with nitrates as a feed supplement and the associated health issues.

Sheep in southern Australia

Nitrate is to be included in lick-blocks with urea and fed to sheep under summer dry conditions when the crude protein content of the pasture is less than 6% dry matter. Assume that the maximum proportional intake of nitrate is the same as cattle. Hence, it is assumed that the maximum intake of nitrate is 3.4 g/day based on a maximum intake of 20 g/d in cattle and relative intakes of poor quality pasture of 0.85 and 5.0 kg/day, respectively for sheep and cattle. Nitrate would represent approximately 4g/kg DMI. A similar assumption to northern cattle was used, i.e. maximum intake of 3.4 g/d nitrate reduces methane emissions by 6.5% compared with urea supplements. Using the assumption for northern cattle, no change in feed intake will occur when nitrate replaces urea in blocks for sheep. Using the same assumptions as for northern cattle, no change in growth rate will occur when nitrate replaces urea in blocks for sheep.

On the basis of the experiments of Li *et al*. (2013) and de Raphelis-Soissan*et al*. (2014), it is assumed that wool growth is increased towards the lower rates observed because of the lower intake of nitrate expected under dry feeding conditions with lick-blocks, than were used in the experiments. It is assumed that wool growth during the nitrate supplement period is increased by 10%.

Table 20 Key parameters for feeding 3.4 g/d nitrate as a replacement to urea in southern sheep consuming low protein forage

Effect of 3.4 g/day nitrate replacing urea on feed intake of southern sheep	No effect of nitrate on feed intake
Effect of 3.4 g/day nitrate replacing urea on growth rate of southern sheep	Assume no effect on growth rate

Effect of 3.4 g/day nitrate replacing urea on wool growth rate of southern sheep	Wool growth assumed to increase by 10%
Effect of 20 g/day nitrate replacing urea in FarmGas simulations for southern sheep	Simulations for southern sheep when forage protein < 6% and assume a 6.5% reduction in methane emissions

Cost of implementation

As for beef.

Feedlot cattle

Nitrate is assumed to be included in the mixed rations available to feedlot cattle at the rate of 10 g/kg DM. On the basis of Hulshof *et al.* (2012)(2012) and Velazco*et al.* (2014), it is assumed that methane emissions are reduced by 15% per unit of dry matter intake. There is also strong evidence (Hulshof et al., 2012, Hegarty et al., 2013, Velazco et al., 2014)that feed intake of feedlot cattle offered nitrate supplements is reduced by approximately 10%. On the basis of the experiment by Velazco*et al.* (2014) it is assumed that liveweight gain for the control animals is 2.0 kg/day and the growth rate of the nitrate supplemented animals would be that resulting from a 10% reduction in feed intake.

Table 21 Key parameters for feeding nitrate to feedlot cattle at 10 g/kg DM

Effect of nitrate supplement on feed intake of feedlot cattle	Feed intake is assumed to be reduced by 10%
Effect of nitrate on growth rate of feedlot cattle	Assume growth rate reduced by the amount consistent with a 10% reduction in feed intake
Effect of nitrate in FarmGas simulations for feedlot cattle	Simulations for feedlot cattle a 15% reduction in methane emissions when feed intake is reduced

Cost of implementation

It has been assumed that nitrate has been applied for 365 days at a cost of 25c per day. The analysis has not taken into account the feeding issues associate with nitrates as a feed supplement and the associated health issues.

Dairy cows

Based on the experiments of van Zijderveld*et* al. (2010, 2011), it is assumed nitrate is included in the total mixed rations for dairy cows the rate of 20 g/kg DM. Based on the experiments of van Zijderveld*et* al. (2010, 2011), it is assumed that methane is reduced by 15%, but feed intake is unaffected and there is no effect of dietary nitrate on milk yield.

Table 22 Key parameters for feeding nitrate to dairy cows at 20 g/kg DM

Effect of nitrate supplement on feed intake of dairy cows	Assume no effect on intake
Effect of nitrate on milk yield of dairy cows	Assume no effect on milk yield

Effect of nitrate in FarmGas simulations for feedlot cattle	Simulations for dairy cows with a 15% reduction in methane emissions

Cost of implementation

It has been assumed that nitrate has been applied for 365 days at a cost of 25c per day. The analysis has not taken into account the feeding issues associate with nitrates as a feed supplement and the associated health issues.

3.1.13 NOP

Nitrooxypropanol (NOP) was not studied in NLMP, but has been shown to reduce methane emissions. NOP and the ethyl variant, ethyl-3-nitrooxypropanol, are compounds synthesised by the animal feed supplement company DSM in Switzerland. The compounds appear to bind to the active site of the enzyme methyl-coenzyme (CoM) reductase which catalyses the last step in the reduction of CO_2 to CH_4 by the hydrogenotrophic methanogenicarchaea. The compounds are highly volatile, with a short survival time in feed or the rumen unless imbedded in other compounds that reduce the volatility. DSM is currently working to reduce the volatility for practical feeding of the compounds. The company is also undertaking toxicology evaluation.

In vitro experiments and *in vivo* experiments have been conducted with sheep and dairy cows (Patent No. US 2014/014 7529 A1 - May 29, 2014) (Haisan et al., 2014, Reynolds et al., 2014, Martínez-Fernández et al., 2014). The longest experiment has been for 30 days. All experiments with animals have shown a significant reduction in methane emission and methane yield (methane/feed intake). However, the range in methane depression has been from 4-29% over five experiments. The mean reduction in methane/kg feed intake is close to 15%. The methane reduction potential was maintained from 14 to 30 days in one experiment. Some of the variation in methane reduction can be attributed to the method of feeding. For most experiments reported, the compounds were placed directly in the rumen once or twice daily or once daily wrapped in tissue paper. In another experiment, the compound was mixed with ground barley, molasses and canola oil and put into a total mixed ration.

On the basis of the experiments reported to date, a reduction in methane emissions in animals of 15% appears to be a reasonable assumption. However, the methane reduction obtained in several *in vitro* studies has been as high as 95%. The discrepancy between the types of experiments could result from the high volatility of the compound or a high rate of degradation within the rumen, associated with the pulse method of feeding in the animal experiments. Experiments are required where the dose of NOP mimics commercial feeding regimes to determine its potential for reducing methane emissions.

There is no evidence NOP reduces feed intake. However, in one experiment (Reynolds et al., 2014) digestibility of organic matter tended to decline at the highest dose of 2.5 g/d. One experiment showed an increase in body weight gain in lactating dairy cows with NOP, but this did not appear or was not measured in the other experiments. There was no effect of NOP on milk production. An increase in energy available to the animal would be expected because hydrogen concentrations in the rumen are known to rise. Because of likely improvements in the method for feeding NOP a simulation with 30% reduction in methane emissions has also been conducted. NOP was assumed to be available for all production situations, because dose rate for cattle appears to be around 2 g/d so it could be provided in lick or block form to grazing animals.

Table 23 Key parameters for NOP

Effect of NOP on feed intake	No effect on feed intake
Effect of NOP on growth rate	Assume 40% of energy saved from methane inhibition is available for growth. No effect on milk yield identified.
Effect of NOP FarmGas simulations	Two simulation for each production region assuming a 15% and 30% reduction in methane emissions

Cost of implementation

An ingredient that can be readily added to either TMR or blocks-licks at little extra cost except for the cost of the product. The product cost has not been set yet and will probably depend on 'what the market will stand'. Likely to be made available to dairy cows first because this the animal industry with greatest profitability. It is assumed the cost will be 25c per head per day for 365 days.

3.1.14 Biochar

Recent research (Leng et al., 2012b) with cattle supports *in vitro* studies (Leng et al., 2012a, Leng et al., 2013, Hansen et al., 2012) confirming that biochar can reduce methane emissions in ruminants. The research with young cattle found that feeding 0.6% biochar increased growth rate by 25% and reduced methane emissions by 22% per day without affecting feed intake. The impact of biochar in the cattle experiment was larger than observed for the *in vitro* experiments, where the depression in methane emissions ranged from around 10-17%. Leng*et al*. (2013) showed that the reduction in methane emissions *in vitro* also varied with the type of biochar.

Biochar has a large surface area to weight ratio and is extremely porous. This porous structure stimulates microbial colonisation and biofilm formation, which enhances microbial growth and increases VFA and protein supply to the animal. Methanogens are found on the outer surface of biofilms and are thought to remove H_2, which stimulates the digestion of cellulose and other feed compounds by maintaining a low hydrogen tension. The additional microbial growth and incorporation of H_2 into microbes may be one reason for the decrease in methane production and increase in growth rate. Biochar has also been shown to increase the ratio of methanotrophs to methanogens in rice paddy soils. If the same occurs on biochar in the rumen, the increase in methanotrophic, methane oxidizing organisms would also reduce methane release and increase microbial growth. The original research was conducted in cattle fed cassava chips and cassava foliage and its applicability to common forage or feedlot diets is unknown. Growth rate of the cattle in the experiment was low at around 0.14kg/day.

Evidence form Leng et al. (2012b) suggests growth rate could be increased due to improved microbial growth. These results are from only one experiment, so will assume that biochar could increase growth rate by 15%. There is no evidence from the experiment that biochar affects feed intake when added at 0.6% of the diet.

On the basis of the one cattle experiment and the *in vitro* experiments, it is assumed that biochar can reduce methane emissions by 15% and increase growth rate by 15%. The strategy could be applied to all production categories, because it requires a low concentration on diets and could be provided in lick or block form to grazing animals.

Table 24 Key parameters for biochar

Effect of biochar on feed intake	No effect on feed intake
Effect of biochar on growth rate	Increase in growth rate of 15%
Effect of biochar FarmGas simulations	One simulation for every animal category with 15% reduction in methane emission

Cost of implementation

The cost of biochar is currently $1,000 per tonne with prices expected to be $400 per tonne for large quantities, including transport. Biochar represents 0.6% of diet. It is assumed the cost per head per day applied by lick will be 2c for cattle and 0.5c for sheep.

3.1.15 Summary of assumptions made

Summaries of the assumptions made about percentage emissions reductions and costs of implementation are presented below. Assumed changes in potential emissions reductions are based on research results to date. Emissions reductions for the management practice change options were modelled in *FarmGas* based on prior studies documenting these practices (MLA, 2015; Eady, 2011; Young, 2013).

Table 25 Assumed Emissions Reductions – Percentage Decrease

Practice Option	Beef	Sheep	Dairy	Feedlot Beef
Production efficiency	7.53	-	-	-
Phosphorus supplementation	14.81	-	-	-
Flock type change	-	0.8	-	-
Conception and survival	-	2.0	-	-
Genetics	0.4% / year; 8% after 20 years	0.4% / year; 8% after 20 years	16% after 10 years	0.4% / year; 8% after 20 years
Vaccination against methanogenic archaea	10 & 20	10 & 20	10 & 20	10 & 20
Leucaena	28	-	-	7
Algae as a feed supplement	30 & 60	30 & 60	30 & 60	30 & 60
Plant bioactive compounds	25	25	25	25
Wheat feeding at high rates to dairy cows	-	-	40	-
Grape marc		10	20	10
Nitrate supplements	6.5	6.5	6.5	6.5

NOP as a feed supplement	15 & 30	15 & 30	15 & 30	15 & 30
Biochar as a feed supplement	15	15	15	15

Assumptions about implementation costs are based on advice from industry experts. Costs of implementation are not available for the management practice change options since calculations were made on the basis of changes in gross margins achieved for case studies utilising these practice options.

Table 26 Costs of Implementing Practice Options

Practice Option	Beef	Sheep	Dairy	Feedlot Beef
Genetics	Zero	Zero	Zero	Zero
Vaccination against methanogenic archaea	$4.50 per head, per annum	$2.00 per head, per annum	$4.50 per head, per annum	$4.50 per head, per annum
Leucaena	$250 per hectare establishment @ 10% x 10 years	NA	NA	Zero – replaced other feed costs
Algae as a feed supplement	15 cents per day, per head, for 365 days	3 cents per day, per head, for 365 days	15 cents per day, per head, for 365 days	15 cents per day, per head, for 365 days
Plant bioactive compounds	50 cents per day, per head, for 365 days	10 cents per day, per head, for 365 days	50 cents per day, per head, for 365 days	50 cents per day, per head, for 365 days
Wheat feeding at high rates to dairy cows	NA	NA	87.5 cents per day, per head, for 300 days	NA
Grape marc	NA	$6.60 per head, per annum	Zero – replaced other feed costs	Zero – replaced other feed costs
Nitrate supplements	25 cents per day, per head, for 182 days	5 cents per day, per head, for 182 days	25 cents per day, per head, for 365 days	25 cents per day, per head, for 365 days
NOP as a feed supplement	25 cents per day, per head, for 365 days	5 cents per day, per head, for 365 days	25 cents per day, per head, for 365 days	25 cents per day, per head, for 365 days
Biochar as a feed supplement	2 cents per day, per head, for 365 days	0.5 cents per day, per head for 365 days	2 cents per day, per head, for 365 days	2 cents per day, per head, for 365 days

Section 3.2 outlines how these assumptions are utilised in estimating potential emissions reductions and associated impacts on profitability for a series of case study farms as well as national emissions reductions potential for each methane reduction practice option examined.

3.2 NLMP Investment analysis

3.2.1 Representative farms and national scale analysis

The investment analysis was conducted for a representative farm case study from each of the following farming systems:

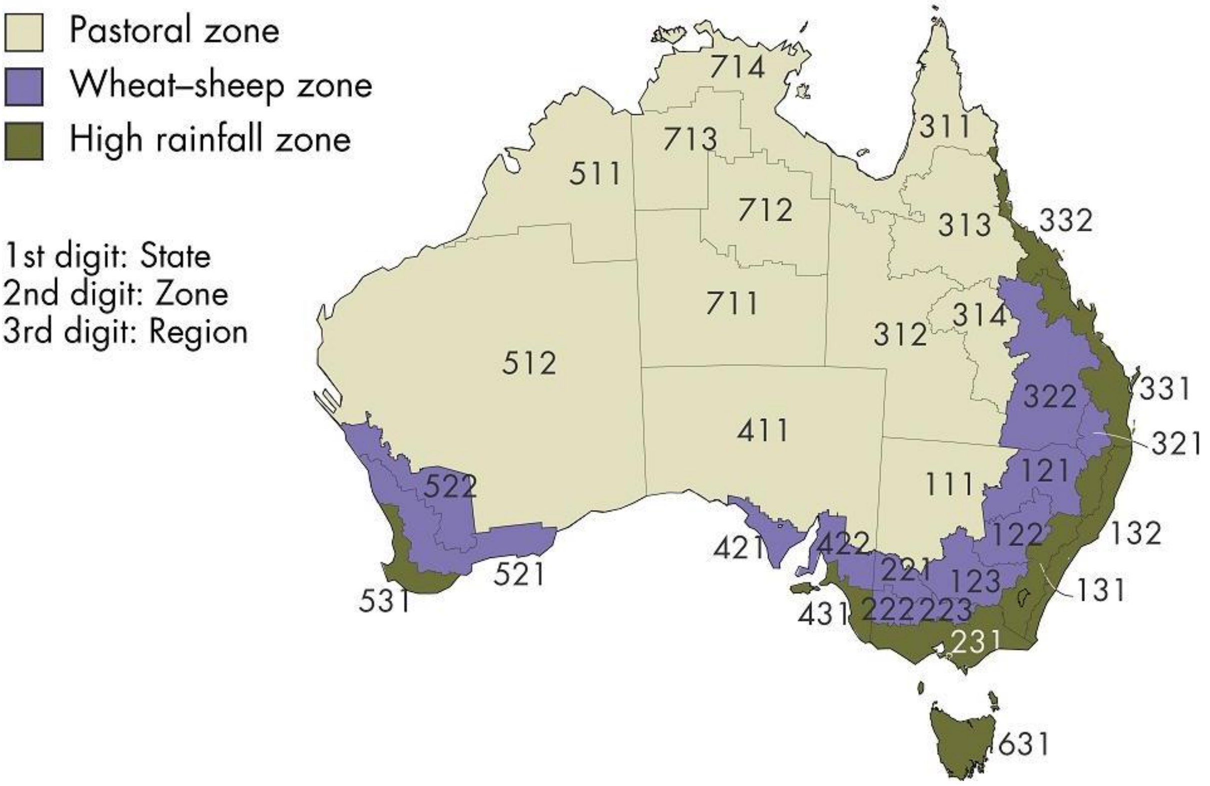
- Northern Coastal Beef (NCB)
- Northern Rangeland Beef (NRB)
- Temperate/Sub-Tropical Beef (TSTB)
- Fine Sheep (FS)
- Medium Sheep (MS)
- Pastoral Sheep (PS)
- Dairy (D)
- Feedlot Beef (FB)

The choice of representative farms was informed by interviews with researchers and leading farmers. General farm information and production data for the representative farms includes farm size, herd composition and baseline emissions, and was obtained from ABARE where possible. Representative farms for broad acre beef and sheep farming systems are median farms from ABARE. Data for the representative dairy farm was obtained from Dairy Australia. Since data for feedlot beef was not available from ABARE or another recognised source, representative feedlot beef data was based on a case study on a small feedlot of the year previously undertaken by one of the project authors.

The results of the case study analysis were then scaled up to estimate the national potential for each of the mitigation strategies under investigation. Since the case study analysis was used as the basis for national estimates, the use of ABARE median farms for the majority of farming systems provided a standard basis of measurement for the national estimates.

Figure 1 shows ABS classifications for broad acre zones and regions. Total numbers of beef cattle and sheep for each of these three-digit regions were obtained from ABS and assigned to one of the six broad acre beef and sheep farming systems listed above. Five-year averages were calculated to reduce the impact of annual variations in herd numbers. Total numbers for dairy by state were obtained from Dairy Australia, while the national herd number for feedlot beef came from MLA.

Figure 1 Australian broad acre zones and regions



The emissions potential for each practice option in a farming system was calculated by multiplying the estimated case study emissions reduction per head for each practice option by the total number of head across all regions in a farming system. Statistical regions were associated with the different farming systems as per tables for each farming system shown in sections below. Three scenarios were run for assumed adoption rates of 5, 10 and 20%.

National emissions potentials for beef, sheep, dairy and feedlot beef were then derived by adding together the relevant farming systems emissions totals for each practice option. Economic potential at national scale was assessed in a similar manner based on marginal profits.

The following sub-sections show the regions making up each of our eight farming systems as well as information for each of the representative farm case studies.

3.2.1.1 Northern Coastal Beef

The Northern Coastal Beef farming system includes ABS regions 331: South Queensland Coastal - Curtis to Moreton and 332: North Queensland Coastal - Mackay to Cairns. The average total herd across these two regions is 2,278,110.

Table 27 Average total herd by region - Northern coastal beef

331	High Rainfall	QLD: South Queensland Coastal - Curtis to Moreton	1,852,295
332	High Rainfall	QLD: North Queensland Coastal - Mackay to Cairns	425,815
Total herd			2,278,110

The representative case study farm for this farming system is from region 332: North Queensland Coastal. The numbers of head on hand in each month total 722. Farm size, baseline emissions and DSE are also shown.

Table 28 Case study information - Northern coastal beef

Cows 2 years & older	307
Heifers 1-2 year old	78
Steers 1 year and older	143
Heifer calves (less than 1 year old)	90
Steer calves (less than 1 year old)	91
Bulls 1 year & older	13
Bulls less than 1 year old	0
Total number of head per month	722
Total DSE's per month	6,332
Baseline Emissions (tonnes CO_{2e})	1,166.82
Area in hectares	2,578

3.2.1.2 Northern Rangeland Beef

The Northern Rangeland Beef farming system includes 11ABS regions and has an average total herd of 9,290,912.

Table 29 Average total herd by region - Northern rangeland beef

111	Pastoral	NSW: Far West	289,515
311	Pastoral	QLD: Cape York and the Queensland Gulf	632,097
312	Pastoral	QLD: West and South West	1,662,404
313	Pastoral	QLD: Central North	2,028,401
314	Pastoral	QLD: Charleville - Longreach	1,287,766
511	Pastoral	WA: The Kimberly	810,367
512	Pastoral	WA: Pilbara and the Central Pastoral	512,614
711	Pastoral	NT: Alice Springs Districts	181,318
712	Pastoral	NT: Barkly Tablelands	817,798
713	Pastoral	NT: Victoria River District - Katherine	1,020,251
714	Pastoral	NT: Top End Darwin and the Gulf of Northern Territory	48,380
Total herd			9,290,912

The representative case study farm for this farming system is from region 313: QLD Central North. The numbers of head on hand in each month are shown below.

Table 30 Case study information - Northern rangeland beef

Cows 2 years & older	1,056
Heifers 1-2 year old	218
Steers 1 year and older	553
Heifer calves (less than 1 year old)	325
Steer calves (less than 1 year old)	325

Bulls 1 year & older	55
Bulls less than 1 year old	0
Total number of head per month	2,532
Total DSE's per month	22,100
Baseline Emissions (tonnes CO_{2e})	4,101.54
Area in hectares	15,877

3.2.1.3 Temperate/Sub-Tropical Beef

The Temperate/Sub-Tropical Beef farming system includes 18 ABS regions and has an average total herd of 13,899,161.

Table 31 Average total herd by region – Temperate/Sub-Tropical Beef

121	Wheat Sheep	NSW: North West Slopes and Plains	1,293,799
122	Wheat Sheep	NSW: Central West	734,875
123	Wheat Sheep	NSW: Riverina	703,658
131	High Rainfall	NSW: Tablelands (Northern Central and Southern)	1,780,320
132	High Rainfall	NSW: Coastal	620,659
221	Wheat Sheep	VIC: Mallee	96,450
222	Wheat Sheep	VIC: Wimmera	42,336
223	Wheat Sheep	VIC: Central North	265,830
231	High Rainfall	VIC: Southern and Eastern Victoria	1,889,178
321	High Rainfall	QLD: Eastern Darling Downs	475,987
322	Wheat Sheep	QLD: Darling Downs and Central Highlands of Queens	3,717,673
411	Pastoral	SA: North Pastoral	230,068
422	Wheat Sheep	SA: Murray Lands and Yorke Peninsula	174,651
431	High Rainfall	SA: South East	686,012
521	Wheat Sheep	WA: Central and South Wheat Belt	222,432
522	Wheat Sheep	WA: North and East Wheat Belt	50,715
531	High Rainfall	WA: South West Coastal	448,013
631	High Rainfall	TAS: Tasmania	466,502
Total			13,899,161

The representative case study farm for this farming system is from region 121: NSW North West Slopes and Plains. The numbers of head on hand in each month total 469.

Table 32 Case study information - Temperate/subtropical beef herd

Cows 2 years & older	186
Heifers 1-2 year old	39
Steers 1 year and older	102
Heifer calves (less than 1 year old)	66
Steer calves (less than 1 year old)	66
Bulls 1 year & older	10
Bulls less than 1 year old	0

Total number of head per month	469
Total DSE's per month	4,008
Baseline Emissions (tonnes CO_{2e})	755.22
Area in hectares	863

3.2.1.4 Fine Sheep

The Fine sheep farming system includes 4 ABS regions and has an average total flock of 10,081,696.

Table 33 Average total flock by region – Fine sheep flock

131	High Rainfall	NSW: Tablelands (Northern Central and Southern)	6,683,587
321	High Rainfall	QLD: Eastern Darling Downs	216,033
322	Wheat Sheep	QLD: Darling Downs and Central Highlands of Queens	939,659
631	High Rainfall	TAS: Tasmania	2,242,417
Total flock			10,081,696

The representative case study farm for this farming system is from region 121: NSW North West Slopes and Plains. The numbers of head on hand in each month total 2,656.

Table 34 Case study information - Fine sheep flock

Breeding Ewes (with lamb during the period)	1,100
Maiden Ewes (1-2 yo to be joined next year)	273
Other Ewes (2 year & older not joined)	0
Lambs/Hoggets (to 1 year old)	683
Rams	25
Wethers (more than 12 months old)	575
Total number of head per month	2,656
Total DSE's per month	3,532.8
Baseline Emissions (tonnes CO_{2e})	418.39
Area in hectares	863

3.2.1.5 Medium Sheep

The medium sheep farming system includes the 6 ABS regions and has an average total flock of 55,793,156.

Table 35 Average total flock by region – Medium sheep flock

421	Wheat Sheep	SA: Eyre Peninsula	1,305,891
422	Wheat Sheep	SA: Murray Lands and Yorke Peninsula	3,090,499
431	High Rainfall	SA: South East	4,721,102
521	Wheat Sheep	WA: Central and South Wheat Belt	10,514,403
522	Wheat Sheep	WA: North and East Wheat Belt	2,550,976
531	High Rainfall	WA: South West Coastal	1,788,512

Total flock	55,793,156

The representative case study farm for this farming system is from region 123: NSW Riverina. The numbers of head on hand in each month total 2,724.

Table 36 Case study information - Medium sheep flock

Breeding Ewes (with lamb during the period)	1,300
Maiden Ewes (1-2 yo to be joined next year)	334
Other Ewes (2 year & older not joined)	0
Lambs/Hoggets (to 1 year old)	867
Rams	33
Wethers (more than 12 months old)	190
Total number of head per month	2,724
Total DSE's per month	3,743.2
Baseline Emissions (tonnes CO_{2e})	411.06
Area in hectares	2,139

3.2.1.6 Pastoral Sheep

The pastoral sheep farming system includes 4 ABS regions and has an average total flock of 6,910,773.

Table 37 Average total flock by region – Pastoral sheep

111	Pastoral	NSW: Far West	3,253,435
312	Pastoral	QLD: West and South West	1,286,205
314	Pastoral	QLD: Charleville - Longreach	1,156,660
411	Pastoral	SA: North Pastoral	1,214,473
Total flock			6,910,773

The representative case study farm for this farming system is from region 411: SA North Pastoral. The numbers of head on hand in each month total 4,115.

Table 38 Case study information - Pastoral sheep flock

Breeding Ewes (with lamb during the period)	2,000
Maiden Ewes (1-2 yo to be joined next year)	439
Other Ewes (2 year & older not joined)	0
Lambs/Hoggets (to 1 year old)	1,277
Rams	71
Wethers (more than 12 months old)	328
Total number of head per month	4,115
Total DSE's per month	5,746.2
Baseline Emissions (tonnes CO_{2e})	627.32
Area in hectares	131,666

3.2.1.7 Dairy

The dairy farming system has an average total herd of 2,658,328. Numbers for dairy are available by state rather than regions.

Table 39 Average total herd by state – Dairy

NSW	339,636
QLD	169,302
VIC	1,673,079
SA	141,210
WA	111,190
TAS	223,911
Total herd	2,658,328

The representative case study farm for this farming system is from region 231: Southern and Eastern Victoria. The numbers of head on hand in each month total 413.

Table 40 Case study information - dairy

Milking cows	250
Heifers > 1	75
Heifers < 1	75
Mature bulls	5
Immature bulls	8
Total number of head per month	413
Litres Milk Produced per cow per day	19.6
Baseline Emissions (tonnes CO_{2e})	980
Area in hectares	200

3.2.1.8 Feedlot Beef

The national herd for feedlot beef totals 763,689 (Source: MLA).

The case study for this farming system is from region 321: QLD Eastern Darling Downs. The numbers of head on hand in each month total 1643, with a daily average of 450 head in the feedlot. This feedlot is small compared to many representative feedlots; however our results are expected to be generalisable to larger feedlots. As previously indicated, this existing case study was used since data on representative feedlots was not available from ABARE.

Table 41 Case study information –feedlot beef

Total number of head per month	1643
Average daily number in the feedlot	450
Baseline Emissions (tonnes CO_{2e})	732.4
Area in hectares	2578
Days on feed	100

3.2.1.9 Summary of case study farms

Summary information for the eight case study farms is shown below. There is substantial variation in the size, number of head and baseline emissions across the cases, reflecting differences in the farms that make up each farming system. This variation impacts the potential for emissions reductions and associated changes to profitability across the case studies.

Table 42 Summary– case study farms

Farming System	ABS Region	Area in hectares	Number of head	Baseline Emissions (tonnes CO_{2e})
Northern Coastal Beef	332: North Queensland Coastal	2,578	722	1,166.82
Northern Rangeland Beef	313: QLD Central North	15,877	2,532	4,101.54
Temperate Sub-Tropical Beef	121: NSW North West Slopes and Plains	863	469	755.22
Fine Sheep	121: NSW North West Slopes and Plains	863	2,656	418.39
Medium Sheep	123: NSW Riverina	2,139	2,724	411.06
Pastoral Sheep	411: SA North Pastoral	131,666	4,115	627.32
Dairy	231: Southern and Eastern Victoria	200	413	980.00
Feedlot Beef	321: QLD Eastern Darling Downs	2,578	450 per day	732.44

3.2.2 Estimation of emissions reductions and productivity changes

The GHG emissions associated with the implementation of NLMP and other mitigation strategy practice options shown in Table 3 were estimated using the *FarmGAS* and *DGAS* tools, based on representative herds/flocks for each region. These tools were also used to facilitate the calculation of expected productivity changes associated with those practice options where these are able to be reliably estimated. The use of *FarmGAS* and *DGAS* to estimate emissions reductions provided a standardised measurement approach across the broad range of methane mitigation practice options examined.

Overview of the *FarmGAS* and *DGAS tools*

FarmGAS is an online tool developed by the Australian Farm Institute for estimating GHG emissions from many of Australia's agricultural enterprises, including beef cattle, feedlot cattle and sheep, but not Dairy. *FarmGAS* can be used to estimate GHG emissions from individual livestock enterprises as well as a whole farm system. It can also be used to investigate GHG mitigation options through modifications of emission calculations and 'what if' scenarios.

The *DGAS* calculator, which is a spreadsheet model, was developed by staff from the University of Tasmania, University of Melbourne and the Victorian Department of Environment and Primary Industries. *DGAS* was developed to explore the implications of a range of diet, herd or feedbase management options on the GHG emissions for a dairy enterprise.

The calculations in *FarmGAS* and *DGAS* are based on the internationally accepted GHG accounting methodologies that are used by the Department of the Environment to estimate emissions from the agricultural sector at a national level. The details of the emission calculation methodology (2012) can be obtained at: http://www.environment.gov.au/climate-change/greenhouse-gas-measurement/publications/.

Both *FarmGAS* and *DGAS* tools use this methodology to facilitate GHG calculations at the farm or enterprise level. The *FarmGAS* tool and manuals can be accessed at: http://www.farminstitute.org.au/calculators/farm-gas-calculator. The *DGAS* calculator and manuals can be accessed at: http://www.greenhouse.unimelb.edu.au/Tools.htm.

For GHG accounting purposes, most GHG emissions are calculated and reported as tonnes of carbon dioxide equivalents (CO_{2e}). Carbon dioxide equivalents are the standard unit of GHG emissions used to express the combined effect of groupings of different GHGs, each of which has a different warming effect in the atmosphere. For example, a tonne of methane (CH4) in the atmosphere has the same warming effect as 21 tonnes of CO_{2e}; hence methane is allocated a Global Warming Potential (GWP) of 21 for emission accounting purposes.

Modifications to FarmGAS

Although the majority of the GHG results could have been estimated using the online version of *FarmGAS*, several of the scenarios required adjustments to embedded calculations which were not possible in the online calculator. For the purposes of this project, the Australian Farm Institute's 'test bed' version (Excel spreadsheet) of the calculator was used, enabling the required modifications to be made. These modifications did not alter the fundamental National Inventory Report (NIR) based methodology. Rather, they allowed the necessary adjustments to be made to include the NLMP mitigation results for feed and gross energy intake, liveweight gain and wool production, and to facilitate modelling outputs.

For example, in the Temperate Sub-Tropical Beef – Genetics – scenario (section 3.1.6), the reduction in methane emissions is due to a) lower methane production for the same feed intake and/or b) lower feed intake for the same growth rate. Under the NIR methodology (2014) feed intake is a function of growth rate (liveweight gain)[6]. The first scenario (a) can be carried out in the online version of *FarmGAS* (by way of adjustments to the final methane result). However, for the second scenario (b), adjusting feed intake and keeping liveweight gain static required modification to the *FarmGAS* methane calculations. Consequently, by using the *FarmGAS* spreadsheet, the results from the NIR equation 4A.1a_1 were reduced by 1.09%, without having to adjust feed intake via changes to liveweight gain.

Modifications were also made to the spreadsheet to enable adjustments to final methane results, liveweight gain and wool production for individual classes of beef cattle and sheep.

Emissions estimations

The base farm data obtained for each representative farm case study was entered into the *FarmGAS* tool (*DGAS* for dairy) to calculate the baseline GHG emissions for that farm. Each GHG emissions mitigation strategy was then modelled separately for each case study farm using the *FarmGAS* tool.

The whole farm GHG emissions results for each mitigation strategy were then compared to the base GHG emissions for each farm. This comparison was used to calculate the estimated reduction in GHG emissions for each mitigation strategy on each case study farm. These emissions reductions were used for the marginal abatement cost curve analysis described in section 3.2.4.

[6] 'National Inventory Report 2012 Volume 1, Commonwealth of Australia 2014', p. 262, equation 4A.1a_1.

Modelling outputs from *FarmGas* and *DGAS* were also used to estimate cash flows related to productivity changes and carbon credits described in the next section on investment analysis.

3.2.3 Investment Analysis Methodology

For each mitigation strategy analysed, financial modelling was carried out which involved identifying all capital and operating costs associated with the implementation of the practice option on farm. In cases where there was uncertainty, estimates from industry experts and relevant Government departments were used.

The modelling involved projections over periods ranging from 1 to 20 years, with the majority having project lives of just one year. For example, vaccinations would be administered on an annual basis. Modelling for Leucaena is based on a 20 year project life with an assumption that pastures are converted progressively over the first ten years while benefits extend well beyond the initial investment period. Although genetics is a multiyear project, the financial analysis used percentage annual changes as outlined in section 3.1.5 and was therefore based on a one year project life.

For annual scenarios where no capital expenditure was required, marginal profit or loss was used as the financial indicator. Only those cash flows that were different to the business-as-usual case were included to calculate marginal profits and losses related to the adoption of each mitigation strategy. These include implementation costs, estimated impacts of productivity improvements, and cash flows from carbon credits.

Carbon prices of $0, $14 and $50 per tonne were modelled to reflect the current uncertainty around future carbon prices under the Emissions Reduction Fund. The first auction for these funds conducted in April 2015 resulted in an average price of $13.95 per tonne of carbon. However not all land owners are able to access these auction funds and it is therefore also important to consider the analysis when a carbon price of $0 is assumed. On the other hand, it is possible that the carbon price could increase dramatically in future years and it is worth considering the implications of a high carbon price, hence the modelling at $50.

For mitigation strategies with greater than a one year life, discounted cash flow techniques were applied to determine the financial results and the net present value (NPV). NPVs represent the difference between the capital expenditure associated with a scenario and the present value of projected cash flows over the strategy's project life. To calculate NPVs, future changes in cash flows (from the business-as-usual base case) were discounted using an assumed discount rate of 5%. This is the discount rate for BCAs agreed by the Council for RDCs. Positive NPVs indicate profitable investment opportunities. This approach is different to the enterprise gross margin approach used in some prior research. It provides an estimate in current day terms of the value of future cash flows emanating from a specific investment or project. It enables robust comparisons to be made of the potential financial outcomes of investments or projects with different project lives and capital expenditure requirements.

Several assumptions were made for the financial analysis. Standard costs have been used to facilitate comparisons between representative farms. A flexible budgeting approached was used with farm production multiplied by standardised regional financial price data such as historical cattle sale prices. Annual rather than monthly average prices were used to eliminate the impact of case specific decisions around the months of sales or purchases. This approach improves comparability of each mitigation strategy between farms and regions as it focuses on the impacts of specific mitigation strategies rather than other factors such as timing of commodity sales that can impact on price and have the effect of skewing the financial results. However, the price assumptions are based on historical data comparable to regional market prices and any future change to these prices in real terms will have a significant bearing on the viability of the scenarios analysed.

Assumptions about implementation costs, the extent of emissions reductions, and effects on feed intake and growth rates are based on the specific information about each mitigation strategy presented in Section 3.1 of the report.

Outputs of the investment and emissions analysis were used to construct a marginal abatement cost curve for each case study farm.

3.2.4 MACC methodology

A marginal abatement cost curve (MACC) was developed for each representative farm based on the financial analysis discussed above. Marginal abatement cost curves were developed by McKinsey & Company (2007) to identify how much abatement an economy can afford and where policy should be directed to achieve the emission reductions. Employment of the MACC at the individual farm scale allows farm businesses to consider the prioritisation of alternate GHG emissions mitigation strategies based on their financial characteristics. The MACC financial modelling tool used in this research has been developed at the University of Southern Queensland and tailored to suit the particular needs of the Australian livestock sector.

The number of possible mitigation strategy practice options for each representative farm was limited to those that are, or might in future be, applicable for that particular farming system.

Each bar in the MACC analysis discussed in this report represents a mitigation strategy practice option. The width is the amount of CO_{2e} that could potentially be reduced per year by implementing that strategy. The height is the average cost of avoiding one tonne of CO_{2e} with this strategy, relative to the activities that would otherwise occur in the business-as-usual case. Thus each of the practice options examined was compared on a like-for-like basis. Those practice options that fall ‘below the carbon price line’ represent opportunities to both reduce GHG emissions and increase profitability; with the most profitable strategies per tonne of CO_{2e} abated being those at the left of the MACC. Practice options that fall ‘above the carbon price line’ are projected to cost more to implement than the potential cost savings or revenues associated with the strategy.

The initial analyses assumed that none of the energy that would have been lost in methane prior to the mitigation strategy being implemented is retained by the animal for productive purposes. Section 4.3 illustrates the consequences of utilising different proportions of the energy saved through methane mitigation by vaccination or feeding of algae for productive purposes on the MACC analysis outputs.

4 Results

4.1 Case study Farms

4.1.1 Northern Coastal Beef

This section reports the results of GHG emissions and financial modelling for the mitigation practice options evaluated for the northern coastal beef farming system. The table and marginal abatement cost curves (MACCs) presented below show data for the case study farm used to depict this farming system. This farm has 722 head of cattle and baseline emissions of 1166.82 tonnes CO_{2e}.

Table 43 shows modelled emissions savings and financial data for all mitigation strategies relevant to this farming system. Marginal profitability relative to business as usual is shown for carbon price scenarios of $0, $14 and $50 per tonne CO_{2e}.

In accordance with the emissions reduction assumptions made in Section 3.1 based on research results to date, those practice options showing the greatest potential for emissions reductions are algae, NOP, Leucaena and plant bioactives. Both high and low estimates are shown to demonstrate the impact of the assumptions made. For example, the analysis is conducted on the basis of 60% and 30% methane reduction for algae to reflect the uncertainty in research results available at the time of writing this report.

The marginal profits/losses shown in the table are negative for many of the practice options examined. This is due to high implementation costs and/or an inability to reliably model productivity gains for those practice options where no or very limited prior research evidence is available.

Results of this investment analysis indicate that the financial viability of each potential mitigation strategy depends on:

1. **The cost of implementing the strategy on farm.** These costs are currently quite high for some of the NLMP direct mitigation strategies evaluated, making them financially unviable. Implementation costs for plant bioactives, nitrates, NOP, algae and Leaucaena are high.
2. **Productivity gains.** A proportion of the energy saved by inhibiting methane emissions can be retained for animal productive purposes to varying degrees. Productivity gains have the potential to offset the cost of implementation for some mitigation strategies such as vaccination, and can increase profitability for practice options such as biochar where productivity gains are estimated to exceed implementation costs.
3. **Carbon credits.** Potential for increased profitability from accessing carbon credits is secondary to increased profits from productivity gains. Our analysis shows that even when a carbon price of $50 per tonne of CO_{2e} is assumed, money earned from carbon credits is insufficient to offset implementation costs for many of the mitigation strategies considered.

Hence, it is difficult to make comparisons across practice options in terms of marginal profits and losses since we were unable to model the impacts of growth rate changes for many of the direct (science) mitigation strategies and these need to be determined through further research. Growth rate increases from energy saved were able to be estimated for Leucaena and biochar; however it should be noted that the estimates for biochar are based on one experiment on atypical diets and may therefore not be reliable. Growth rates were unable to be confirmed for the other direct mitigation strategies.

The mitigation strategies for which we were able to model growth rate changes (Leucaena, biochar) show marginal profits (annualised NPV for Leucaena which is modelled over 20 years) while the remaining direct mitigation strategies tend to show marginal losses.

The two management practice change options that were included for comparative purposes, production efficiency and phosphorus supplementation, show relatively high marginal profits. However caution is warranted for these practice options since they were based on case studies for which the generalisability of results across regions is uncertain and they do not fully incorporate indirect costs associated with the changes required to implement these options.

The first marginal abatement cost curve (MACC) shown in figure 2 has a bar representing each of the mitigation strategy practice options relevant to the northern coastal beef farming system. A carbon price of $14 is assumed. The width of each bar is the amount of CO_{2e} that could potentially be reduced per year by implementing that strategy. The height is the average cost of avoiding one tonne of CO_{2e} per annum with this strategy, relative to the activities that would otherwise occur in the business-as-usual case.

The bars on the MACC which are below the ‘zero’ line indicate potentially profitable options to reduce GHG emissions; with the most profitable strategies per tonne of CO_{2e} abated being those at the left of the MACC. The first two bars on the left show that the management practice changes have the potential to both reduce methane emissions and increase profitability. Based on an extrapolation of results achieved by Peter Whip, production efficiencies have the potential to increase annual profitability by $90,724 ($120 per head plus $1.58 per head for carbon credits) and reduce over 81.7 tonnes of CO_{2e} for the case study farm. Phosphorous supplementation could increase annual profitability by $34,799 ($47 per head plus 1.31 per head for carbon credits) and reduce emissions by 117.6 tonnes CO_{2e}. However there are caveats associated with a simple extrapolation of these results that need to be considered.

The next bar from the left indicates that biochar also has the potential to both reduce methane emissions and increase profitability due to potential productivity gains. This practice option is estimated to increase annual profitability by $25,079 ($34.73 per head) and reduce total farm emissions by 175 tonnes CO_{2e}.

Leucaena also has potential to produce profits while reducing emissions. However with a net present value of $55,400 for a project with a 20 year life, annualised marginal profits are relatively low at $7,348 (10.18 per head). Further, a large capital investment is required for establishment, with a payback period of approximately 15 years. Estimated annual emissions reduction potential for Leucaena is 327 tonnes of CO_{2e} for the case study farm.

Genetics and vaccination are financially viable due to assumed income from carbon credits, but would loss making if carbon credits were not able to be accessed. The emissions reduction potential for genetics is quite low at 89.8 tonnes of CO_{2e} and is based on the assumption of 20 years of genetic gain. The expectation would be much lower for earlier years, limiting any potential for financial gains from carbon credits.

All other practice options fall ‘above the line’ are projected to cost more to implement than any potential productivity gains associated with the strategy. The highest cost options for reducing emissions are plant bioactives at $437 per tonne CO_{2e}, nitrates at $418 per tonne CO_{2e}, NOP at $362 per tonne CO_{2e} reduced when an emissions reduction of only 15% is assumed for NOP. The lowest cost options for reducing emissions are management practice changes, biochar, genetics and vaccination.

Figure 3 shows the northern coastal beef MACC based on a carbon price of $50 and demonstrates the potential for low cost strategies like vaccination to become financially attractive under a scenario of high carbon prices.

Figure 4 examines the impact of implementation costs using algae as an example. Given the uncertainty around the potential to produce algae at scale, this version of the MACC shows the impact of a higher price for algae. Relative to the MACC shown in Figure 2 where algae is assumed to be available for

$1.50/kg, Figure 4 depicts algae as being well above the line, i.e. not financially viable or close to it when a purchase price of $5.00/kg is assumed. A carbon price of $14 is assumed for this MACC. At $5.00/kg, algae becomes as expensive to implement as plant bioactives on a per head basis ($182.50 per year or 50 cents per day).

The potential impact of productivity gains from methane energy saved are shown in Figure 5. In this MACC, a 40% energy saving is simulated for vaccination, algae, NOP and plant bioactives (see section 4.3 for a detailed explanation and analysis of results for these simulations using energy savings of 20, 40 and 80%). Under this scenario, vaccination and algae show potential to both reduce emissions and increase profitability, when an emissions reduction of 60% is assumed for algae. This MACC demonstrates that, while the cost per tonne to reduce CO_{2e} is substantially reduced, NOP and plant bioactives remain unprofitable even when energy capture is assumed. This is due to the assumed high costs of implementation for these mitigation practice options. A carbon price of $14 and an algae price of $1.50 are assumed for this MACC.

Table 43 Investment and emissions analysis - northern coastal beef

	Production Efficiency	Phosphorus Supplementation	Genetics*	Vaccination 10% reduction in methane	Vaccination 20% reduction in methane	Leucaena	Algae 30% reduction in methane emissions	Algae 60% reduction in methane emissions	Plant bioactives	Nitrates	NOP 15% reduction in methane emissions	NOP 30% reduction in methane emissions	Biochar
Project Life (years)	1	1	1	1	1	20	1	1	1	1	1	1	1
Emissions Savings (tonnes C02e)	81.7	117.6	89.8	116.7	233.4	327.0	350.0	700.1	292.0	76.0	175.0	350.0	175.0
Marginal Profit / Loss at a Carbon Price of $0	$86,640	$33,852	$0	-$3,249	-$3,249	$2,770	-$39,530	-$39,530	-$131,765	-$32,851	-$65,883	-$65,883	$22,629
Carbon Credits at a Carbon Price of $14	$1,143	$947	$1,258	$1,634	$3,268	$4,578	$4,900	$9,801	$4,088	$1,064	$2,450	$4,900	$2,450
Carbon Credits at a Carbon Price of $50	$4,084	$3,382	$4,492	$5,835	$11,670	$16,350	$17,500	$35,005	$14,600	$3,800	$8,750	$17,500	$8,750
Marginal Profit / Loss at a Carbon Price of $14	$87,783	$34,799	$1,258	-$1,615	$19	$7,348	-$34,630	-$29,728	-$127,677	-$31,787	-$63,433	-$60,983	$25,079
Marginal Profit / Loss at a Carbon Price of $50	$90,724	$37,234	$4,492	$2,586	$8,421	$19,120	-$22,030	-$4,525	-$117,165	-$29,051	-$57,133	-$48,383	$31,379
*Simulation for 1 year after 20 years of accumulation of genetic gain. Same for all except dairy													

Figure 2 Marginal abatement cost curve for northern coastal beef at a $14 cost of carbon

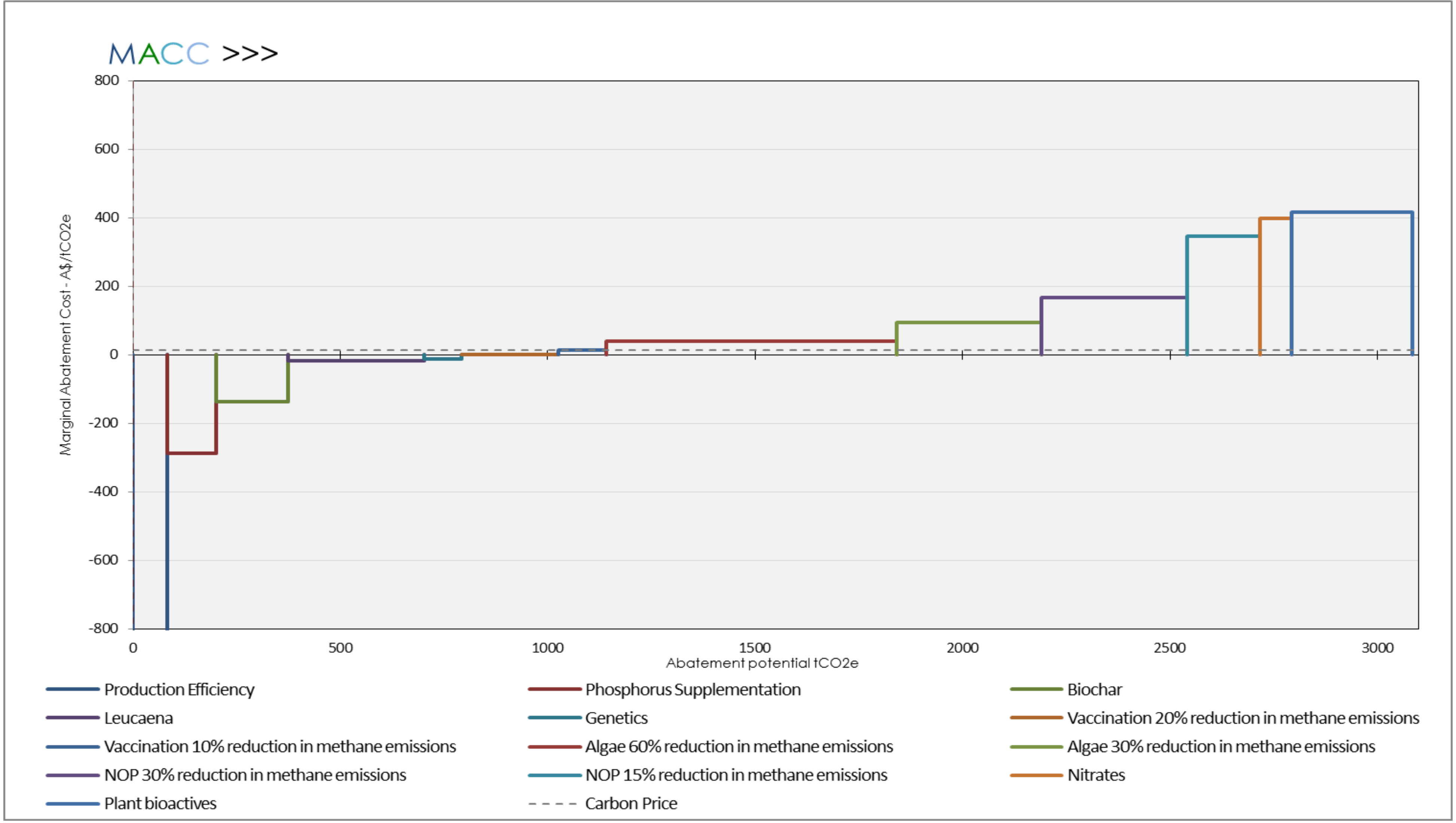


Figure 3 Marginal abatement cost curve for northern coastal beef at a $50 cost of carbon

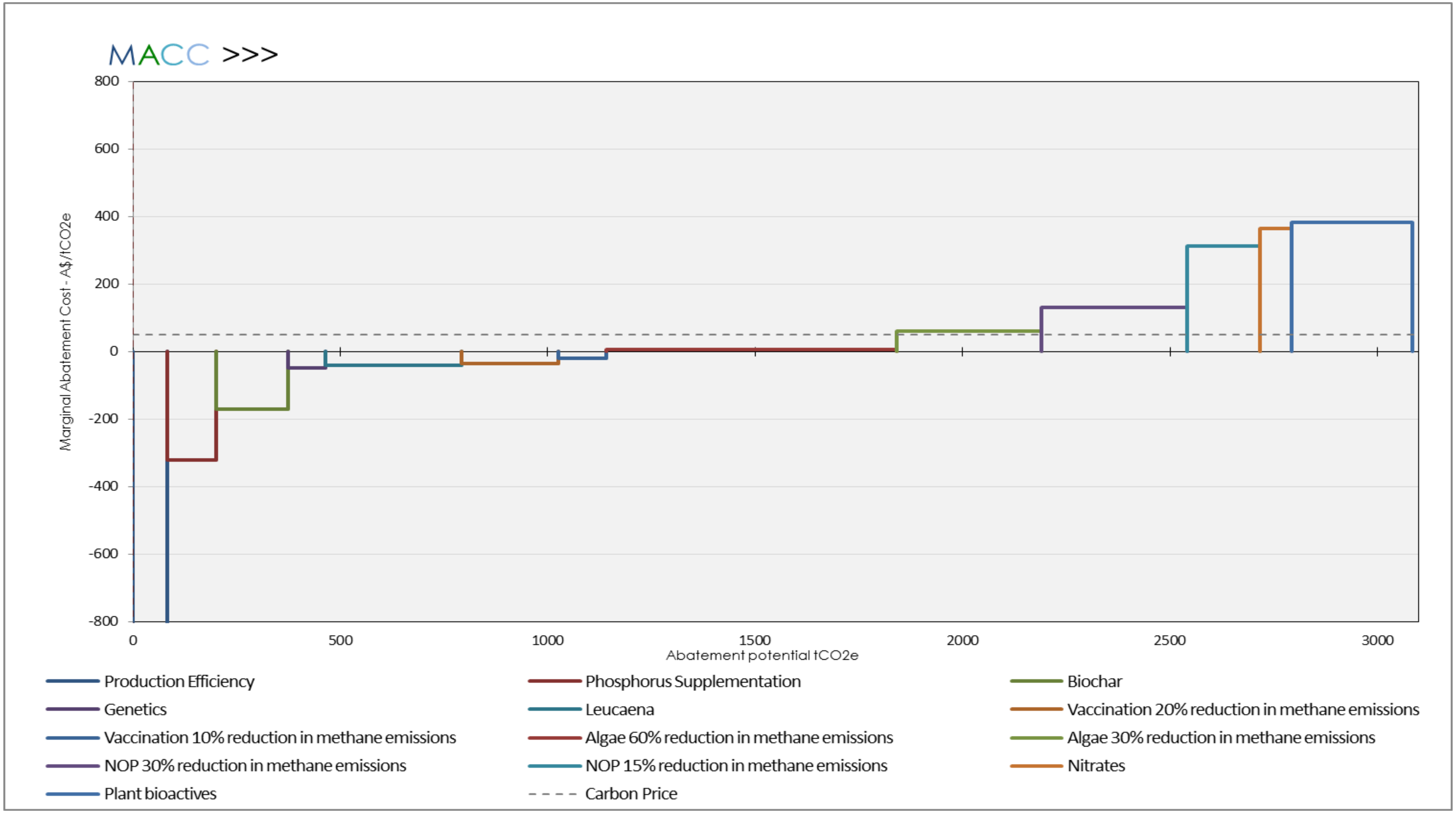


Figure 4 Marginal abatement cost curve for northern coastal beef at a $14 cost of carbon and algae cost of implementation $5/kg

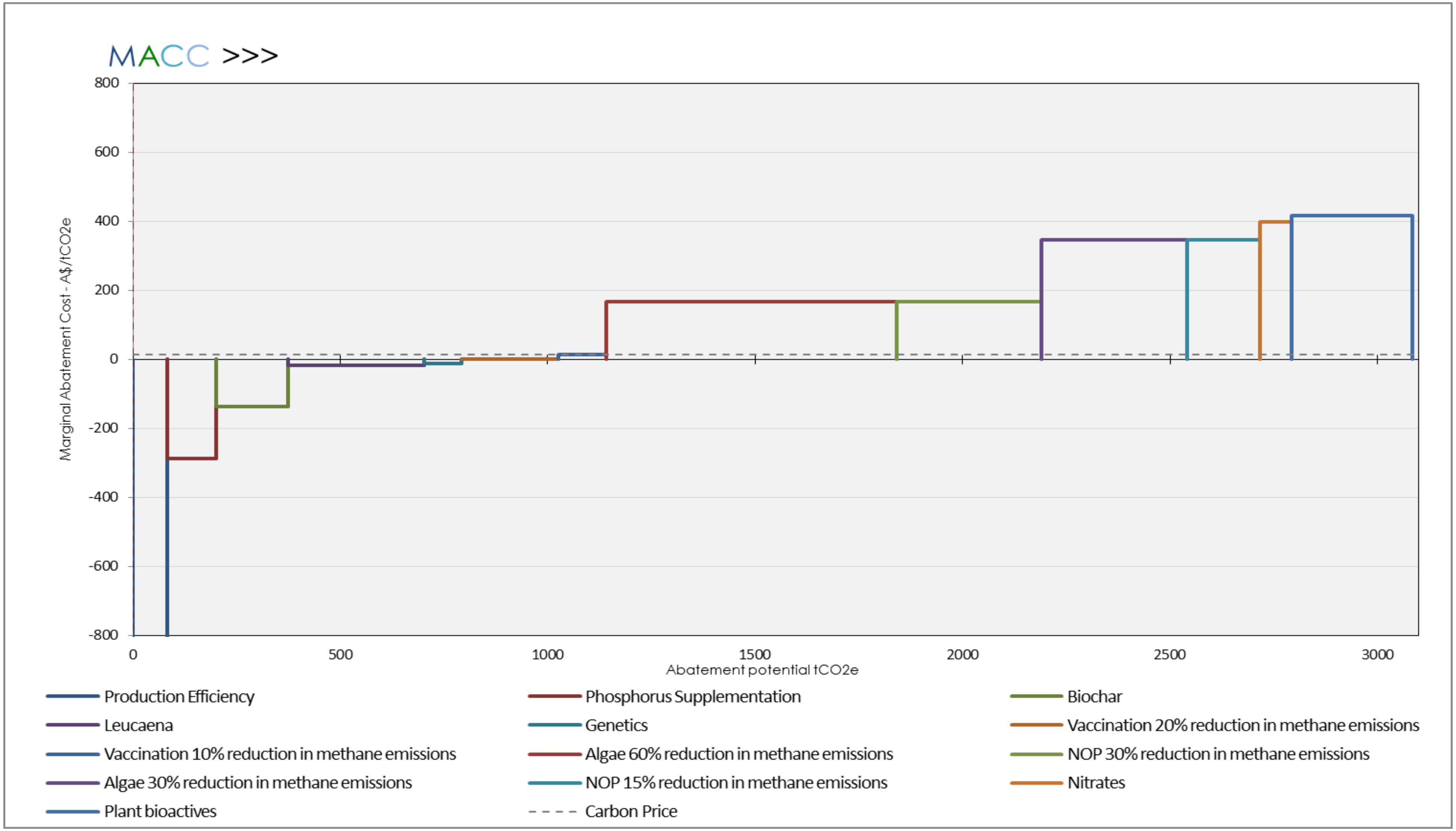
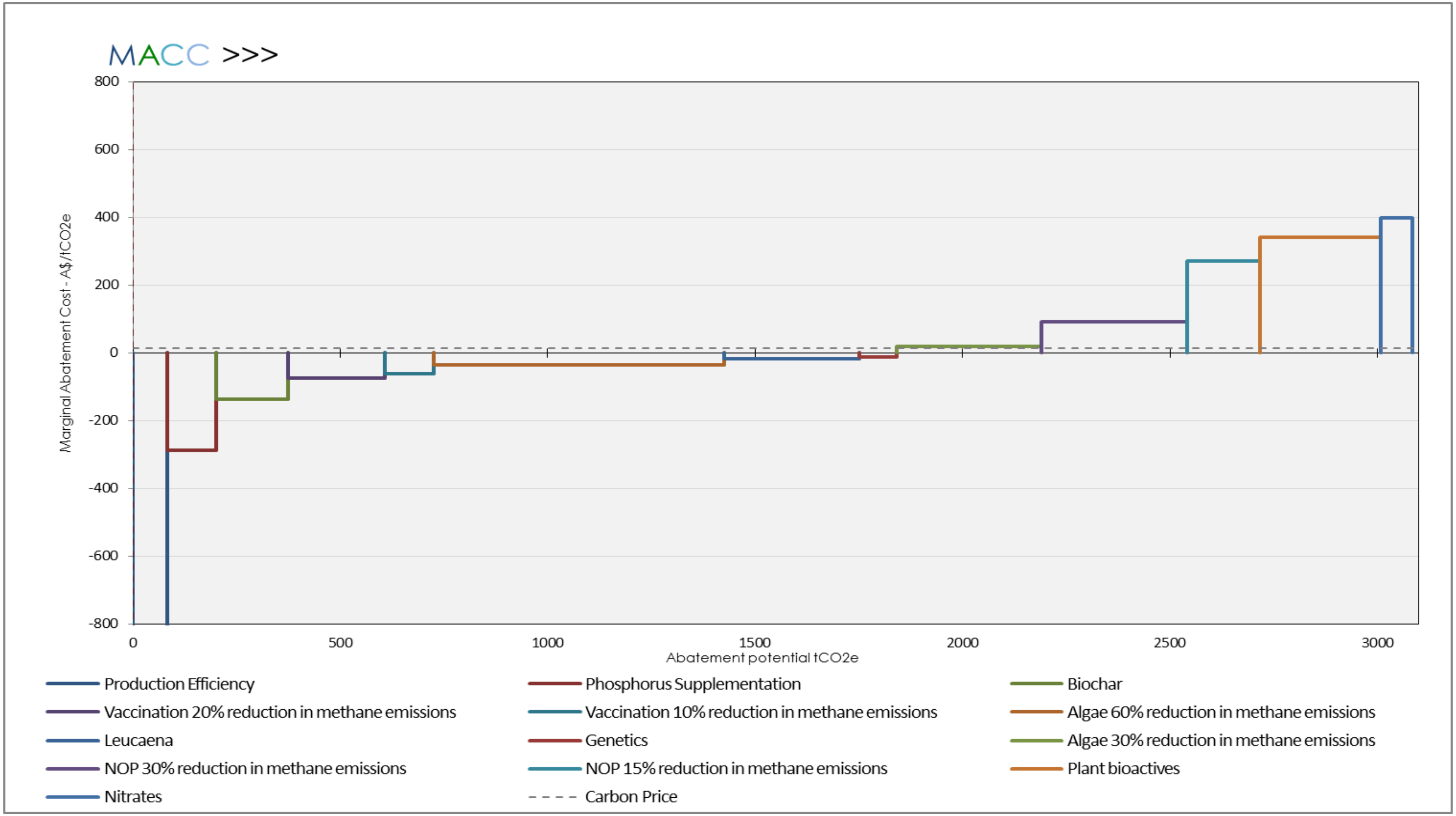


Figure 5 Marginal abatement cost curve for northern coastal beef at a $14 cost of carbon and energy capture of 40%



4.1.2 Northern Rangeland Beef

This section reports the results of emissions and financial modelling for the mitigation practice options evaluated for the northern rangeland beef farming system. The case study farm has 2,532 head of cattle and baseline emissions of 4101.54 tonnes CO_{2e}.

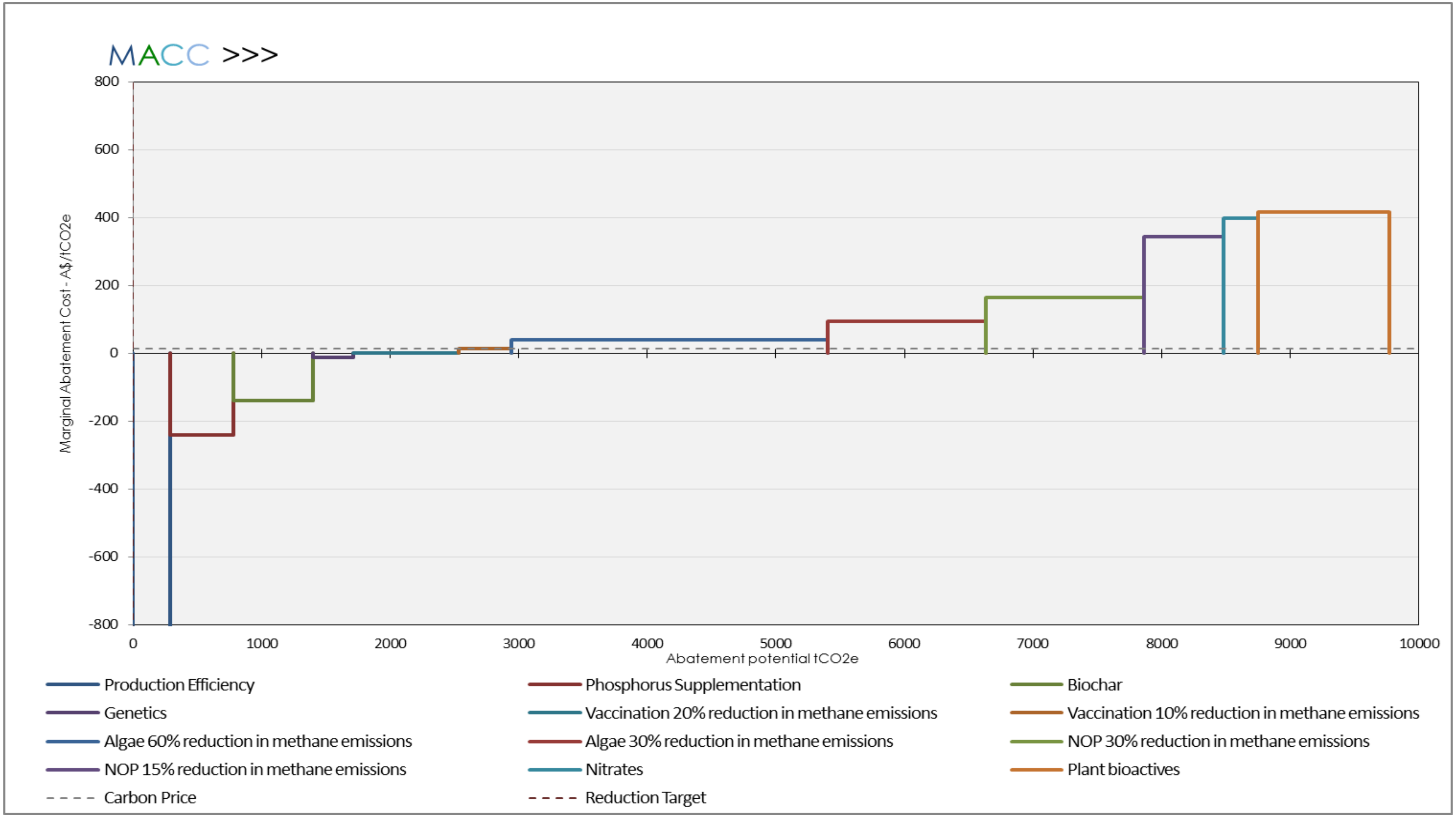
Table 44 shows results that are qualitatively similar to those for the northern coastal beef farming system; however the amounts of emissions reductions and marginal impacts on profitability are greater reflecting the larger scale of this case study. Leucaena was not an option for this system.

The MACC shown in figure 6 assumes a carbon price of $14 per tonne and is similar to Figure 2 for northern coastal beef with the exclusion of Leucaena.

Table 44 Investment and emissions analysis – northern rangeland beef

	Production Efficiency	Phosphorus Supplementation	Genetics	Vaccination 10% reduction in methane	Vaccination 20% reduction in methane	Algae 30% reduction in methane emissions	Algae 60% reduction in methane emissions	Plant bioactives	Nitrates	NOP 15% reduction in methane emissions	NOP 30% reduction in methane emissions	Biochar
Project Life (years)	1	1	1	1	1	1	1	1	1	1	1	1
Emissions Savings (tonnes C02e)	287.1	496.0	315.8	410.2	820.3	1,230.5	2,460.9	1,025.4	266.6	615.2	1,230.5	615.2
Marginal Profit / Loss at a Carbon Price of $0	$303,840	$118,151	$0	-$11,394	-$11,394	-$138,627	-$138,627	-$462,090	-$115,206	-$231,045	-$231,045	$81,446
Carbon Credits at a Carbon Price of $14	$4,019	$7,406	$4,421	$5,743	$11,484	$17,227	$28,657	$14,356	$3,732	$8,613	$17,227	$8,613
Carbon Credits at a Carbon Price of $50	$14,355	$26,450	$15,790	$20,510	$41,015	$61,525	$102,345	$51,270	$13,330	$30,760	$61,525	$30,760
Marginal Profit / Loss at a Carbon Price of $14	$307,859	$125,557	$4,421	-$5,651	$90	-$121,400	-$109,970	-$447,734	-$111,474	-$222,432	-$213,818	$90,059
Marginal Profit / Loss at a Carbon Price of $50	$318,195	$144,601	$15,790	$9,116	$29,621	-$77,102	-$36,282	-$410,820	-$101,876	-$200,285	-$169,520	$112,206

Figure 6 Marginal abatement cost curve for northern rangeland beef at a $14 cost of carbon



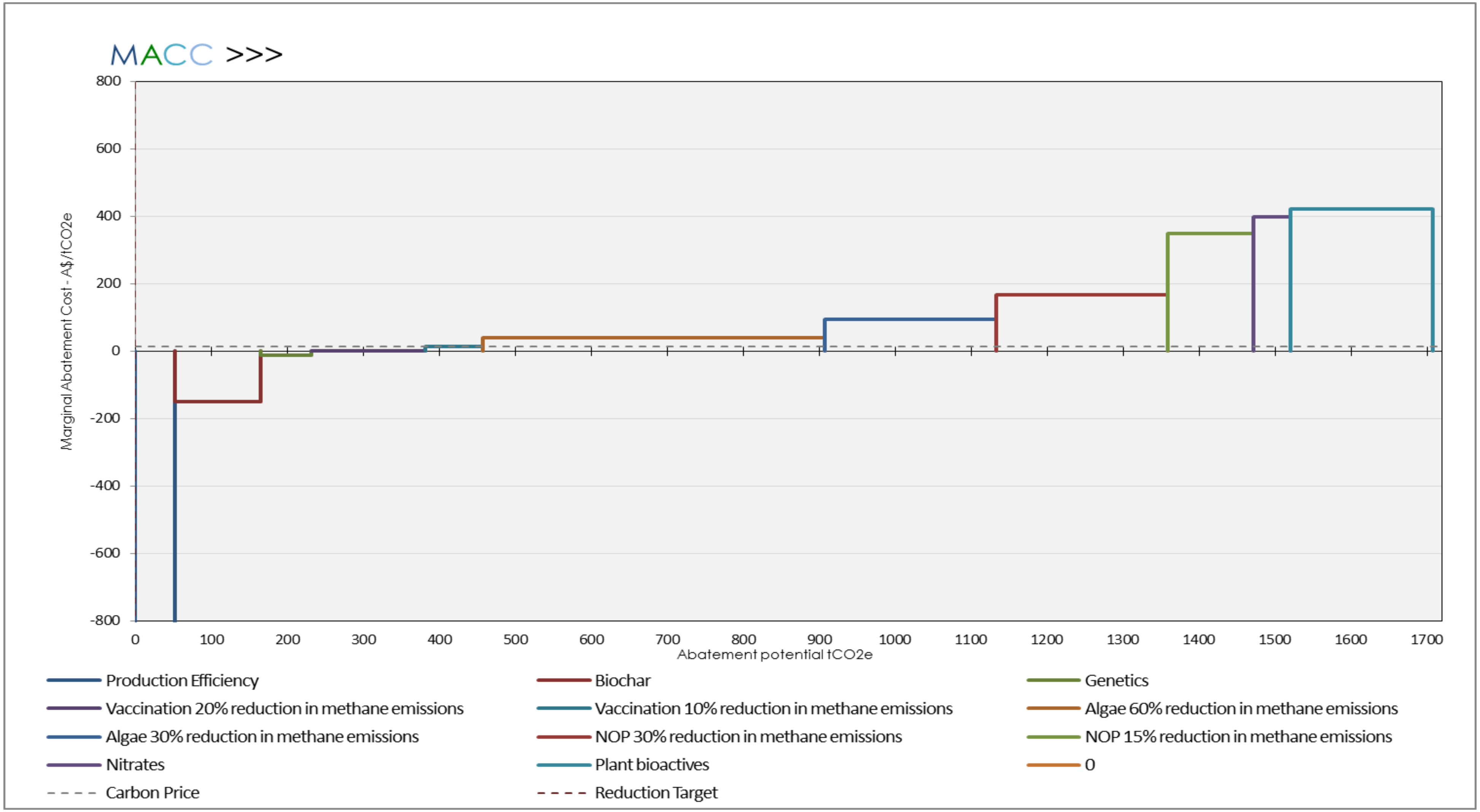
4.1.3 Temperate/Sub-Tropical Beef

Results for the temperate/sub-tropical beef farming system case study are qualitatively similar to those for the other beef farming systems. However the extent of potential emissions reductions are proportionally lower across all mitigation strategies reflecting the smaller size of this representative case study farm. This farm has 469 head of cattle and baseline emissions of 755.22 tonnes CO_{2e}. Neither Leucaena nor phosphorus supplementation are applicable for this farming system.

Table 45 Investment and emissions analysis – temperate/sub-tropical beef

	Production Efficiency	Genetics	Vaccination 10% reduction in methane	Vaccination 20% reduction in methane	Algae 30% reduction in methane emissions	Algae 60% reduction in methane emissions	Plant bioactives	Nitrates	NOP 15% reduction in methane emissions	NOP 30% reduction in methane emissions	Biochar
Project Life (years)	1	1	1	1	1	1	1	1	1	1	1
Emissions Savings (tonnes C02e)	52.6	66.5	75.1	150.2	225.4	450.7	187.8	48.8	112.7	225.4	112.7
Marginal Profit / Loss at a Carbon Price of $0	$56,400	$0	-$2,111	-$2,111	-$25,678	-$25,678	-$85,593	-$21,105	-$42,796	-$42,796	$16,023
Carbon Credits at a Carbon Price of $14	$736	$931	$1,051	$2,103	$3,156	$6,310	$2,629	$683	$1,578	$3,156	$1,578
Carbon Credits at a Carbon Price of $50	$2,630	$3,325	$3,755	$7,510	$11,270	$22,535	$9,390	$2,440	$5,635	$11,270	$5,635
Marginal Profit / Loss at a Carbon Price of $14	$57,136	$931	-$1,059	-$8	-$22,522	-$19,368	-$82,963	-$20,422	-$41,218	-$39,641	$17,601
Marginal Profit / Loss at a Carbon Price of $50	$59,030	$3,325	$1,645	$5,400	-$14,408	-$3,143	-$76,203	-$18,665	-$37,161	-$31,526	$21,658

Figure 7 Marginal abatement cost curve for temperate/sub-tropical beef at a $14 cost of carbon



4.1.4 Fine Sheep

This section reports the results of emissions and financial analyses for the practice options evaluated for the fine sheep farming system. The table and MACCs presented below show data for the case study farm used to depict this farming system. This farm has 2,656 head of sheep and baseline emissions of 418.39 tonnes CO_{2e}.

Table 46 shows results that are qualitatively similar to those for the three beef farming systems discussed in previous sections.

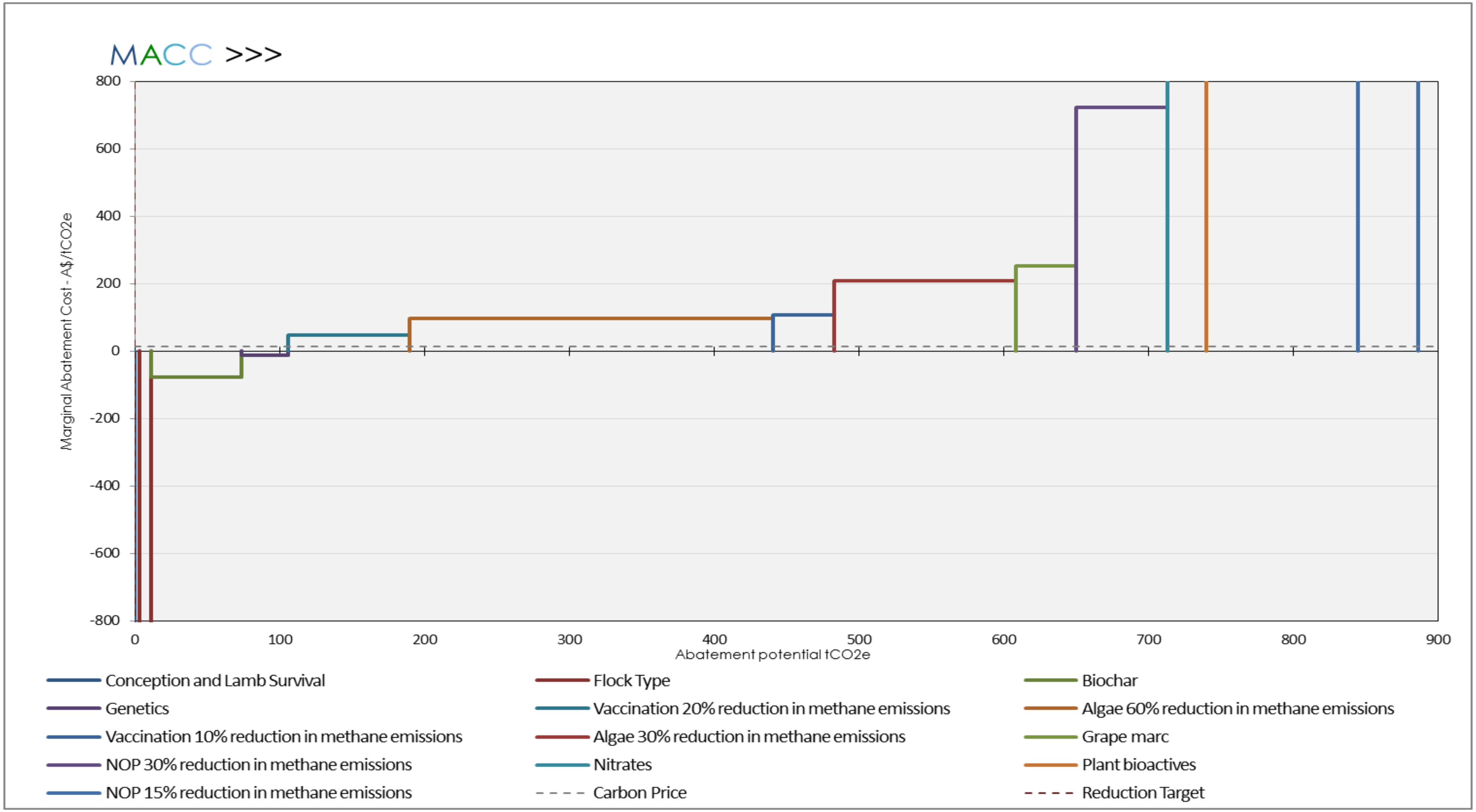
The MACC shown in figure 8 indicates that the management practice change options, while profitable, have little potential for emissions reductions on this case study farm. The next bar from the left indicates that biochar has the potential to both reduce methane emissions and increase profitability. The remaining practice options lead to similar conclusions to those for the beef farming systems.

As for the beef farming systems, it is difficult to make comparisons across practice options in terms of the financial analysis since we were unable to model the impacts of growth rate changes for many of the direct mitigation strategies and these need to be determined through further research.

Table 46 Investment and emissions analysis – fine sheep

	Conception and Lamb Survival	Flock Type	Genetics	Vaccination 10% reduction in methane emissions	Vaccination 20% reduction in methane emissions	Algae 30% reduction in methane emissions	Algae 60% reduction in methane emissions	Plant bioactives	Nitrates	Grape marc	NOP 15% reduction in methane emissions	NOP 30% reduction in methane emissions	Biochar
Project Life	1	1	1	1	1	1	1	1	1	1	1	1	1
Emissions Savings	3.2	7.9	32.2	41.8	83.7	125.5	251.0	104.6	27.2	41.8	62.8	125.5	62.8
Marginal Profit / Loss at a Carbon Price of $0	$7,219	$15,147	$0	-$5,312	-$5,312	-$29,083	-$29,083	-$96,944	-$24,170	-$11,686	-$48,472	-$48,472	$4,180
Carbon Price - $14	$45	$111	$451	$585	$1,172	$1,757	$3,514	$1,464	$381	$585	$585	$879	$879
Carbon Price - $50	$161	$397	$1,610	$2,090	$4,185	$6,275	$12,550	$5,230	$1,360	$2,090	$2,090	$3,140	$3,140
Marginal Profit / Loss at a Carbon Price of $14	$7,264	$15,258	$451	-$4,727	-$4,140	-$27,326	-$25,569	-$95,480	-$23,789	-$11,101	-$47,887	-$47,593	$5,059
Marginal Profit / Loss at a Carbon Price of $50	$7,380	$15,544	$1,610	-$3,222	-$1,127	-$22,808	-$16,533	-$91,714	-$22,810	-$9,596	-$46,382	-$45,332	$7,320

Figure 8 Marginal abatement cost curve for fine sheep at a $14 cost of carbon



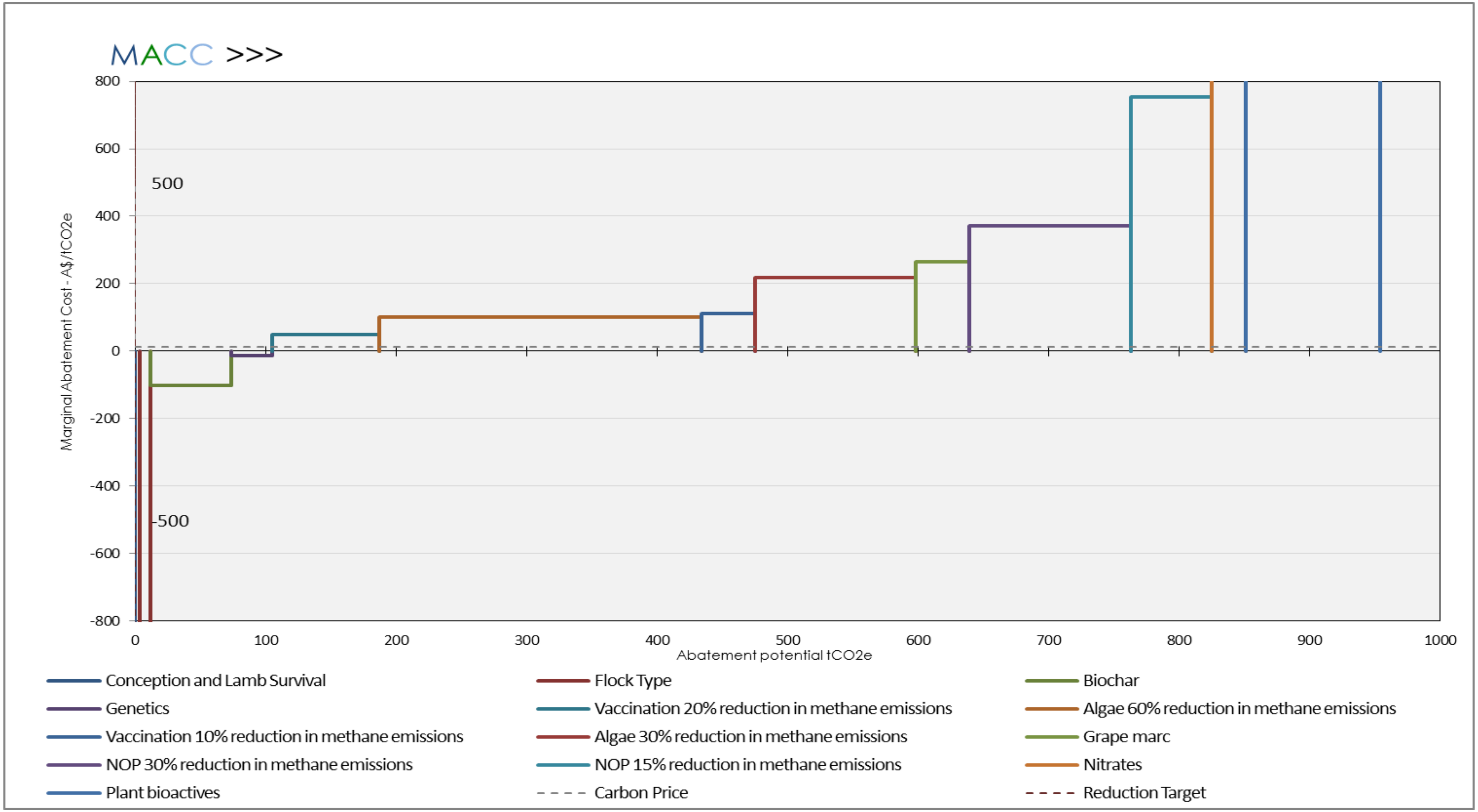
4.1.5 Medium Sheep

Results for the medium sheep case study are qualitatively similar to those for the fine sheep farming system. This representative case study farm has 2,724 head of sheep and baseline emissions of 411.06 tonnes CO_{2e}.

Table 47 Investment and emissions analysis – medium sheep

	Conception and Lamb Survival	Flock Type	Genetics	Vaccination 10% reduction in methane emissions	Vaccination 20% reduction in methane emissions	Algae 30% reduction in methane emissions	Algae 60% reduction in methane emissions	Plant bioactives	Nitrates	Grape Marc	NOP 15% reduction in methane emissions	NOP 30% reduction in methane emissions	Biochar
Project Life	1	1	1	1	1	1	1	1	1	1	1	1	1
Emissions Savings	3.4	8.4	31.7	41.1	82.2	123.30	246.60	102.82	26.70	41.10	61.70	123.40	61.7
Net Profit / Loss (change from Baseline)	$7,648	$16,047	$0	-$5,448	-$5,448	-$29,828	-$29,828	-$99,426	-$24,788	-$11,986	-$49,713	-$49,713	$5,775
Carbon Price - $14	$48	$118	$444	$575	$1,151	$1,726	$3,452	$1,439	$374	$575	$864	$1,728	$864
Carbon Price - $50	$170	$420	$1,585	$2,055	$4,110	$6,165	$12,330	$5,141	$1,335	$2,055	$3,085	$6,170	$3,085
Marginal Profit / Loss at a Carbon Price of $14	$7,696	$16,165	$444	-$4,873	-$4,297	-$28,102	-$26,375	-$97,987	-$24,415	-$11,410	-$48,849	-$47,985	$6,638
Marginal Profit / Loss at a Carbon Price of $50	$7,818	$16,468	$1,585	-$3,393	-$1,338	-$23,663	-$17,498	-$94,285	-$23,453	-$9,931	-$46,628	-$43,543	$8,860

Figure 9 Marginal abatement cost curve for medium sheep at a $14 cost of carbon



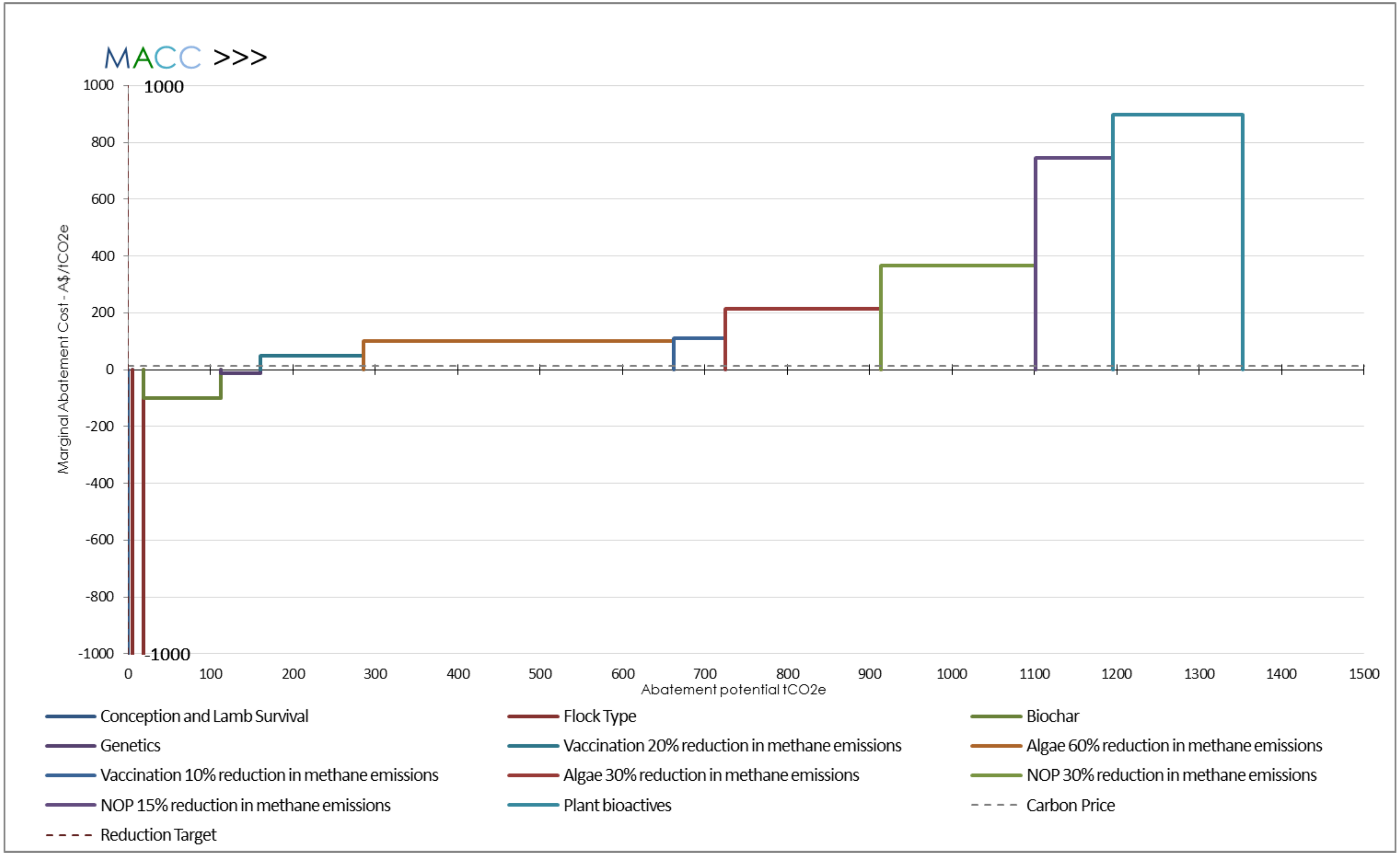
4.1.6 Pastoral Sheep

Results for the pastoral sheep case study are qualitatively similar to those for the other two sheep farming systems. This farm has 4,115 head of sheep and baseline emissions of 627.32 tonnes CO_{2e}.Grape marc was not a practice option for this farming system.

Table 48 Investment and emissions analysis – pastoral sheep

	Conception and Lamb Survival	Flock Type	Genetics	Vaccination 10% reduction in methane emissions	Vaccination 20% reduction in methane emissions	Algae 30% reduction in methane emissions	Algae 60% reduction in methane emissions	Plant bioactives	NOP 15% reduction in methane emissions	NOP 30% reduction in methane emissions	Biochar
Project Life	1	1	1	1	1	1	1	1	1	1	1
Emissions Savings	5.2	12.9	48.4	62.7	125.4	188.2	376.3	156.9	94.2	188.3	94.2
Marginal Profit / Loss at a Carbon Price of $0	$11,741	$24,635	$0	-$8,230	-$8,230	-$45,059	-$45,059	-$150,198	-$75,099	-$75,099	$8,440
Carbon Price - $14	$73	$181	$677	$878	$1,756	$2,634	$5,269	$2,197	$1,318	$2,636	$1,318
Carbon Price - $50	$261	$645	$2,419	$3,136	$6,272	$9,408	$18,817	$7,846	$4,708	$9,416	$4,708
Marginal Profit / Loss at a Carbon Price of $14	$11,814	$24,815	$677	-$7,352	-$6,474	-$42,425	-$39,791	-$148,001	-$73,781	-$72,462	$9,759
Marginal Profit / Loss at a Carbon Price of $50	$12,002	$25,280	$2,419	-$5,094	-$1,958	-$35,651	-$26,242	-$142,352	-$70,391	-$65,683	$13,148
Capital Cost											
	1	2	3	4	5	6	7	8	9	10	11
Emissions Savings	0.8%	2.1%	7.7%	10.0%	20.0%	30.0%	60.0%	25.0%	15.0%	30.0%	15.0%
Net Profit / Loss (change from Baseline)	17.5%	36.7%	0.0%	-12.3%	-12.3%	-67.1%	-67.1%	-223.6%	-111.8%	-111.8%	12.6%

Figure 10 Marginal abatement cost curve for pastoral sheep at a $14 cost of carbon



4.1.7 Dairy

Table 49 shows emissions reduction and financial data for mitigation strategies relevant to the dairy farming system. The representative case study farm used for this modelling has 413 head of cattle and baseline emissions of 980 tonnes CO_{2e}. Results for this case study are qualitatively similar to those for the beef and sheep farming systems.

As for the other farming systems examined, algae, NOP and plant bioactives show strong potential for emissions reductions. In addition, wheat feeding can substantially reduce emissions in dairy herds.

The MACC shown in figure 11 indicates that grape marc and wheat feeding have the potential to increase profitability and reduce emissions for the dairy farming system. Biochar is not depicted as profitable for this farming system since the potential for productivity gains in the form of increased milk production has not been tested in the research literature. Genetics and vaccination show potential to become financially viable when the carbon price is assumed to be at least $14. All other practice options fall above the line and are loss making.

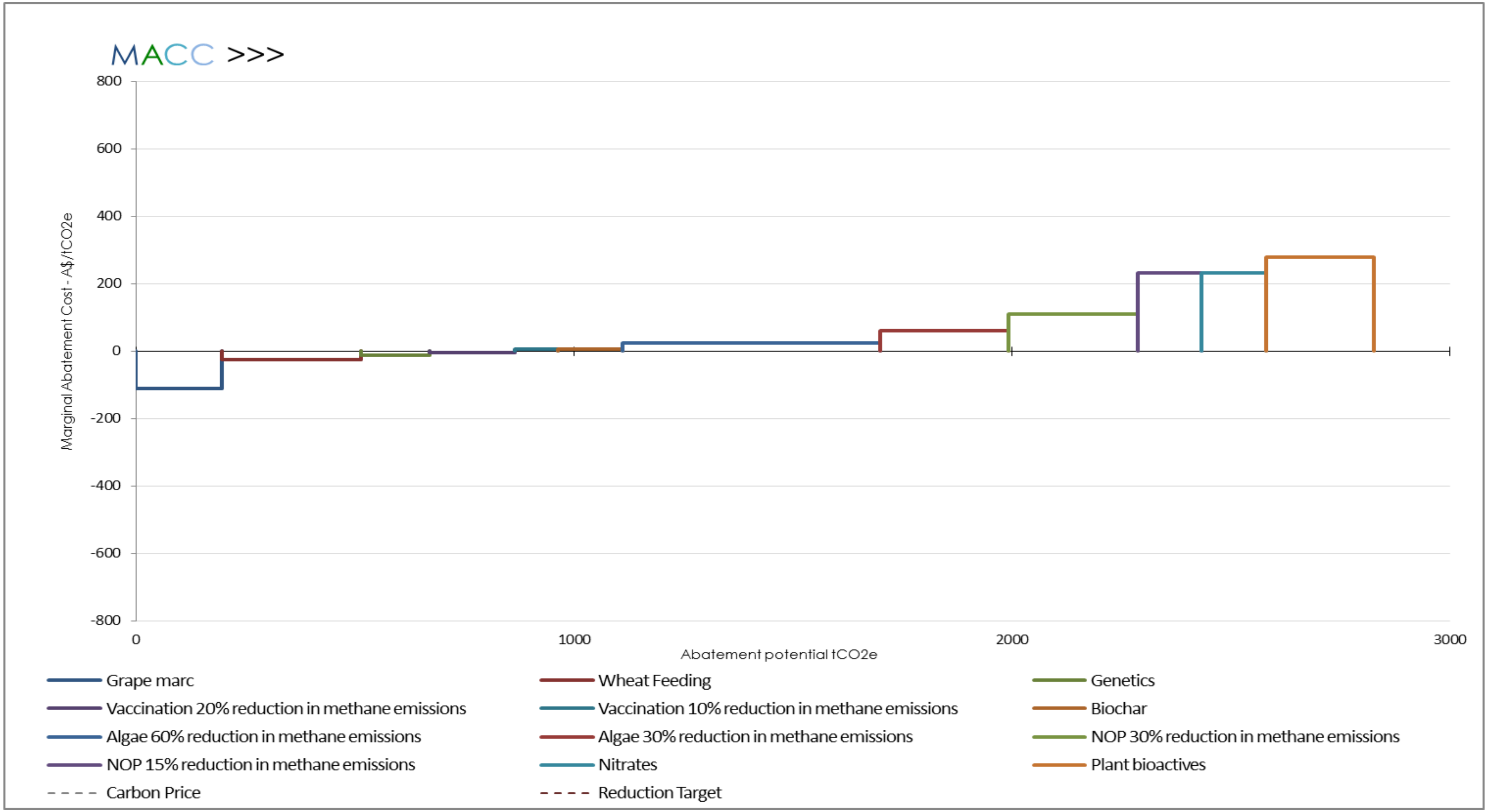
When MACC’s based on assumed carbon prices of $0 and $50 are generated, the results are similar and algae and biochar show potential to become financially viable at a carbon price of $50.

Table 49 Investment and emissions analysis – dairy

	Wheat Feeding	Genetics*	Vaccination 10% reduction in methane emissions	Vaccination 20% reduction in methane emissions	Algae 30% reduction in methane emissions	Algae 60% reduction in methane emissions	Plant bioactives	Nitrates	Grape marc	NOP 15% reduction in methane emissions	NOP 30% reduction in methane emissions	Biochar
Project Life	1	1	1	1	1	1	1	1	1	1	1	1
Emissions Savings	316.8	156.8	98.0	196.0	294.0	588.0	245.0	147.0	196.0	147.0	294.0	147.0
Marginal Profit / Loss at a Carbon Price of $0	4,282	0	-1,859	-1,859	-22,612	-22,612	-75,373	-37,686	19,813	-37,686	-37,686	-3,015
Carbon Price - $14	4,435	2,195	1,372	2,744	4,116	8,232	3,430	2,058	2,744	2,058	4,116	2,058
Carbon Price - $50	15,840	7,840	4,900	9,800	14,700	29,400	12,250	7,350	9,800	7,350	14,700	7,350
Marginal Profit / Loss at a Carbon Price of $14	8,717	2,195	-487	886	-18,496	-14,380	-71,943	-35,628	22,557	-35,628	-33,570	-957
Marginal Profit / Loss at a Carbon Price of $50	20,122	7,840	3,042	7,942	-7,912	6,788	-63,123	-30,336	29,613	-30,336	-22,986	4,335

*Assume cumulative 16% reduction in methane emissions after 10 years

Figure 11Marginal abatement cost curve for dairy at a $14 cost of carbon



4.1.8 Feedlot Beef

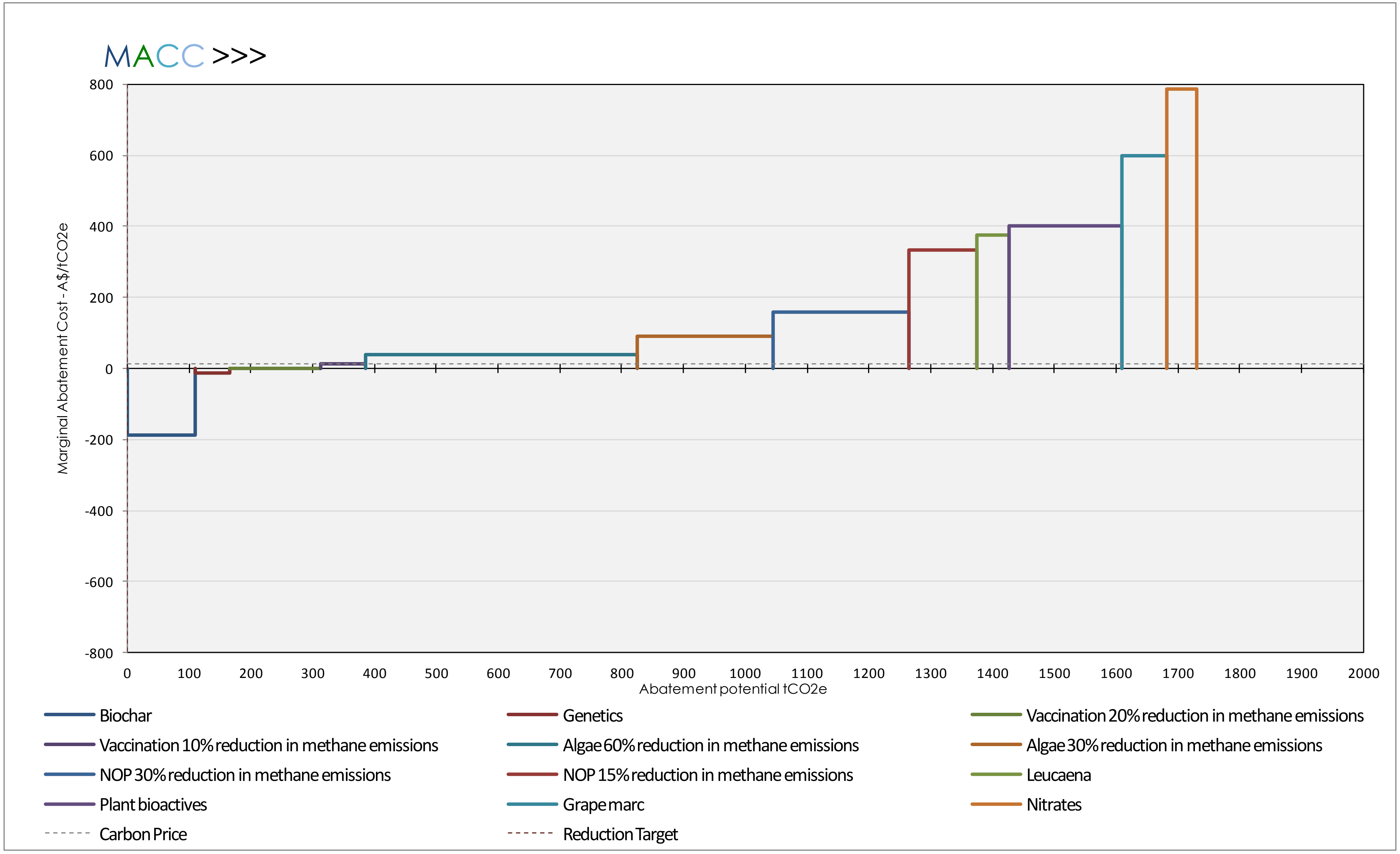
Table 50 shows emissions reduction and financial data for mitigation strategies relevant to the feedlot beef farming system. This feedlot is quite small with an average daily number of 450 head of cattle, 1643 head per month and baseline emissions of 732.4 tonnes CO_{2e}. Results for this case study are qualitatively similar to those for the other farming systems examined. In contrast to the results for the northern coastal beef farming system, Leucaena is not financially viable in feedlots since it decreases rather than increases productivity in a feedlot situation.

The MACC shown in figure 12 indicates that biochar has the potential to both reduce methane emissions and increase profitability. All other mitigation strategies show low financial viability under the assumptions made, with the exception of vaccination which could be potentially viable based on profits from carbon credits. If productivity gains from methane energy saved were to be confirmed for some of the high cost strategies such as algae, NOP or plant bioactives, these practice options could become profitable for feedlots.

Table 50 Investment and emissions analysis – feedlot beef

	Genetics	Vaccination 10% reduction in methane emissions	Vaccination 20% reduction in methane emissions	Leucaena	Algae 30% reduction in methane emissions	Algae 60% reduction in methane emissions	Plant bioactives	Nitrates	Grape marc	NOP 15% reduction in methane emissions	NOP 30% reduction in methane emissions	Biochar
Project Life	1	1	1	1	1	1	1	1	1	1	1	1
Emissions Savings	56	73	146	51	220	439	183	48	73	110	220	110
Marginal Profit / Loss at a Carbon Price of $0	$0	-$2,025	-$2,025	-$21,484	-$24,638	-$24,638	-$82,125	-$41,063	-$48,409	-$41,063	-$41,063	$20,860
Carbon Price - $14	790	1,025	2,051	718	3,076	6,152	2,563	666	1,025	1,538	3,076	1,538
Carbon Price - $50	2,820	3,662	7,324	2,563	10,986	21,971	9,155	2,380	3,662	5,493	10,986	5,493
Marginal Profit / Loss at a Carbon Price of $14	790	(1,000)	26	(20,766)	(21,562)	(18,486)	(79,562)	(40,396)	(47,383)	(39,525)	(37,987)	22,398
Marginal Profit / Loss at a Carbon Price of $50	2,820	1,637	5,299	(18,921)	(13,652)	(2,666)	(72,970)	(38,682)	(44,747)	(35,570)	(30,077)	26,353

Figure 12 Marginal abatement cost curve for feedlot beef at a $14 cost of carbon



4.2 National Outcomes

The emissions potential for each practice option in a farming system was calculated by multiplying the estimated case study emissions reduction per head for each practice option by the total number of head across all regions that are estimated to be managed under the relevant farming system. National emissions potentials for beef, sheep, dairy and feedlot beef were then derived by adding together the relevant farming systems' emissions totals for each practice option.

Three scenarios were run for assumed adoption rates of 5, 10 and 20%. The potential for adoption of each mitigation practice option is related to a range of factors including ease of implementation, potential for significant emissions reductions and financial viability.

For example, the national emissions reduction potential for nitrates from northern coastal beef is calculated as the estimated case study emissions reduction per head (0.11 tonnes of CO_{2e}) by the number of head for all regions in this farming system (2,278,110) and assuming adoption rates of 5, 10 and 20%. These results were then added to those from the remaining two beef farming systems to estimate total emissions potential from nitrates for beef of 133,060 tonnes of CO_{2e} when 5% adoption is assumed.

Realised adoption rates for these mitigation strategies will depend to at least some extent on whether they are profitable and practicable under commercial conditions. Expectations for adoption of genetics across the northern beef farming systems is low at only 5 to 10% with a considerable time lag to implementation, whereas adoption of genetics in dairy cows would approach 100% with an assumed time lag of only a few years.

4.2.1 Beef

The size of the total Australian beef cattle herd used to calculate national emissions potential is approximately 25.4 million head. In accordance with the emissions reduction assumptions made in Section 3.1 based on research results to date, the results in Table 51 indicate those practice options showing the greatest potential for emissions reductions across the national beef herd are algae, NOP, plant bioactives, vaccination and biochar. Each of these practice options is broadly applicable across Australia's three beef farming systems. For example, when 10% adoption and 60% emissions reduction are assumed, algae has the potential to reduce annual emissions from Australia's beef cattle herd by more than 2.4 million tonnes of CO_{2e}, while plant bioactives have the potential for another 1 million tonnes in reductions.

Leucaena is not applicable to a large proportion of the herd and therefore has relatively lower potential to reduce national emissions.

Table 51National Emissions Savings for Beef Scenarios at Varying Adoption Rates

	Emissions Saving at 5% Adoption (Tonnes CO_{2e})	Emissions Saving at 10% Adoption (Tonnes CO_{2e})	Emissions Saving at 20% Adoption (Tonnes CO_{2e})
Production Efficiency	143,338	286,675	573,350
Phosphorus Supplementation	207,884	415,768	831,535

Genetics	183,163	366,326	732,652
Vaccination 10% reduction in methane emissions	315,753	631,506	1,263,011
Vaccination 20% reduction in methane emissions	520,608	1,041,216	2,082,432
Leucaena	51,589	103,178	206,355
Algae 30% reduction in methane emissions	614,254	1,228,509	2,457,017
Algae 60% reduction in methane emissions	1,228,376	2,456,753	4,913,506
Plant bioactives	511,882	1,023,764	2,047,527
Nitrates	133,060	266,121	532,242
NOP 15% reduction in methane emissions	307,121	614,243	1,228,486
NOP 30% reduction in methane emissions	614,261	1,228,522	2,457,044
Biochar	307,121	614,243	1,228,486

4.2.2 Sheep

The size of the total Australian sheep flock used to calculate national emissions potential is approximately 72.8 million head. Algae, NOP, plant bioactives, vaccination and biochar show the strongest potential to reduce national emissions from the Australian sheep flock. Each of these practice options is broadly applicable across Australia's three sheep farming systems. For example, when 10% adoption and 60% emissions reduction are assumed, algae has the potential to reduce annual emissions from Australia's sheep flock by more than 0.66 million tonnes of CO_{2e}. Despite the size of the national sheep flock being considerably larger than the national beef cattle herd, the potential for emissions reductions is not as great.

Table 52 National Emissions Savings for Sheep Scenarios at Varying Adoption Rates

	Emissions Saving at 5% Adoption (Tonnes CO_{2e})	Emissions Saving at 10% Adoption (Tonnes CO_{2e})	Emissions Saving at 20% Adoption (Tonnes CO_{2e})
Conception and Lamb Survival	4,531	9,063	18,126
Flock Type	11,197	22,395	44,789
Genetics	42,638	85,275	170,551

Vaccination 10% reduction in methane emissions	55,291	110,582	221,163
Vaccination 20% reduction in methane emissions	110,601	221,201	442,402
Algae 30% reduction in methane emissions	165,891	331,783	663,565
Algae 60% reduction in methane emissions	331,783	663,565	1,327,131
Plant bioactives	138,327	276,653	553,306
Nitrates	32,506	65,012	130,024
Grape Marc	50,024	100,048	200,096
NOP 15% reduction in methane emissions	83,013	166,026	332,051
NOP 30% reduction in methane emissions	166,007	332,013	664,026
Biochar	83,013	166,026	332,051

4.2.3 Dairy

Results for Australia's dairy herd are much lower than for beef or sheep, reflecting the much smaller size of this total herd at approximate 2.6 million head. In addition to the emissions reduction practice options identified as showing strong potential in beef and sheep farming systems, wheat feeding in dairy has the potential to reduce emissions by a total of over 51 thousand tonnes of CO_{2e} when 10% adoption is assumed.

Table 53 National Emissions Savings for Dairy Scenarios at Varying Adoption Rates

	Emissions Saving at 5% Adoption (Tonnes CO_{2e})	Emissions Saving at 10% Adoption (Tonnes CO_{2e})	Emissions Saving at 20% Adoption (Tonnes CO_{2e})
Wheat Feeding	25,637	51,273	102,546
Genetics	12,689	25,378	50,755
Vaccination 10% reduction in methane emissions	7,930	15,861	31,722
Vaccination 20% reduction in methane emissions	15,861	31,722	63,444
Algae 30% reduction in methane emissions	23,791	47,583	95,166
Algae 60% reduction in methane emissions	47,583	95,166	190,332

Plant bioactives	19,826	39,652	79,305
Nitrates	11,896	23,791	47,583
Grape marc	15,861	31,722	63,444
NOP 15% reduction in methane emissions	11,896	23,791	47,583
NOP 30% reduction in methane emissions	23,791	47,583	95,166
Biochar	11,896	23,791	47,583

4.2.4 Feedlot beef

The Australian national herd for feedlot beef totals 763,689. The results below confirm those from the other livestock farming systems in terms of which mitigation practice options demonstrate the greatest potential for abatement.

Table 54 National Emissions Savings for Feedlot Scenarios at Varying Adoption Rates

	Emissions Saving at 5% Adoption (Tonnes CO_{2e})	Emissions Saving at 10% Adoption (Tonnes CO_{2e})	Emissions Saving at 20% Adoption (Tonnes CO_{2e})
Genetics	5,214	10,428	20,856
Vaccination 10% reduction in methane emissions	6,771	13,543	27,085
Vaccination 20% reduction in methane emissions	13,543	27,085	54,171
Leucaena	4,740	9,480	18,960
Algae 30% reduction in methane emissions	20,314	40,628	81,256
Algae 60% reduction in methane emissions	40,628	81,256	162,512
Plant bioactives	16,928	33,857	67,713
Nitrates	4,401	8,803	17,605
Grape marc	6,771	13,543	27,085
NOP 15% reduction in methane emissions	10,157	20,314	40,628
NOP 30% reduction in methane emissions	20,314	40,628	81,256

Biochar	10,157	20,314	40,628

4.2.5 Summary of National Emissions Reduction Potential

A summary of the estimated national emissions reductions for those practice options indicating a reasonable amount of potential is shown below. A 10% rate of adoption is assumed throughout. For those practice options where we undertook modelling based on more than one assumed emission reduction percentage, the higher amounts are shown in the table below. For example, we modelled vaccination based on both 10% and 20% emissions reductions, but only the national emissions estimate for 20% is shown below.

Table 55 Potential national emission savings (tCO2e) with 10% adoption assumed

Practice Option	Beef	Sheep	Dairy	Feedlot Beef	Total
Production Efficiency	286,675	-	-	-	286,675
Phosphorus Supplementation	415,768	-	-	-	415,768
Wheat feeding	-	-	51,273	-	51,273
Genetics	366,326	85,275	25,378	10,428	487,407
Vaccination 20% reduction in methane emissions	1,041,216	221,201	31,722	27,085	1,321,224
Leucaena	103,178	-	-	9,480	112,658
Algae 60% reduction in methane emissions	2,456,753	663,565	95,166	81,256	3,296,740
Plant bioactives	1,023,764	276,653	39,652	33,857	1,373,926
Nitrates	266,121	65,012	23,791	8,803	363,727
Grape Marc	-	100,048	31,722	13,543	145,313
NOP 30% reduction in methane emissions	1,228,522	332,013	47,583	40,628	1,648,746
Biochar	614,243	166,026	23,791	20,314	824,374

The results of this study indicate that, when all farming systems are considered at national scale, the practice options with the greatest potential to reduce Australia's greenhouse gas emissions inventory are algae, NOP, plant bioactives, vaccination and biochar.

4.3 Additional Analysis on Methane Energy Saved

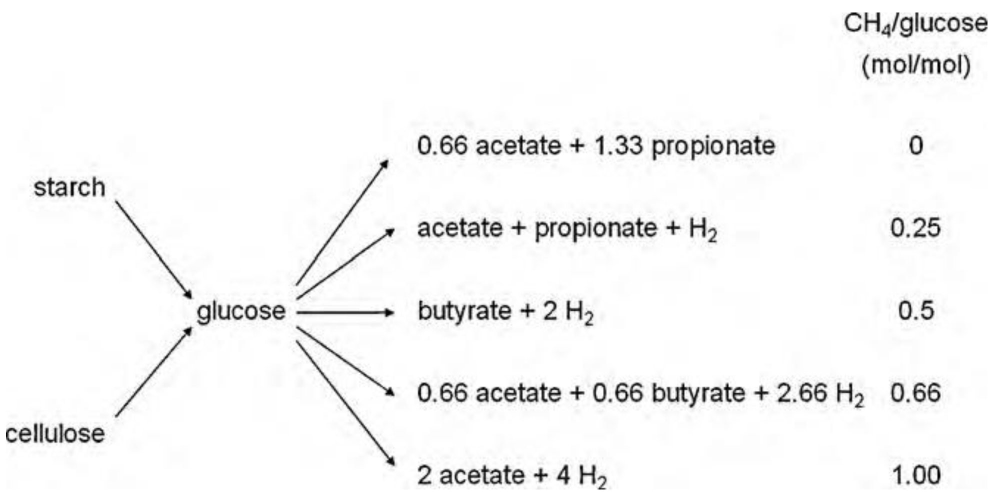
Although there appears not to be an accepted value in the literature, a calculation has been undertaken for this project to predict the amount of methane energy saved by inhibiting methane emissions that could be retained for animal productive purposes. Estimates of potential impacts on liveweight gain and marginal profitability have been made for vaccination and algae for the three beef farming systems. These estimates provide an initial indication of the potential for methane energy saved to contribute to the financial viability of these methane mitigation strategies.

Glucose energy capture (%)	
93	1
86	2
78	3
72	4
62	5

4.3.1 Calculation Method

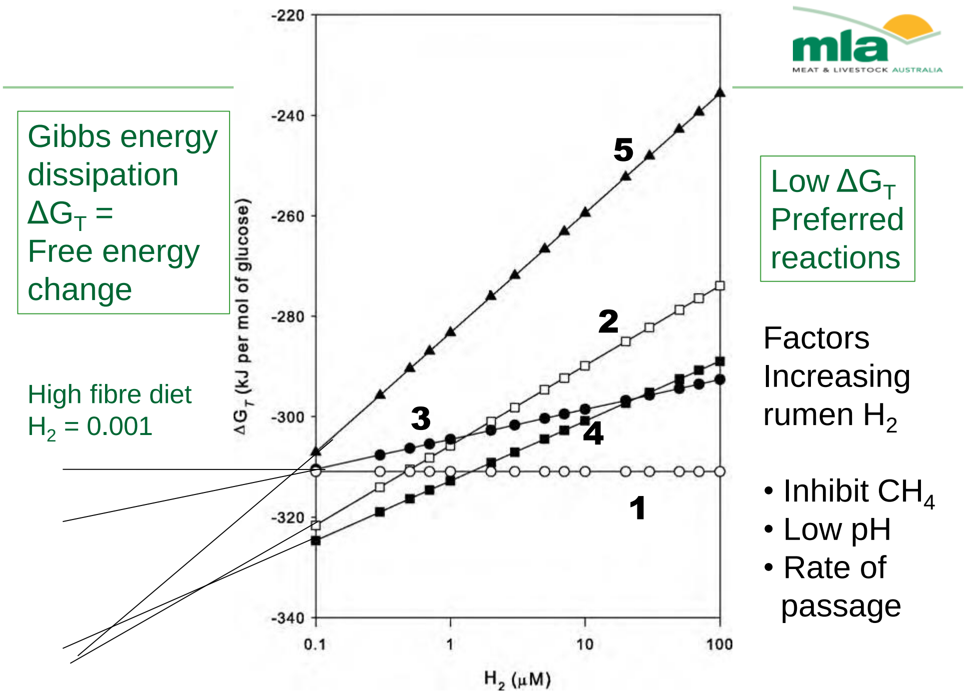
Based on knowledge of control by rumen hydrogen concentration of the relative rates of the five pathways for the conversion of glucose from either starch or cellulose fermentation by rumen microbes to volatile fatty acids (Janssen 2010), it is predicted that around 40% of the energy not lost in methane could be used by the animal. An outline of the calculations used to predict the saving in energy from methane not emitted follows.

The primary carbohydrates fermented in the rumen by micro-organisms are starch and cellulose. Both these compounds consist of chains of glucose molecules linked either by 1-4 α bonds in the case of starch or 1-4 β bonds for cellulose. Hence, fermentation of either starch or cellulose produces glucose as the primary substrate for micro-organism to use within the rumen of animals. Glucose can be degraded by five competing pathways to produce volatile fatty acids (VFA). These pathways produce different amounts of methane and have different efficiencies of energy conversion from glucose to VFA as follows:



The reactions are numbered 1-5 from the highest to lowest efficiency. The bottom pathway (5) produces the most methane and has an efficiency of conversion of glucose energy to VFA energy of 62% compared with the top pathway (1) which produces no methane and has a efficiency of conversion of energy of 93%. Clearly, the more energy that passes through the top pathway, the lower the methane production and the higher the efficiency of energy use by the animal.

Two major factors drive the competition between these competing biochemical pathways; i) Gibbs energy dissipation or free energy change with lower free energy pathways being preferred; and ii) the relative Michaelis Menten kinetics of the reactions, particularly the relative km values. Janssen (2010) shows that the Gibbs energy dissipation of the five reactions change with hydrogen concentration in the rumen. The hydrogen concentration in the rumen increases with certain methane inhibition strategies, such as algae, chloroform, bromochloromethane (BCM), NOP; low pH due to grain feeding; and high rate of passage of digesta. The relative competitiveness of the five reactions change as rumen H_2 concentration changes as illustrated below where the free energy change of reaction 1 is not affected by hydrogen concentration, but it is markedly reduced in pathway 5.



Pathways 4 and 5, which produce large amounts of methane at low efficiency of dietary energy conversion predominate when hydrogen concentration is low as with a high fibre diet, but the energetically more efficient pathways that produce less methane predominate at high rumen hydrogen concentrations.

Accounting for the effects of rumen hydrogen concentration on the relative activity of the five pathways based in Gibbs free energy change alone proved to be insufficient to predict the changes observed in methane emissions and VFA ratios when algae was given to sheep (Tomkins unpublished) or BCM given to goats (Mitsumori *et al*. 2012). There appears to be no information in the literature on the relative km values for these five reactions. Consequently, the relative rates of these reactions were further altered on a trial and error basis until the approximate reductions in methane and changes in VFA patterns observed when algae were fed to sheep and BCM fed to goats were predicted. When this occurred, the relative rates of the above five reactions were such that approximately 40% of the energy in glucose was retained in VFA.

This approach is still an over-simplification because the effect of microbial growth as a hydrogen sink and as a supply of energy and protein to the animal was not taken into account. However, the calculations do provide a logical way for suggesting the possible amount of energy saved from methane mitigation strategies that may be used for animal productive purposes. Further mechanistic rumen simulation modelling is required to better account for the changes in these reaction rates and the contribution microbial growth may make to the nutrients available to animals when various methane mitigation strategies are adopted.

This energy saving calculation was initially not used in the MACC analyses shown in the bulk of the report. It was assumed that none of the energy saved from reducing methane emissions was used for productive purposes, except where this was explicitly stated such as with biochar and supported by empirical evidence. However, the effect of saving different proportions of energy from methane mitigation with algae, vaccination, NOP and plant bioactives has been applied to changes in liveweight gain within the MACC calculations and is shown in the next section. The proportion of methane energy saved that was presumed to be used by the animal for increasing liveweight gain was 0, 20, 40 or 80%.

The calculation used to predict the effects of saved energy on liveweight gain follows:

The NIR (2012) calculations for enteric methane in pasture beef cattle – temperate regions – include the relationship between gross energy intake lost as methane and the liveweight gain of the animal. The calculations are based on the approach developed by Blaxter and Clapperton (1965); corrected by(Wilkerson et al., 1995)).

> *"…The Blaxter and Clapperton (1965)approach requires the estimation of gross energy intake and then calculates the proportion of this energy that is converted into methane, based on the digestibility at maintenance of the feed energy and the level of feed intake relative to that required for maintenance. The figure for methane can then be expressed on an equivalent mass basis, using the conversion factor of 55.22 MJ/kg CH4 (Brouwer, 1965)…".*

[Source: Australian National Greenhouse Accounts National Inventory Report 2012 Volume 1 p.263]

The level of feed intake is determined using the equation presented in Minson and McDonald (1990) which calculates feed intake of non-lactating cattle from liveweight and liveweight gain data. For lactating cattle the additional intake for milk production (MA) is included to give total intake (I kg dry matter/head/day):

$$I = (1.185 + 0.00454W - 0.0000026\,W^2 + 0.315\,LWG)^2 \times MA \qquad (4A.1b\_1)$$

Where: W = liveweight in kg
LWG = liveweight gain in kg/head/day

$$MA = (LC \times FA) + ((1-LC) \times 1) \qquad (4A.1b\_2)$$

Where: LC= proportion of Cows >2 year old lactating
FA = feed adjustment
(The intake of all breeding cattle is increased by 30% during the season in which calving occurs and by 10% in the following season)

A gross energy content of 18.4 MJ/kg is used to convert the dry matter intake into gross energy intake (GEI_{MJ}):

$$GEI = I \times 18.4 \qquad (4A.1b\_3)$$

The intake of the animals relative to that needed for maintenance (L) is calculated as actual intake divided by maintenance intake (i.e. intake of non-lactating animal with liveweight gain is set to zero).

$$L = I / (1.185 + 0.00454\,W – 0.0000026\,W^2 + (0.315 x 0))^2 \quad (4A.1b\_4)$$

The percentage of the gross energy intake yielded as methane (Y) is the Blaxter and Clapperton(1965) calculation:

$$Y = 1.3 + 0.112 DMD + L\,(2.37 – 0.050 DMD) \quad (4A.1b\_5)$$

Where: DMD = digestibility of feed (expressed as a %)
L = feed intake relative to that needed for maintenance

The total daily production of methane (M kg CH4/head/day) for animals on temperate pastures is then determined as:

$$M = (Y / 100) \times (GEI / F) \quad (4A.1b\_6a)$$

(F = 55.22 MJ/kg $_{CH4}$)

Calculations to estimate increased production

The energy saved in Methane ($EiM_{MJ/day}$) is calculated using:

Baseline energy in methane EiM_B = GEI x Y

Scenario energy in methane EiM_S = EiM_B x (1 - %reduction in methane)
(% reduction expressed as a fraction e.g. 0.30 for 30%)

With the difference: ES_S = EiM_B- EiM_S

An example:

Based on a steer of liveweight 300 kgs, liveweight gain 1.0 kg/day and dry matter digestibility of pasture at 70%:

I	=	6.9kg MD
GEI	=	127 Mj/day
L	=	1.29
Y	=	7.68
EiM_B	=	9.76 Mj/day

Assuming the mitigation strategy results in a 30% reduction in enteric methane:

EiM_S = 9.76 x (1 – (30 / 100)) = 6.83 Mj/day

and therefore: ES_S = 2.93 Mj/day (9.76 – 6.83)

Assuming 40% of the energy saved in the methane is available for increased productivity by the animal:

Productivity contribution = ES x 40 /100
= 1.17 Mj/day

As a portion of dry matter intake:

Iportion = (ES_S / DMD) / 18.4

= 0.0909 (equivalent kgs dry matter/day in the energy saved)

The amount of Intake above that required for maintenance (using I above with LWG = 1.0 kg/day and I with LWG = 0 (for maintenance)) is:

= 1.556 kgs / day

The proportional gain for CH4 saved energy above maintenance in terms of dry matter intake is then:

= 0.0909 / 1.556

= 0.058 or 5.8%

for every kg liveweight gain for the 300 kg steers on pasture of 70% digestibility.

The proportional gain for a steer of 300kgs growing at 0.5 kg/day on 70% DMD pasture is 11.8%.

4.3.2 Results

Estimates of potential impacts on marginal profitability were made for vaccination, algae, NOP and plant bioactives across the three beef farming system case studies. These estimates provide an initial indication of the potential for productivity gains from methane energy saved to contribute to the financial viability of these methane mitigation strategies. Methane energy saved levels of 20, 40 and 80% were simulated and marginal profits/losses were compared with the 0% baseline where no productivity gains from energy saved were assumed. That is, the assumption used for the MACCs presented in Section 4.1 indicating that these practice options were generally not financially viable.

Table 56 shows results for the northern coastal beef farming system for carbon prices of $0 and $14 per tonne. Panels A and B show total estimated marginal profits/losses for the case study farm, while the Panel C shows estimated impact on profitability per head.

Table 56 Estimated impacts on profitability of energy saved from methane not emitted - Northern Coastal Beef

Panel A	**Total Annual Marginal Profit/Loss at Carbon Price $0**			
Methane energy saved levels	**0%**	**20%**	**40%**	**80%**
Vaccination- 20% CO_{2e} reduced	(3,249)	5,944	15,142	26,578
Algae - 60% CO_{2e} reduced	(39,530)	(11,945)	15,640	70,811
NOP - 30% CO_{2e} reduced	(65,883)	(52,090)	(38,298)	(10,713)
Plant bioactives-25% CO_{2e} reduced	(131,765)	(120,271)	(108,777)	(85,791)
Panel B	**Total Annual Marginal Profit/Loss at Carbon Price $14**			
Methane energy saved levels	**0%**	**20%**	**40%**	**80%**
Vaccination- 20% CO_{2e} reduced	19	9,212	18,410	29,846
Algae - 60% CO_{2e} reduced	(29,728)	(2,144)	25,441	80,612
NOP - 30% CO_{2e} reduced	(60,983)	(47,190)	(33,398)	(5,813)
Plant bioactives -25% CO_{2e} reduced	(127,677)	(116,183)	(104,689)	(81,703)
Panel C	**Annual Marginal Profit/Loss per Head at Carbon Price $14**			
Methane energy saved levels	**0%**	**20%**	**40%**	**80%**
Vaccination- 20% CO_{2e} reduced	0.026	12.76	25.50	41.34

Algae - 60% CO_{2e} reduced	(41.17)	(2.97)	35.24	111.65
NOP - 30% CO_{2e} reduced	(84.46)	(65.36)	(46.26)	(8.05)
Plant bioactives -25% CO_{2e} reduced	(176.84)	(160.92)	(145.00)	(113.16)

The simulation results for vaccination suggest that even when the financial benefits of a carbon price are ignored, productivity gains from energy saved provide profits under all 'energy to growth' scenarios evaluated (Panel A). Potential profits for vaccination are further increased when carbon credits are considered (Panels B and C), ranging from $12.76 to $41.34 per head additional profitability potential from a combination of productivity gains and carbon credits.

Algae becomes financially viable when 40 or 80% energy saved is captured as a productivity gain. However it is loss making if only 20% of energy is saved for growth. The high methane emissions reduction potential for algae indicated in prior research leads to high estimates of potential profits if energy saved can be converted to growth, especially if carbon credits are able to be earned. Simulation results indicate $35.24 per head when 40% energy saving is assumed and $111.65 per head for 80% at a carbon price of $14 a tonne CO_{2e}.

Under the assumptions of 60% methane reduction and 40% energy saved for algae, the estimated annual profit per head of $35.24 is comprised of a productivity gain of $76.41 and carbon credits of $13.57 per head, offset by a cost of $54.75 to purchase algae at $1.50/kg or 15 cents per head, per day. The breakeven price for algae under these methane reduction and energy saving assumptions would be approximately $2.50/kg or 25 cents per head, per day.

Results for NOP and plant bioactives demonstrate that potential productivity gains from methane energy saved are insufficient to offset the currently high costs of these mitigation strategies. Our assumed costs for these practice options are 25 cents per day, per head for NOP and 50 cents per day, per head for plant bioactives. Even when the potential financial benefits from carbon credits are included, these mitigation strategies provide a marginal loss under all scenarios examined. Implementation costs would need to decrease to less than 12 cents per head, per day for NOP and 10 cents per head, per day for plant bioactives to become financially viable under the assumption that 40% of energy is saved and carbon credits at $14 tonne CO_{2e} are available.

Results for the northern rangeland and temperate sub-tropical beef farming system are very similar to those for northern coastal beef and lead to the same conclusions.

5 Discussion

5.1 Interpretation of results for each practice option examined

Overview

The outputs from these analyses depend greatly on the assumptions made. Some of the assumptions are based on sound scientific or economic evidence, but many either do not yet have sufficient experimental results or cost of implementation of various practices are not fully known. The overall economic benefit of a methane mitigation strategy depends on assumptions made for: i) methane emission reduction; ii) potential productivity gains; iii) cost of implementation; and iv) carbon credits earned. These analyses show clearly that the greatest economic benefits come from those methane mitigation strategies that increase animal productivity and have low costs for implementation. The price paid for carbon credits has an impact on profitability, but the effect is generally smaller than the impact of a strategy on animal productivity. Consequently, implementation of best practice farming options generally results in the greatest profitability due to improved productivity, despite relatively low savings in methane emissions.

Results from these analyses can be used to help identify areas of research that are suitable for further investment. However, other considerations such as amount of additional investment required, chances of research success, cost and practicality of implementation of a new methane mitigation strategy are needed before these decisions can be made effectively. Some of these issues are explored in the consideration of individual mitigations strategies that follows.

Production efficiency

Production efficiency was modelled as a management practice change option for the three broad acre beef farming systems. It involves mating earlier to reduce pressure on pastures, improve calving rates and maintaining wiener target weights. With no adjustment in cow herd numbers, The results were a reduction in the total stocking rate (in Adult Equivalents) for the property and increased turn-off. Any abatement from a system that increases absolute levels of GHG emissions within the project is reliant on > 0% "reverse" leakage, i.e. the increase in production must result in a price signal that causes a marginal producer (with a higher GHG intensity) to reduce production.

This practice option was profitable for all three systems with estimated emissions reductions of approximately 0.11 tonnes CO_{2e} per head. Improving production efficiency showed substantial increases in farm profitability in all three cattle regions examined because of improvements in the efficiency of feed use and production. However, the assumptions for cost of implementation of the strategy was simplified and full whole farm analyses need to be undertaken for any specific application of the procedures.

Phosphorus Supplementation

Phosphorus supplementation was modelled as a management practice option for the two northern broad acre beef farming systems. This practice option was profitable for both systems, with moderate emissions reduction potential.

Flock type

Flock type change was modelled as a management practice change option for the three sheep farming systems. This practice option was profitable for all three systems, however based on an extrapolation of Young's (2013) results, estimated emissions reductions were low. Profit improvements from adopting changes in flock structure again result from improvements in animal productivity and overall efficiency of the use of feed on a farm. Full whole farm modelling is needed when assessing the potential benefit to an individual property.

Conception and lamb survival

This management practice change option was modelled for the three sheep farming systems. This practice option was profitable for all three systems, however estimated emissions reductions were very low. The results were a reflection of changes in overall farm profitability and more efficient use of feed resulting in slightly lower methane emissions across the farm.

Genetics

Selecting animals for low methane emissions showed moderate potential across all farming systems examined. Although the reduction in methane emissions was relatively small, the cost of implementing the practice was considered to be zero because many producers already use systems such as BREEDPLAN or LAMBPLAN for selecting sires. The methane emissions reduction trait has already been incorporated into BREEDPLAN and results are being collected from sheep to allow incorporation of methane emission reduction into LAMBPLAN. However, the cost to the stud breeders could be substantial, particularly until there is a robust genomic selection for low methane emitting animals. It is possible that there is an opportunity cost of selecting less for more profitable traits, however these costs are difficult to estimate and are likely to be low. There is likely to be a considerable time lag before individual sires will be included into selection indices, so the results presented here are what may be expected in 10 to 20 years time except for dairy cows, where both identification of superior animals and transfer of genes through the industry is more streamlined than for the other ruminant industries.

As indicated, there are currently sufficient research results to effectively apply the methane modified BREEDPLAN to *Bostaurus* cattle and further research is needed to develop heritability values for northern *Bosindicus* breeds. It is anticipated that implementation of methane emissions procedures within LAMBPLAN for the sheep industry will come from current research. However, it is likely to take many years before animals with low methane emitting genes have accumulated within the ruminant populations.

Vaccination

Vaccination against methanogenic archaea showed considerable potential for emissions reductions across the majority farming systems examined. The potential emissions savings were predicted to be greater than for practice management change options or selecting animals for low methane. This was particularly the case when a 20% reduction in methane emissions was assumed. Since confirmed growth rate increases for energy saved were not available from current research into the effects of vaccination, financial modelling for this practice option initially did not include productivity increases and showed a marginal loss. Carbon credits of at least $14/ tonne were predicted to be required to make vaccination profitable under most production systems. A major advantage from using vaccination for reducing methane emissions is that implementing the practice is relatively easy and should be readily adopted if profitable. Even when a low adoption rate of 10% is assumed with a methane emissions reduction of 20%, national reductions in methane emissions result in CO_2 equivalent reductions of approximately 1 million and 220,000 tonnes annually for the Australian beef and sheep industries annually (Tables 51 & 52).

Preliminary analysis simulating the potential impacts of using energy saved from reducing methane emissions for productivity was undertaken for the beef farming systems. Results from this additional analysis indicate that potential productivity gains from methane energy saved make vaccination a profitable mitigation strategy (Table 56). For example for northern coastal beef and 20% reduction in methane emissions, farm profitability rose from -$3249, $5944, $15142 to $26578 as the percentage of energy from reduced methane emissions saved for productivity increased from 0, 20, 40 to 80%, when there was no price for carbon credits. With a $14/t price for CO_2 equivalents, the profits were $19,

$9212, $18410 and $29846, respectively for 0, 20, 40 and 80% retention of methane emission energy saved (Table 56). These analyses confirm the value of conducting research that measures the proportion of methane energy savings that can be used for productivity and the value of research to increase the capture of this energy.

Despite the potential apparent effectiveness of vaccination for reducing methane emissions and for increasing farm profitability, considerable additional research is required to develop an effective vaccine. Research within NLMP and related projects is likely to identify surface proteins that are unique to methanogenic *Archaea* and not rumen bacteria. These proteins could be used as antigens for vaccine development. However, many other potential issues are involved in developing an effective vaccine with considerable risk (Wedlock et al., 2013). Significant new investment is likely to be required with substantial risk in achieving desired outcomes.

NOP

NOP showed considerable potential for emissions reductions across all farming systems examined. NOP is effective at extremely low concentrations (mg/day) and, if able to be incorporated into lick-blocks or supplements, could be applicable to all production systems. With 10% adoption, NOP was predicted to reduce methane emissions as CO_2 equivalents by 1.2 million tonnes for the Australian beef industry and 330,000 tonnes for the sheep industry. Since confirmed growth rate increases for energy saved were not available for NOP, financial modelling and MACCs for this practice option did not include productivity increases and showed a marginal loss.

Preliminary analysis simulating the potential impacts of using energy saved from reducing methane emissions for productivity was undertaken for the beef farming systems. However, due to the high costs of implementation, this mitigation strategy continued to indicate marginal losses when potential energy savings were included. Implementation costs would need to decrease to less than 12 cents per head, per day for NOP to become financially viable under the assumption that 40% of energy is saved and carbon credits at $14 tonne CO_{2e} are available.

NOP is a product produced by the company, DSM, and has not been studied within NLMP projects. The compound is rather volatile and the company is undertaking research to improve the effectiveness of methane reduction. DSM assumes that reductions in methane emission could be above the 30% assumed in these analyses. NOP is likely to be registered as a methane inhibitor and should be available commercially. The majority of animal experiments undertaken to date have been with dairy cows and further research is required to evaluate its practicability for most Australian production systems.

Biochar

In theory, the large surface area of biochar enhances microbial film development and therefore may enhance feed digestion while reducing methane emissions. In one experiment, not within NLMP, that has been conducted with cattle, methane emissions were reduced and cattle growth rate increased. When conservative values from this experiment were included in the analyses reported, biochar showed moderate potential for emissions reductions across the majority of farming systems (15%). Growth rate increases for energy saved and the low cost meant that feeding biochar was predicted to be profitable for all production systems except dairy, even when there was no price on CO_2 equivalents. However, it should be noted that the estimates for biochar are based on the one experiment using atypical diets with low animal growth rates and may therefore not be reliable. The impact of biochar is likely to vary with different sources of the material and its effective surface area. The results from these analyses suggest there would be value in investing in further research to determine whether the methane emission reduction potential and increased animal performance is achievable under typical Australian production systems.

Algae

Algae showed the greatest potential for emissions reductions across all farming systems examined. Since confirmed growth rate increases for energy saved were not available for algae, the primary financial modelling for this practice option did not include productivity increases and showed a marginal loss. It was assumed that if algae was fed at approximately 2% of the diet, and could be readily incorporated into licks and supplements, it could be applicable to all Australian production systems. With 60% methane reduction and 10% adoption across production systems, it was predicted that total methane emission reduction would be a saving in CO_2 equivalents of 2.4 million tonnes for cattle and 660,000 tonnes for sheep across the whole of Australia. However, with a price of algae assumed to be $1.50/kg, a price well below current costs, feeding algae to ruminants proved not to be profitable for any production system.

Preliminary analysis simulating the potential impacts of energy saved from reducing methane emissions on productivity and profitability was undertaken for the beef farming systems. Results of this additional analysis (Table 56) indicate that potential productivity gains from methane energy saved would be sufficient to offset the price of algae assumed in this study when 40% of the energy is saved.

These analyses with algae show the interactions between the price of the treatment and the proportion of methane mitigation energy saved for production on profitability. The breakeven price for zero profit for algae can be calculated for different methane mitigation potentials, different proportions of methane energy saved for productivity and different prices for carbon credits. For example, the breakeven price for algae would be $0.52/kg if there was a 30% methane inhibition, 20% methane energy saving for productivity and no price on carbon. However, with a 60% reduction in methane, 80% retention of methane energy for productivity and a $50/tonne price for carbon credits, the breakeven price would be $5.25/kg. Assuming likely values of 40% retention of methane energy for productivity and $14/tonne for carbon credits, the breakeven prices for algae would be $1.23 for a 30% and $2.46 for a 60% reduction in methane emissions.

If retail prices for algae can realistically be reduced to around $2/kg (20 cents per head, per day), further research investigating algae production systems and the practical feeding of algae should be undertaken for different production systems. The opportunity for incorporating the specific red algae into other agricultural production systems such as using prawn farm effluent or marine aquaculture become attractive lines for investigation.

The analyses conducted in this project again emphasise the importance of improving productivity while reducing methane emissions. These predictions again provide good evidence for the production advantages that could be obtained from methane mitigation if proportionally more of the energy is retained for production purposes. For example, for steers in the northern coastal beef region, live weight gain was increased by 22, 44 and 89 g/day as the percentage of energy from methane used for productivity increased from 20, 40 to 80% when methane inhibition from algae was assumed to be 60%.

Leucaena

Leucaena showed potential for substantial emissions reductions and potential to be profitable for the northern coastal beef farming system. Leucaena increased animal productivity while reducing methane emissions and again emphasises the importance of increasing productivity when making methane inhibition strategies financially attractive. However a large capital investment is required to establish Leucaena pastures ($250-350/ha if undertaken by the farmer and $450/ha when established under contract) and this is likely to inhibit adoption.

It was not applicable for the remaining two broad acre beef farming systems. Although Leucaena is applicable only to the northern coastal beef region, it is predicted to reduce CO_2 equivalent methane production by around 100,000 tonnes annually if adopted by 10% of farmers. Much is known about the growing of Leucaena in northern regions and promotion of its benefits to cattle producers appears to be the most appropriate future activity. The most urgent research required is to develop a relationship between proportion of Leucaena in the diet of cattle and reduction in methane emissions as well as increases in growth rate of cattle. These results are needed for the development of an effective ERF methodology that can be adopted by producers to gain carbon credits.

The possibility of feeding Leucaena to feedlot cattle in a dried and pelleted form was examined. Leucaena pellets are not yet produced in Australia, but some producers are examining the possibility. In the example investigated, Leucaena was used to replace cotton seed meal and silage and resulted in a decrease in the energy content of the diet because of the high oil content in the replaced cotton seed meal and inclusion of straw to act as effective fibre. Under these conditions, cattle were predicted, using a feedlot model, to consume less energy and this resulted in a decline in productivity. Although a small reduction in methane emission was predicted, the presumed decrease in growth rate meant that the strategy was not profitable even when the price of carbon credits was $50/tonne.

If Leucaena pellets become available in Australia, there may be an opportunity to evaluate these pellets in feedlots with a range of dietary ingredients. However, with 10% adoption across the sector, our analyses suggest that only around 10,000 tonnes of CO_2 equivalents would be saved annually for feedlots.

Plant Bioactives

Plant bioactives showed considerable potential for emissions reductions across all farming systems examined. Since confirmed growth rate increases for energy saved were not available for plant bioactives, financial modelling and MACCs for this practice option did not include productivity increases and showed a marginal loss under all farming systems. The amount of these bioactive compounds needed for methane inhibition is likely to be around 25 to 50 mg/day and can therefore be applied to all ruminant production systems in Australia. If this occurred with 10% adoption, it is estimated that approximately 1 million tonnes of CO_2 equivalents would be saved across Australia from methane inhibition in cattle production systems and 275,000 tonnes in sheep production systems.

Preliminary analysis simulating the potential impacts of using energy saved from reducing methane emissions for productivity was undertaken for the beef farming systems. However, due to the high costs of implementation, this mitigation strategy continued to indicate marginal losses when potential energy savings were included. Implementation costs would need to decrease to less than 10 cents per head, per day for plant bioactives to become financially viable under the assumption that 40% of energy is saved and carbon credits at $14 tonne CO_{2e} are available.

Currently, no animal experiments have been conducted using plant bioactive compounds. The estimated 25% reduction in methane inhibition is based on comparisons between *in vitro* and *in vivo* respiration chamber experiments with other plants. Further investment should be conducted using these bioactive compounds in sheep and cattle within respiration chambers to confirm that methane emissions are reduced to the level presumed.

Wheat Feeding

Wheat feeding was modelled as a methane reduction strategy for the dairy farming system. This practice option was profitable when wheat replaced fresh pasture and shows potential for a substantial reduction in methane emissions for the Australian dairy herd. With 10% adoption by the Australian dairy herd, the total reduction in CO_2 equivalents would be around 50,000 tonnes annually. The primary reason for the enhanced profitability was a substantial increase in milk yield resulting from the replacement of fresh pasture with cereal grain. However the increased cost for wheat compared to pasture silage eroded much of the financial gain from increased yield. The final experiment within NLMP showed that the response in methane emission to wheat feeding depended on the quality to the wheat offered. Further experiments are warranted to determine the specifications of the wheat and other components of the diet needed to ensure a predictable reduction in methane emissions. These experiments are likely to be undertaken from future funding sources.

Nitrates

Nitrates showed relatively low potential for emissions reductions across all farming systems examined. Nitrate was included in the diet at a relatively low rate to prevent nitrite poisoning. In addition, nitrate was not offered all year in the predictions made as it was only assumed to be made available during a six month dry season period. Consequently, the impact on methane reduction was small in all production systems examined. The total saving in methane across all Australian production systems was estimated to be less than 370,000 tonnes of CO_2 equivalents annually.

Furthermore, nitrate decreased feed intake in feedlot situations. The low methane inhibition and reduced animal productivity resulted in reduced financial returns in several production systems. Since confirmed growth rate increases for energy saved were not available for nitrates, financial modelling for this practice option did not include productivity increases and showed a marginal loss. Additional analysis simulating the potential impacts of energy saved on productivity and profitability is needed for this practice option. Nevertheless, feeding of nitrate as a replacement for urea does not appear to be the most economical way to reduce methane emissions in current ruminant production systems. There may be ways to reduce the risk of nitrite poisoning, but with the current evidence from NLMP projects, further research into the use of nitrates as a methane mitigation strategy does not appear warranted.

Grape Marc

Grape marc is a product that is available only in restricted regions of Australia in proximity to the wine industries. The MACC analyses were conducted only for the non-pastoral sheep, feedlot and dairy industries. Grape marc was used as a feed for maintaining animals or as a substitute for an ingredient with similar energy content. When this was done, it proved to be a profitable strategy for the dairy industry when it replaced an ingredient with the same energy value, but not for the non-pastoral sheep or feedlot industries. The assumptions made relating to cost of grape marc have a major effect on predicted profitability. It appears likely that the primary value for grape marc will be for ruminants held under energy maintenance conditions during periods of feed shortage and on farms with close proximity to a grape marc source. The analyses suggest that when applied in this way feeding grape marc could reduce annual methane emissions by approximately 145,000 tonnes annually. However, this calculation assumes that sufficient grape marc would be available and the costs of transport are limited.

There does not appear to be any reason to undertake further research with grape marc. However, the NLMP project has allowed development of new analytical methods for identifying types of tannins and plant polyphenols. These assays could be valuable in exploring the impact of different polyphenols on methane inhibition and general animal nutrition.

5.2 Extent to which project objectives have been met

Objective 1 - NLMP practice options research question

Research Question – what is the comparison of expected GHG mitigation and financial returns for practice options examined as part of the NLMP that appear to be financially viable or have the potential to be financially viable.

A total of 13 mitigation strategies were analysed for abatement potential and financial outcomes. These options included management practices that improve production efficiency and reduce methane emissions, strategies resulting from NLMP project research and strategies considered potentially valuable for reducing methane emissions resulting from research conducted outside NLMP. The management strategies were included in the analyses to demonstrate the relative impact of direct methane mitigation interventions compared with what can possibly be achieved by adopting existing livestock and/or nutrition management options. The results of the case study analysis were then scaled up to estimate the national potential for each of the mitigation strategies under investigation using assumed adoption rates of 5, 10 and 20%.

Objective 2 - NLMP Investment analysis research question

Research question – what are the estimated financial outcomes for a range of possible scenarios for those mitigation options demonstrating the greatest potential

Financial outcomes were estimated utilising case studies from eight different farming systems. Many methane abatement strategies were evaluated across all farming systems, but some applied only to specific systems. Annual changes to profitability (marginal profits/losses) associated with the implementation of a practice option were estimated for each mitigation strategy is it applied to a particular farming system.

A marginal abatement cost curve was constructed for each of the case studies to identify those mitigation strategies with the greatest potential to both reduce emissions and increase farm profitability. Carbon prices of $0, $14 and $50 were considered.

Additional financial analysis includes estimation of the cost per tonne to reduce carbon for each of the practice options examined and break even analysis.

6 Conclusions/Recommendations

6.1 Mitigation Options

Those mitigation strategies showing the greatest potential for methane reductions across the range of farming systems examined are algae, NOP, vaccinations, plant bioactives and biochar. If some of these strategies were adopted by the Australian ruminant industries they may have potential to significantly decrease greenhouse gas emissions from enteric methane. For example, feeding algae and assuming

60% methane reduction and 10% adoption across production systems, a saving was predicted in CO_2 equivalents of 2.4 million tonnes for cattle and 660,000 tonnes for sheep across the whole of Australia. Even with only 10% adoption, this strategy would reduce total greenhouse gas emissions from ruminants in Australia by over 5%. The direct (science) mitigation strategies tended to demonstrate stronger methane emissions reduction potential than the management practice options examined.

In addition, wheat feeding can significantly reduce emissions for the dairy industry, while Leucaena has strong potential for the northern coastal beef farming system.

The overall economic benefit of a methane mitigation strategy depends on assumptions made in the analyses for: i) methane emission reduction; ii) potential productivity gains; iii) cost of implementation; and iv) carbon credits earned. The analyses showed clearly that the greatest economic benefits come from those methane mitigation strategies which increase animal productivity and have low costs for implementation. The price paid for carbon credits has an impact on profitability, but the effect is generally smaller than the impact of a strategy on animal productivity.

Financial outcomes can be categorised as a) zero cost or profitable, b) potentially financially viable or profitable, and c) high cost. The practice options that are zero cost or profitable include

- management practice changes
- genetic selection
- feeding biochar to beef cattle and sheep
- introducing Leucaena plantations in the northern coastal region
- feeding high quality wheat at the rate of around 9 kg/day to dairy cows consuming pasture
- grape marc for dairy in regions in close proximity to wine production

Of these, Leucaena, wheat feeding and biochar show the strongest potential for emissions reductions for the farming systems where they apply. While Leucaena is estimated to be profitable in the long term, the investment required to establish pastures is at least $250/ha and this may inhibit adoption. Feeding of biochar appeared to be financially attractive under most production systems, but the assumptions used in the analyses were based on one experiment conducted with low producing cattle fed an atypical diet. These assumptions need to be assessed for animals under Australian conditions before biochar could be recommended as a viable mitigation strategy.

Moderate emissions reductions are also possible for grape marc and genetics in the dairy industry and management practice changes in broadacre beef farming systems. Breeding southern cattle for low methane emissions through the use of the recently updated BREEDPLAN software provides potential for profits from carbon credits, but cannot yet be rapidly adopted for the majority of farming systems. Further, genetics showed limited emissions reduction potential for farming systems other than diary. Most management options result in improvements in animal productivity and have relatively low costs for implementation. While moderate emissions reductions were achieved for the management practice changes examined for beef farming systems, the practice management changes examined for sheep farming systems showed low emissions reduction potential.

Other strategies showing greater mitigation potential, such as algae, plant bioactive compounds, NOP and vaccination are either at early stages of research and/or need to reduce the cost of implementation. Although significant research has been undertaken to understand the science and practicality of feeding nitrate as a methane mitigation strategy, its methane mitigation potential is small when intake is restricted to amounts unlikely to produce nitrite poisoning.

Some practice options, while not profitable, have potential to become financially viable if sufficient income can be earned from carbon credits and/or productivity gains can be established by the research. When a price on carbon is ignored, estimated costs of emissions reductions for vaccination are $13.92 ($27.84) per tonne CO_{2e} when an emissions reduction of 20% (10%) is assumed, and $56.47 ($112.94) per tonne CO_{2e} when an emissions reduction of 60% (30%) is assumed for algae. This is based on an assumed implementation cost of $1.50 for algae, which may not be achievable. When income from carbon credits is considered, the cost of reducing a tonne of CO_{2e} reduces to $0 ($13.84) for vaccination when an emissions reduction of 20% (10%) and a price on carbon of $14 are assumed.

Preliminary analysis with vaccination and algae feeding showed that increasing the energy from methane mitigation that is utilised for productive purposes markedly changed the potential profitability of a strategy. Vaccination became quite profitable for energy savings of 20% or greater. For algae, the cost of reducing a tonne CO_{2e} reduced to $17.06 when an emissions reduction of 60% and energy savings of 20% were assumed and became profitable when energy savings of 40% or greater were assumed.

The analyses also demonstrated that there were strong interactions between the mitigation potential of a strategy, the proportion of methane saved energy used for productivity and the price paid for carbon credits. For example, the breakeven price for algae would be $0.52/kg if there was a 30% methane inhibition, 20% methane energy saving for productivity and no price on carbon. However, with a 60% reduction in methane, 80% retention of methane energy for productivity and a $50/tonne price for carbon credits, the breakeven price would be $5.25/kg.

The highest cost options for reducing emissions are plant bioactives at $437 per tonne CO_{2e}, nitrates at $418 per tonne CO_{2e}, NOP at $362 ($188) per tonne CO_{2e} when an emissions reduction of 15% (30%) is assumed for NOP. Neither productivity gains nor income from carbon credits have the potential to make these practice options financially viable, and a reduction in implementation costs would be needed to realise their emissions reduction potential.

6.2 Research Opportunities

From the analyses conducted in this report, when considered in conjunction with research progress within NLMP projects, several research opportunities can be identified for the examined strategies that should i) provide better evidence for assumptions made about the methane mitigation potential; ii) assist with improving and reducing the costs of implementation on farm; or iii) provide information needed for development and application of methodologies under the ERF for claiming carbon credits. These opportunities are listed below for each mitigation strategy in a possible order of priority.

Leucaena

Much is known about the mitigation potential and agronomic aspect of growing Leucaena, but research is required to develop a dose response curve for the effects of Leucaena on methane emissions and animal growth. This information is needed to develop and implement a methodology under the ERF for producers to claim carbon credits for introduction of Leucaena onto their properties.

Capturing energy from methane mitigation

The analyses conducted have highlighted the importance of increased animal productivity in determining the financial viability of any methane mitigation strategy. Evidence was provided in section 4.3 of the large difference between alternative biochemical pathways in the ability of ruminants to capture digested energy. There is sound evidence from NLMP and associated research that these pathways may be amenable to manipulation by enhancing the capture of hydrogen released during microbial fermentation through enhancement of the acetogens within the rumen or provision of other hydrogen utilising compounds. Further investment to evaluate these hypotheses appears warranted. The research would best be conducted in conjunction with theoretical simulation models of rumen function to allow quantitative evaluation of hypotheses within the model before undertaking evaluation experiments.

Algae

The red marine alga examined shows the greatest methane mitigation potential of all the above treatments tested in animals, but preliminary results need to be validated in different production scenarios, and the product currently is too expensive to be economical. A commercial company is currently investigating methods for cultivating the species. Additional support may be given to investigating methods for producing algae particularly if effluent from prawn farms or similar can be achieved.

In addition, the impact of feeding algae to feedlot cattle should be investigated. MLA is proposing to undertake the feedlot research in the near future.

Plant bioactive compounds

Two identified plant bioactive compounds have been shown to have substantial methane inhibition capacity when tested in continuous *in vitro* culture systems. However, these compounds have not been evaluated in animals. Research is needed for dose response experiments with these compounds first in sheep, then if successful in cattle. The two identified compounds are available commercially. An evaluation is needed to determine whether the compounds are likely to be available at a price suitable for use as a viable methane mitigation strategy.

Genetics

Genetic selection for reduction in methane emissions is not currently available. Implementation of EBVs (estimated breeding values) for RMP requires more research and collection of more data from cattle that are relevant to the genetic make-up of the national herd. In practice this means the breeders of replacement bulls for the Southern beef herd. In addition implementation of a breeding strategy as a ERF methodology requires the ability to estimate the impact of using genetically-superior cattle at the commercial herd level. This is not a straight-forward procedure and requires much more data on genetically-relevant cattle along with the implementation of genomic selection which is the only practical way in which to implement a genetic improvement strategy for such a 'difficult-to-measure' trait.

Therefore further research is required to enhance the accuracy and relevance of the methane emissions data for southern cattle breeds through continuing methane measurements on the Beef Information Nucleus herds. In addition data on the impact of selection for low RFI (i.e. more feed-efficient cattle) on methane emissions is also required.

Research is also needed to determine the heritability and genetic parameters for methane emissions and feed efficiency (RFI or net feed intake) in northern *Bosindicus* cattle. This will enable decisions as to the likely value of selection for reduced methane emissions in this class of animal.

NOP

NOP is a commercial product and will most likely be made available within Australia in the near to medium future. All previous research has been conducted with dairy cows. Research is needed to evaluate the potential mitigation potential of NOP under Australian conditions, particularly for cattle in northern Australia when offered through lick-blocks or other forms of supplementation.

Biochar

Only one experiment has been conducted where biochar was fed to cattle and this showed substantial depression in methane emissions and increase in growth rate. However, the experiment was conducted with Asian cattle fed cassava based diets and it is not known how the results apply to Australian cattle and feeding conditions. Experiments to evaluate the effect of biochar with different specifications on methane emissions and productivity in cattle under Australian conditions appears warranted, if the initial observations can be validated in more commercially-relevant experiments. When conducting such experiments, it is important to evaluate the proposed theory about the reasons methane is reduced and animal productivity increased; namely increased biofilm and microbial activity increasing digestion and passage of microbes from the rumen and increased activity of methanotrophs that utilise methane for microbial growth.

Wheat feeding to dairy cows

Further research is required to determine the specifications of the wheat and of the forage offered with the wheat to provide sound advice for implementation of the strategy. The required research is likely to be conducted by the Victorian government at Ellinbank with funds from known sources.

Vaccination

Although vaccination is attractive for reducing methane emissions because it is easy to implement, there is not a proven method for implementation. Considerable additional research is required to develop an effective vaccine. Research within NLMP and related projects is likely to identify surface proteins that are unique to methanogenic *Archaea* and not rumen bacteria. These proteins could be used as antigens for vaccine development. However, many other potential issues are involved in developing an effective vaccine with considerable risk (Wedlock et al., 2013). Substantial research is being conducted by groups in New Zealand and the outcome of this research should be reviewed before any investment is made within Australia. It may be feasible to incorporate knowledge regarding Archaea surface protein motifs identified within the NLMP and associated projects into the New Zealand research project through collaboration.

Grape marc

Further research into grape marc does not appear warranted. However, the assays developed for tannins and poly phenols could be of value when assessing the impact of polyphenols on nutrition of various animal species.

Nitrate

There appears to be little future for application of nitrate as a mitigation methodology unless the risk from nitrite poisoning can be eliminated. A review was commissioned within NLMP to examine possible methods for reducing the formation of methaemoglobin. Although several strategies may reduce this risk, considerable research investment would be required to evaluate their efficacy and this does not appear to have the highest priority for reducing methane emissions from ruminants in Australia.

7 Key Messages

Several methane mitigation practice options show strong potential for substantial emissions reductions and have broad applicability across Australia's livestock industries. These are algae, NOP, vaccinations, plant bioactives, and biochar. If some of these strategies were adopted by the Australian ruminant industries it is likely that they would significantly decrease greenhouse gas emissions from enteric methane.

Further investment in research and development is required before these practice options are able to be implemented. Priority areas have been identified and include preliminary research into enhancing the ability of ruminants to capture digested energy, development and cultivation of algae, and plant bioactive compound dose response experiments in sheep and cattle.

Many of the mitigation practice options identified as having strong methane reduction potential may increase productivity and none impair it. Productivity increases are a major determinant of financial viability for emissions reduction practice options.

For some of these practice options such as NOP, plant bioactives and algae to be widely adopted, implementation costs will need to be low enough for them to be financially viable.

Some existing livestock and/or nutrition management practice options that increase productivity and profitability also decrease emissions and immediate adoption of these practices should be encouraged.

8 Bibliography

BANIK, B. K., DURMIC, Z., ERSKINE, W., NICHOLS, P., GHAMKHAR, K. & VERCOE, P. 2013. Variability of in vitro ruminal fermentation and methanogenic potential in the pasture legume biserrula (Biserrula pelecinusL.) *Crop & pasture Science,* 64**,** pp 409-416.

BLAXTER, K. & CLAPPERTON, J. 1965. Prediction of the amount of methane produced by ruminants. *British Journal of nutrition,* 19**,** 511-522.

BROUWER, E. 1965. Report of subcommittee on constants and factors. In: Blaxter, K.L. (Ed.), Energy Metabolism of Farm Animals.: 3rd Symposium on Energy Metabolism. EAAP Publ. no. 11 Academic Press, London, UK.

CALLAGHAN, M., TOMKINS, N., BENU, I. & PARKER, A. 2014. How feasible is it to replace urea with nitrates to mitigate greenhouse gas emissions from extensively managed beef cattle? *Animal Production Science,* 54**,** 1300-1304.

COMMONWEALTH OF AUSTRALIA. 2014. *Methodology for reducing greenhouse gas emissions in beef cattle by feeding nitrate supplements.* [Online]. http://www.mla.com.au/Research-and-development/Environment-research/National-livestock-methane-program. [Accessed 15 May 2015.

CONRAD, K. 2014. Soil Organic Carbon Sequestration and Turnover in Leucaena-grass Pastures of Southern Queensland.

DE RAPHÉLIS-SOISSAN, V., LI, L., GODWIN, I., BARNETT, M., PERDOK, H. & HEGARTY, R. 2014. Use of nitrate and Propionibacterium acidipropionici to reduce methane emissions and increase wool growth of Merino sheep. *Animal Production Science,* 54**,** 1860-1866.

DEPARTMENT OF ENVIRONMENT. 2015. *The Emissions Reduction Fund: Overview* [Online]. http://www.environment.gov.au/climate-change/emissions-reduction-fund/publications/factsheet-emissions-reduction-fund-overview. [Accessed 8 March 2015.

DEPARTMENT OF ENVIRONMENT 2015. *National Greenhouse Gas Inventory - Kyoto Protocol Accounting Framework* [Online]. http://ageis.climatechange.gov.au/. [Accessed 8 March 2015.

EADY, S. 2011. The potential for using improvements in production efficiency to abate greenhouse gas emissions in extensive beef production systems in northern Australia. *In:* CSIRO (ed.).

GARCÍA-GONZÁLEZ, R., LÓPEZ, S., FERNÁNDEZ, M. & GONZÁLEZ, J. Effects of the addition of some medicinal plants on methane production in a rumen simulating fermenter (RUSITEC). International Congress Series, 2006. Elsevier, 172-175.

GOEL, G., MAKKAR, H. P. & BECKER, K. 2009. Inhibition of methanogens by bromochloromethane: effects on microbial communities and rumen fermentation using batch and continuous fermentations. *British journal of nutrition,* 101**,** 1484-1492.

HAISAN, J., SUN, Y., GUAN, L., BEAUCHEMIN, K., IWAASA, A., DUVAL, S., BARREDA, D. & OBA, M. 2014. The effects of feeding 3-nitrooxypropanol on methane emissions and productivity of Holstein cows in mid lactation. *Journal of dairy science,* 97**,** 3110-3119.

HANSEN, H. H., STORM, I. M. L. D. & SELL, A. 2012. Effect of biochar on in vitro rumen methane production. *Acta Agriculturae Scandinavica, Section A–Animal Science,* 62**,** 305-309.

HEGARTY, R., LI, L., MILLER, J., NOLAN, J., PERDOK, H. & LENG, R. 2013. Growth, efficiency and carcass attributes of feedlot cattle supplemented with calcium nitrate or urea. *Greenhouse Gas and Agriculture Animals (GGAA), Dublin, Ireland*.

HULSHOF, R., BERNDT, A., GERRITS, W., DIJKSTRA, J., VAN ZIJDERVELD, S., NEWBOLD, J. & PERDOK, H. 2012. Dietary nitrate supplementation reduces methane emission in beef cattle fed sugarcane-based diets. *Journal of Animal Science,* 90**,** 2317-2323.

HUTTON, P., DURMIC, Z. & VERCOE, P. 2010. Investigating Eremophila glabra as a bioactive agent for preventing lactic acidosis in sheep. *Animal Production Science,* 50**,** 449-453.

JANSSEN, P. H. 2010. Influence of hydrogen on rumen methane formation and fermentation balances through microbial growth kinetics and fermentation thermodynamics. *Animal Feed Science and Technology,* 160**,** 1-22.

KENNEDY, P. & CHARMLEY, E. 2012. Methane yields from Brahman cattle fed tropical grasses and legumes. *Animal Production Science,* 52**,** 225-239.

LEE, C. & BEAUCHEMIN, K. A. 2014. A review of feeding supplementary nitrate to ruminant animals: nitrate toxicity, methane emissions, and production performance. *Canadian Journal of Animal Science,* 94**,** 557-570.

LEE, K.-H. 2012. Carbon accounting for supply chain management in the automobile industry. *Journal of Cleaner Production*.

LENG, R., INTHAPANYA, S. & PRESTON, T. 2012a. Biochar lowers net methane production from rumen fluid in vitro. *Livestock Research for Rural Development,* 24.

LENG, R., INTHAPANYA, S. & PRESTON, T. 2013. All biochars are not equal in lowering methane production in in vitro rumen incubations. *in vitro,* 12**,** 12.

LENG, R. & PRESTON, T. 2010. Further considerations of the potential of nitrate as a high affinity electron acceptor to lower enteric methane production in ruminants. *Livestock Research for Rural Development,* 22.

LENG, R., PRESTON, T. & INTHAPANYA, S. 2012b. Biochar reduces enteric methane and improves growth and feed conversion in local "Yellow" cattle fed cassava root chips and fresh cassava foliage. *Livestock Research for Rural Development,* 24.

LI, L., SILVEIRA, C., NOLAN, J., GODWIN, I., LENG, R. & HEGARTY, R. 2013. Effect of added dietary nitrate and elemental sulfur on wool growth and methane emission of Merino lambs. *Animal Production Science,* 53**,** 1195-1201.

LI, X., DURMIC, Z., LIU, S., MCSWEENEY, C. S. & VERCOE, P. E. 2014. Eremophila glabra reduces methane production and methanogen populations when fermented in a Rusitec. *Anaerobe,* 29**,** 100-107.

MARTÍNEZ-FERNÁNDEZ, G., ABECIA, L., ARCO, A., CANTALAPIEDRA-HIJAR, G., MARTÍN-GARCÍA, A., MOLINA-ALCAIDE, E., KINDERMANN, M., DUVAL, S. & YÁÑEZ-RUIZ, D. 2014. Effects of ethyl-3-nitrooxy propionate and 3-nitrooxypropanol on ruminal fermentation, microbial abundance, and methane emissions in sheep. *Journal of dairy science,* 97**,** 3790-3799.

MCCRABB, G., BERGER, K., MAGNER, T., MAY, C. & HUNTER, R. 1997. blue arrow e-Alerts. *Australian Journal of Agricultural Research,* 48**,** 323-329.

MEAT & LIVESTOCK AUSTRALIA. 2015. *Peter Whip: Climate champion* [Online]. Available: http://www.mla.com.au/Livestock-production/Producer-case-studies/Peter-Whip-Climate-Champion 7 April 2015].

MINSON, D. 1990. Crude de protein In forage. *Forage in Ruminant Nutrition (ed. TJ Cunha) Acad. Press, Inc. San Diego, NY, Boston***,** 178-190.

MITSUMORI, M., SHINKAI, T., TAKENAKA, A., ENISHI, O., HIGUCHI, K., KOBAYASHI, Y., NONAKA, I., ASANUMA, N., DENMAN, S. E. & MCSWEENEY, C. S. 2012. Responses in digestion, rumen fermentation and microbial populations to inhibition of methane formation by a halogenated methane analogue. *British Journal of Nutrition,* 108**,** 482-491.

MOATE, P., WILLIAMS, S., DEIGHTON, M. & WALES, W. 2012. A comparison between wheat or maize grain fed as a high proportion of the diet on milk production and methane emissions from dairy cows. *Proceedings of the 5th Australasian Dairy Science Symposium,* Nov. 13-15, Melbourne, Australia**,** pp 452-453.

MOATE, P., WILLIAMS, S., DEIGHTON, M., WALES, W. & JACOBS, J. 2014a. Effects of white and red grape marcs on milk production and methane emissions from dairy cows. *Proceedings of the 6th Australasian Dairy Science Symposium Nov. 19-21, Hamilton, New Zealand*.

MOATE, P., WILLIAMS, S., DEIGHTON, M., WALES, W. & JACOBS, J. Supplementary feeding of wheat to cows fed harvested pasture increases milk production and reduces methane yield. Proceedings of the 5th Australasian Dairy Science Symposium, 2014b. 177.

MOATE, P., WILLIAMS, S., TOROK, V., HANNAH, M., RIBAUX, B., TAVENDALE, M., ECKARD, R., JACOBS, J., AULDIST, M. & WALES, W. 2014c. Grape marc reduces methane emissions when fed to dairy cows. *Journal of Dairy Science,* 97**,** pp 5073-5087.

NOLAN, J., GODWIN, I., DE RAPHÉLIS-SOISSAN, V., ENTSCH, B. & HEGARTY, R. 2015. Minimising the risk of nitrite toxicity in ruminants when dietary nitrate is used to mitigate methane emissions- Final Report project B.CCH.6188,. Meat & Livestock Australia, Sydney, Australia.

NOLAN, J., HEGARTY, R., HEGARTY, J., GODWIN, I. & WOODGATE, R. 2010. Use of supplementary nitrate to mitigate methane production and provide rumen degradable N for ruminants. *J. Anim. Sci*, 50.

REYNOLDS, C. K., HUMPHRIES, D. J., KIRTON, P., KINDERMANN, M., DUVAL, S. & STEINBERG, W. 2014. Effects of 3-nitrooxypropanol on methane emission, digestion, and energy and nitrogen balance of lactating dairy cows. *Journal of dairy science,* 97**,** 3777-3789.

TOMKINS, N. & HUNTER, R. 2004. Methane reduction in beef cattle using a novel antimethanogen. *Anim Prod Aust,* 25**,** 329.

UNFCCC. 2015. *CDM Project Search* [Online]. https://cdm.unfccc.int/Projects/projsearch.html.

VAN ZIJDERVELD, S., GERRITS, W., APAJALAHTI, J., NEWBOLD, J., DIJKSTRA, J., LENG, R. & PERDOK, H. 2010. Nitrate and sulfate: Effective alternative hydrogen sinks for mitigation of ruminal methane production in sheep. *Journal of Dairy Science,* 93**,** 5856-5866.

VAN ZIJDERVELD, S., GERRITS, W., DIJKSTRA, J., NEWBOLD, J., HULSHOF, R. & PERDOK, H. 2011. Persistency of methane mitigation by dietary nitrate supplementation in dairy cows. *Journal of Dairy Science,* 94**,** 4028-4038.

VELAZCO, J., COTTLE, D. & HEGARTY, R. 2014. Methane emissions and feeding behaviour of feedlot cattle supplemented with nitrate or urea. *Animal Production Science,* 54**,** 1737-1740.

WEDLOCK, D., JANSSEN, P., LEAHY, S., SHU, D. & BUDDLE, B. 2013. Progress in the development of vaccines against rumen methanogens. *animal,* 7**,** 244-252.

WILKERSON, V., CASPER, D. & MERTENS, D. 1995. The prediction of methane production of Holstein cows by several equations. *Journal of Dairy Science,* 78**,** 2402-2414.

WRIGHT, A., KENNEDY, P., O'NEILL, C., TOOVEY, A., POPOVSKI, S., REA, S., PIMM, C. & KLEIN, L. 2004a. Reducing methane emissions in sheep by immunization against rumen methanogens. *Vaccine,* 22**,** 3976-3985.

WRIGHT, A. D. G., KENNEDY, P., O'NEILL, C. J., TOOVEY, A. F., POPOVSKI, S., REA, S. M., PIMM, C. L. & KLEIN, L. 2004b. Reducing methane emissions in sheep by immunization against rumen methanogens. *Vaccine,* 22**,** 3976-3985.

YOUNG, J. M. 2013. Research & Extension Opportunities to Reduce Emissions and Emissions Intensity from Broadacre Sheep Enterprises.