OCTOBER 2020

Dairy Cattle Health and Greenhouse Gas Emissions Pilot Study: Chile, Kenya and the UK

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Executive Summary

In 2019 the Food and Agriculture Organization and Global Dairy Platform published the report 'Climate Change and the Global Dairy Cattle Sector'. This global review identified improved cattle health as one key action for the reduction of Greenhouse gas (GHG) emissions from livestock production; as healthier animals are more productive and thus produce lower emissions per unit of output.

This pilot study was undertaken for the Global Research Alliance on Agricultural Greenhouse Gases and Global Dairy Platform. It sets out practical methods for establishing GHG emissions, what magnitudes of reduction may be expected with defined animal health improvement measures (AHIM) in dairy cattle health and how these may be applied in national reporting to the United Nations Framework Convention on Climate Change (UNFCCC) through the Nationally Determined Contributions (NDC) and the necessary Measurement, Reporting and Verification (MRV) required to achieve such. The study applied the same methodology to the dairy sectors of Chile, Kenya and the United Kingdom (UK), based on assumptions and modelling initially applied in the UK and considers some economic case scenarios in each country; exploring the cost benefit of the applied AHIMs to individual farmers to drive adoption.

Animal Health Improvement Measures (AHIM) and Impact on Greenhouse Gas (GHG) Emissions in Chile, Kenya and the UK

Endemic cattle diseases have a negative effect on dairy cattle production and productivity, and consequential impacts on GHG emissions. This typically stems from: increased mortality, depressed milk production, increased waste from discarded treatment milk and reduced reproductive performance. This study focussed on three specific health and productivity challenges for dairy cattle in the three different countries: 1. **Reproductive performance** - infertility/failure to conceive (barren cows); 2. **Single agent infectious disease** - Bovine Viral Diarrhoea virus (BVDv) and; 3. **Multifactorial or management disease** – mastitis.

The data collected were inputted to the Cranfield University systems-based Life Cycle Assessment (LCA) model to estimate the changes in greenhouse gas (GHG) intensity that occur when cattle health is improved (Williams et al., 2015). The results shown are for the three specific challenges addressed in this study, with the average herd level potential GHG intensity reduction for each, compared to the potential GHG intensity reduction represented by implementing AHIM in the worst 10% of cases. The average herd level potential reductions in GHG intensity for Chile, Kenya and the UK are shown in Table 1 and ranged from: 7% to 24% for infertility; 4% to 5% for BVD and 6% across all three countries for mastitis. However, the potential reduction in GHG intensity for the worst 10% of herds ranged from: 10% to 44% for infertility; 8% to 11% for BVD and 10% to 12% for mastitis.

United Nations Framework Convention on Climate Change (UNFCCC): Measurement, Reporting and Verification (MRV) tools and Nationally Determined Contributions (NDCs)

Developing a baseline for GHG emissions from which to measure impacts is essential for some targets, such as those potentially associated with AHIM, so that the change resulting from the implementation of mitigation activities can be measured and verified.

A Tier 1 GHG inventory uses fixed values for GHG emissions per head of livestock, so changes in total emissions reflect only changes in livestock populations. Tier 2 methodologies require more detailed information on the characteristics and performance of different sub-categories of livestock; they are better able to reflect actual production conditions and their impact on GHG emissions. This is true for all mitigation options one includes in an inventory. Perhaps we should modify the wording a little to note that it's helpful to undertake a full LCA to evaluate full impacts of interventions. We shouldn't set the bar so high for AHIM, when it's not so for other interventions. Undertaking a full LCA enables a more holistic appreciation of the actual (both negative and positive) impacts of AHIM's implemented.

The core working of the model depends on calculating; a) the metabolizable energy requirements (MER) for maintenance, growth, gestation and lactation and, (b) the balance of cows and replacement heifers needed to maintain a herd, assuming a steady state population. Modifiers are then applied to address the effects of health on MER of factors such as milk yield, fecundity, mortality, growth rates and fighting infection. These are accompanied by estimates of the GHG emissions of veterinary and managerial interventions.

This pilot study clearly identifies a considerable potential for cost effective mitigation of GHG emissions from the dairy sector through use of targeted AHIMs. Currently, AHIMs are not explicitly included in Nationally Determined Contributions (NDCs) and we currently lack the necessary standardised Measurement, Reporting and Verification (MRV) tools to achieve this globally or even in a country specific manner in many cases. An approach to MRV for the case examples is outlined below.

The original Cranfield University model was parameterised for UK conditions, including data on both cattle management and health conditions (impacts, treatments, capacity for recovery and prevalence). Additional data requirements across countries for applying MRV tools widely on health related KPIs over time should include commonly recorded factors such as: Age at 1st calving; Calving interval (CI); Cow mortality rate and Milk production per lactation.

The Economic Benefit of AHIMs

The economic benefits for each AHIM in this study have been explored in each of the three countries (*see Table 6-9*). Implementing AHIM across all countries is likely to offer highly significant return on investment at individual farm level as well as for national mitigation of GHG emissions. Elliot et al. (2015) describe the economic benefits in more detail and this model is used as the basis for comparative AHIM case studies.

i. The economic benefit of implementing AHIM that improve Reproductive performance.

   If calving interval (CI) is reduced by only 10 days in a herd then the benefit would be estimated at more than $25/cow/year in the herd, with AHIM such as PD or using heatmount detectors only costing $2-3/cow/year. This therefore represents a potential ten-fold return on typical AHIM investment per year. On this basis, saving a single day in CI covers the cost of investing in reproductive performance AHIM.

ii. The economic benefit of implementing AHIM that improve Single Agent Infectious Disease: BVD.

   If BVD is prevented in a herd then the benefit of associated reduction in disease, fertility and production impacts has been estimated at saving more than $68/cow/year in the herd, with AHIM such as preventative vaccination only costing $2-3/cow/year. This therefore represents potentially more than a twenty-fold return on typical AHIM investment per year.

iii. The economic benefit of AHIM that control Multifactorial/ Management Disease: Mastitis.

   If clinical mastitis is reduced in a herd then the benefit would be estimated at saving more than $670/case/cow/year. A reduction from an average of 40 to 30 cases/cow/year would therefore save more than $6700, with AHIM such as dry cow therapy (DCT) only costing $10/cow/year. AHIM preventing just a single clinical case of mastitis in a herd potentially saves around the cost of typical AHIM investment for 70 cows per year.

Animal Health Improvement Measures (AHIM) offer a real opportunity to significantly mitigate Greenhouse Gas Emissions associated with dairy farming and are overwhelmingly cost-effective to deliver. This study describes an approach to implementing AHIM with Measurement, Reporting and Verification (MRV) in three countries: Chile, Kenya and the UK, that could be delivered more widely.

Introduction

In 2019 the Food and Agriculture Organization and Global Dairy Platform published the report ‘Climate Change and the Global Dairy Cattle Sector’.

This global review identified improved cattle health as one key action for the reduction of Greenhouse gas (GHG) emissions from livestock production; reducing the prevalence of diseases and parasites would generally reduce emissions intensity, as healthier animals are more productive and thus produce lower emissions per unit of output.

The GHG consequences of different diseases and conditions differ in magnitude. A wide range of ‘animal health improvement measures’ (AHIM) exist that can mitigate these conditions, including prevention, control and treatment. These AHIM vary in effectiveness, economic costs and complexity; some may act simultaneously on a number of different diseases, e.g. breeding, animal husbandry, and biosecurity.

The motivation for individual farmers to implement a given AHIM will depend on their individual need and personality profiles, including but not limited to the direct cost/benefit to the farm’s profitability. Drivers for change may also be strongly influenced by regulatory/market requirements; however, motivations are complex and individually constructed.

There may be a significant benefit at a national scale (if not always at the individual farm scale) in terms of GHG mitigation through wide-spread adoption of AHIM. Governments may therefore wish to promote AHIM to farmers to encourage their uptake and increase national GHG mitigation. However, the likelihood of governments doing this, may be contingent on their ability to capture AHIM in national livestock GHG inventories.

There are examples of national government initiatives established to address animal health issues or improve general productivity to fulfil economic and GHG priorities. In these instances, specific monitoring programs have been set up to assess the GHG impacts. In these circumstances, data can be collected at a farm scale to assess the impacts of specific interventions.

This study sets out practical methods for establishing GHG emissions, what magnitudes of reduction may be expected with defined improvements in dairy cattle health (AHIM) and how these may be applied in national reporting to the United Nations Framework Convention on Climate Change (UNFCCC) through the Nationally Determined Contributions (NDC) and the necessary Measurement, Reporting and Verification (MRV) required to achieve such.

The study applied the same methodology to the dairy sectors of Chile, Kenya and the United Kingdom (UK), based on assumptions and modelling initially applied in the UK and considers some economic case scenarios in each country. Importantly the study also explores the cost benefit of the applied AHIMs to individual farmers as this is a key driver for adoption.

Animal Health Improvement Measures (AHIM), Economics and Greenhouse Gas (GHG) Emissions

Endemic cattle diseases have a negative effect on dairy cattle production and productivity, and consequential impacts on GHG emissions.

This typically stems from:

- increased mortality,
- depressed milk production,
- increased waste from discarded treatment milk and,
- reduced reproductive performance

Improving dairy cattle health thus has the potential to decrease the GHG intensity of milk production and if total production is constant, to reduce overall GHG emissions. Country and system specific animal health improvement measures (AHIM) are the route to these reductions. Elliot et al. (2015) described the potential for veterinary intervention to mitigate the economic and GHG emissions impacts of cattle health challenges in the UK.

An economic analysis was applied to the results of the study to quantify the costs of GHG emission abatement by improving cattle health in order to construct a Marginal Abatement Cost Curve (MACC) in a fixed output scenario in the UK context (*see Figure 1*). This included estimation of the actual overall prevalence of each condition across the national herd.

A clear message of the MACC is that many measures to improve cattle health, including improving milking routine management and vaccination against infectious diseases such as Bovine Viral Diarrhoea (BVD) to improve cattle health *are profitable in their own right*, as well as reducing GHG emissions intensity. Targeting these measures effectively can offer enormous financial benefits to producers in addition to the huge opportunity to mitigate global emissions.

Marginal Abatement Cost Curve for control of endemic disease in dairy cattle in the UK (Elliot et al, 2015)

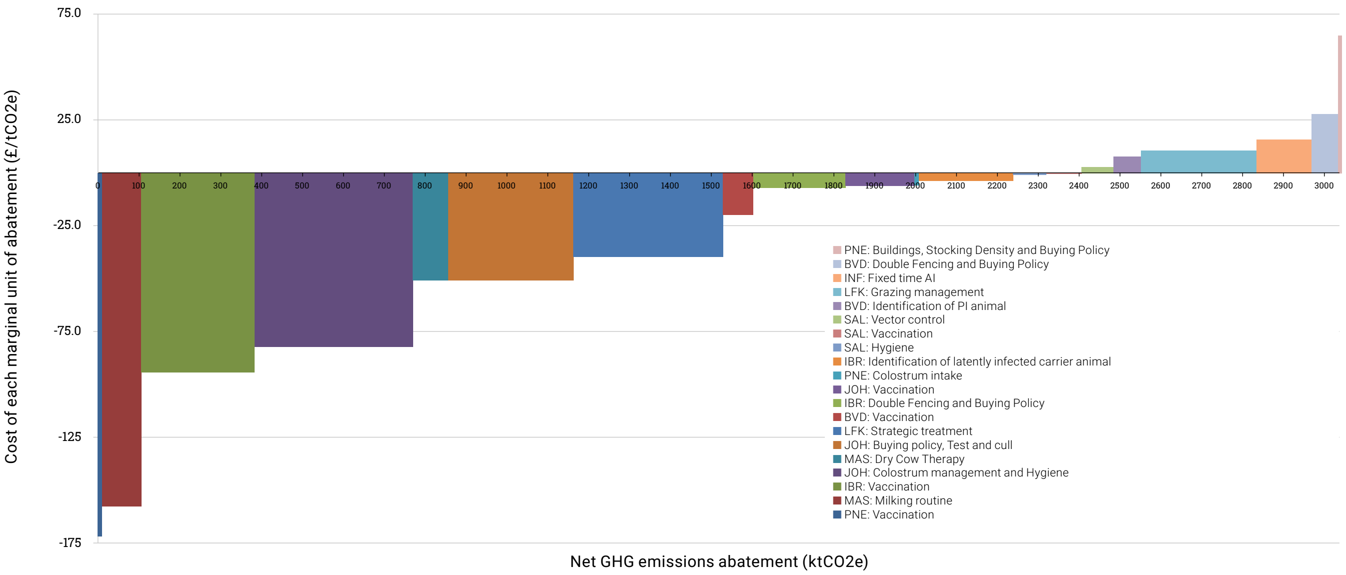

Figure 1: Marginal Abatement Cost Curve for control of top 10 endemic disease in dairy cattle in the UK. (Negative columns show how cost effective the GHG abatement is to the farmer. The width of each column gives the magnitude of GHG abatement for each AHIM.)

The UK research indicates there is significant potential for the reduction of GHG emissions from the dairy sector, with associated economic benefits. But are the same measures applicable in different countries around the world, where farming systems differ widely and access to interventions may be highly variable? Targeting any AHIMs effectively requires knowledge of what management practices are currently undertaken and a knowledge of the baselines of economics and GHG emissions, from which improvements can be measured. This pilot study aims to address some of these questions for the dairy sector in Chile, Kenya and the UK.

United Nations Framework Convention on Climate Change (UNFCCC) and Measurement, Reporting and Verification (MRV)

Developing a baseline for GHG emissions from which to measure impacts is essential for some targets, such as those potentially associated with AHIM, so that the change resulting from the implementation of mitigation activities can be measured and verified. This is a key component of obtaining funding for activities but may also just reflect the desire to attribute reductions in a national inventory to AHIM.

A Tier 1 GHG inventory is the most basic, using fixed values for GHG emissions per head of livestock, so changes in total emissions reflect only changes in livestock populations. Tier 2 methodologies, which require more detailed information on the characteristics and performance of different sub-categories of livestock, are able to better reflect actual production conditions and their impact on GHG emissions.

The global estimates of livestock sector emissions were initially made using the Tier 1 approach. But measuring the effects of changes in livestock management practices on GHG emissions at the country level requires adoption of a Tier 2 approach that can capture the effects of changes in management, diet and animal performance in different production systems, or regions of a country on GHG emissions.

Emissions per animal estimated using a Tier 2 approach can also change over time if data on management practices or productivity are updated. A Tier 2 approach is therefore essential for capturing the effects of livestock development and climate change mitigation policies on emissions from the sector. Better characterization of livestock GHG emissions can also assist policy makers to target and design efforts to mitigate GHG emissions in the livestock sector (Wilkes et al. 2017). As of 2017, 63 countries had adopted a Tier 2 approach to estimating GHG emissions.

This is true for all mitigation options one includes in an inventory. Perhaps we should modify the wording a little to note that it's helpful to undertake a full LCA to evaluate full impacts of interventions. We shouldn't set the bar so high for AHIM, when it's not so for other interventions. Undertaking a full LCA enables a more holistic appreciation of the actual (both negative and positive) impacts of AHIM's implemented.

Assessing the impact of AHIM on GHGE in Chile, Kenya and the UK

This study focussed on three specific health and productivity challenges for dairy cattle in the three different countries:

1. **Reproductive performance** - infertility/failure to conceive (barren cows)
2. **Single agent infectious disease** - Bovine Viral Diarrhoea virus (BVDv)
3. **Multifactorial or management disease** - mastitis

The prevalence of these three challenges and the commonly used AHIM in the UK were reviewed with Chile and Kenya using comparative sets of measures via Delphi panel methodology, based on a group of expert vets in each country, including:

- **Chile**: The Latin American Buiatria Association and Chilean Buiatria Society, Agricultural Research Institute, Cooprinsem, University of Concepción, Agricultural and Livestock Service and independent veterinary advisors.
- **Kenya**: The Kenya Agricultural and Livestock Research Organization and Ministry of Agriculture, Livestock and Fisheries.
- **UK**: The XLVet Group of veterinary practitioners, including Royal College of Veterinary Surgeons (RCVS) Specialists.

1. Reproductive performance – infertility/failure to conceive (non-pregnant cows)

Poor reproductive performance has been costed variously at £2-4/cow/day in UK (Esslemont and Kossaibati, 2002) or up to $3/cow/day in US economic analyses (de Vries, 2006). It increases environmental overhead by prolonging the low yielding tail of the lactation curve, reducing output of calves born and increasing the need for additional replacement animals that impact GHG emissions without production to offset (*see Figure 2*). One-off costs of only a few dollars of veterinary time per cow to deliver pregnancy diagnosis can offer a significant return on investment.

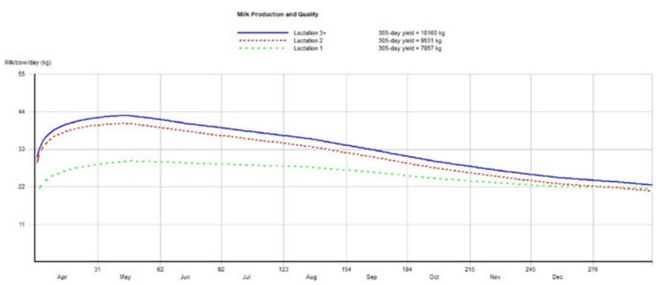

Figure 2: Milk yield decline curve and hence physiological basis to cost of days open due to infertility

AHIM for infertility/failure to conceive in Chile, Kenya and the UK

The Delphi panel identified the current AHIM for infertility/failure to conceive as:

- **Chile**: Early pregnancy diagnosis by ultrasound, sensors and tools to aid heat detection and fixed time artificial insemination programmes.
- **Kenya**: Manual pregnancy diagnosis, tools to aid heat detection (including teaser animals) and extension services.
- **UK**: Early pregnancy diagnosis by ultrasound, sensors and tools to aid heat detection and fixed time artificial insemination programmes.

2. Single agent infectious disease - Bovine Viral Diarrhoea virus (BVDv)

BVDv is a globally present immunosuppressive infectious pestivirus associated disease of cattle (see Figure 3). It has been estimated to cost up to $49/cow (although comprehensive costs are not currently available across countries for this disease). In addition to rendering cattle of all ages more susceptible to a wide range of diseases, it has a dramatic negative effect on fertility and specifically causes respiratory disease. Persistently infected (PI) offspring are a threat to all in-contact animals. One-off costs of only a few dollars for BVDv vaccine can offer a >10 x financial return at c. >$50/cow/year over 5 years in Scottish economic studies (Stott et al., 2012).

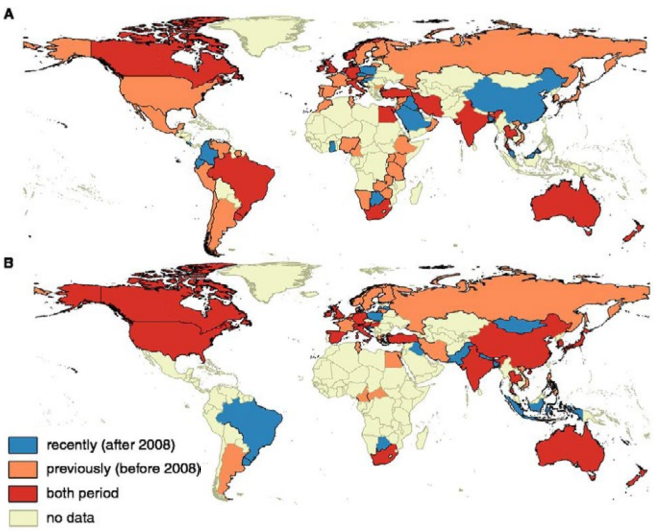

Figure 3: Global prevalence of BVDv (Richter et al 2019's Figure 2: Worldwide bovine viral diarrhoea virus (BVDV) infections map stratified by recent (after 2008; coloured in blue) and historical reports (before 2008; coloured in orange). If one country reported data for both periods it was coloured in red. (a) Antibodies (AB) positive and (b) persistently infected (PI) and viraemic infected (VI) infections.

AHIM for control of BVDv in Chile, Kenya and the UK

The Delphi panel identified current control measures for BVDv as:

- **Chile**: Biosecurity measures and segregation, use of vaccination; testing and eradication of PI animals.
- **Kenya**: Biosecurity measures and segregation [currently no use of vaccination or testing and eradication of PI animals were identified].
- **UK**: Biosecurity measures and segregation, use of vaccination; testing and eradication of PI animals.

3. Multifactorial or management disease - mastitis in dairy cows

Mastitis is globally the most economically significant disease of dairy cattle (Bradley 2002); central estimates of cost around £521/clinical case in the UK (Green, 2009). Infection of the udder tissue by a wide range of pathogens, contagious or environmental in origin, leads to damaged alveolar secretory tissue, pain and inflammation that results in reduced milk production. There are also wider impacts as inflammatory mediators reduce fertility and feed conversion efficiency. A huge variation in mastitis is found between herds (see Figure 4); there is great potential for mitigation. Costs of only a few dollars per cow for teat sealants or training input to milking routine offer a return many times greater.

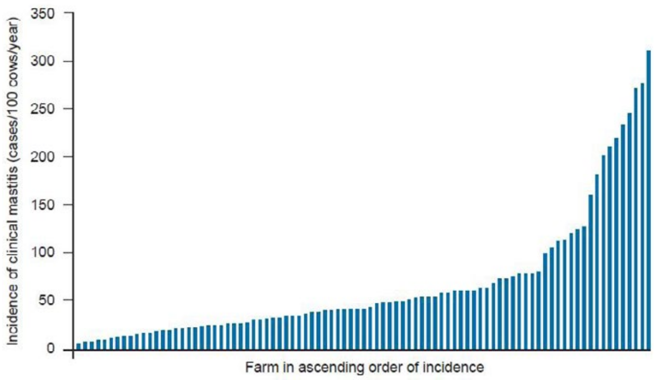

Figure 4: Incidence of clinical mastitis in 89 UK herds in order of increasing incidence; one farm (not shown) had an incidence of 849 cases/100 cows/year (Green et al, 2007).

AHIM for control of mastitis in Chile, Kenya and the UK

The Delphi panel identified the control measures for mastitis as:

- **Chile**: Teat disinfection and hygiene; selective dry cow therapy and milking management training.
- **Kenya**: Teat disinfection and hygiene; dry cow therapy [teat sealant use <1% currently] and milking management actions including changing milking order were identified.
- **UK**: Teat disinfection and hygiene; selective dry cow therapy and milking management training.

Results

The data collected were inputted to the Cranfield University systems-based Life Cycle Assessment (LCA) model to estimate the changes in greenhouse gas (GHG) intensity that occur when cattle health is improved (Williams et al., 2015).

The results shown below are for the three specific challenges addressed in this study, with the average herd level potential GHG intensity reduction for each, compared to the potential GHG intensity reduction represented by implementing AHIM in the worst 10% of cases.

Assumptions have been made in this pilot study based on an initially UK-based LCA model (see Appendix 1) and further development work is required. However, the apparent differences between countries are potentially much less significant than the underlying production and intrinsic biological factors. Infertility mitigation measures appear to represent the greatest opportunity with a potential *of c.10-40% reduction in GHG emission intensity* in the worst 10% of herds, although single-agent infectious and multifactorial/management diseases should not be overlooked.

The *average* herd level potential reductions in GHG intensity for Chile, Kenya and the UK are shown in Table 1 and ranged from:

- 7% - 24% for infertility
- 4% - 5% for BVD
- 6% across all 3 countries for mastitis

However, the potential reduction in GHG intensity for the *worst 10% of herds* ranged from:

- 10% - 44% for infertility
- 8% - 11% for BVD
- 10% - 12% for mastitis

Table 1: Cattle health potential for reducing GHG intensity. (The data are for three conditions with the average herd level potential for each and the potential for the worst 10% of herds.)

Condition	Potential reductions in GHG intensity		
	Chile	Kenya	UK
BVD	5%	4%	4%
BVD worst 10%	9%	8%	11%
Mastitis	6%	6%	6%
Mastitis worst 10%	10%	11%	12%
Infertility	7%	24%	7%
Infertility worst 10%	10%	44%	16%

This pilot study therefore shows considerable potential for long-term cost-effective mitigation of GHG emissions in Chile, Kenyan and UK dairy production through implementation of key AHIM (*see Figure 5, Figure 6 and Figure 7*).

Potential reductions in GHG intensity of milk production in Chile

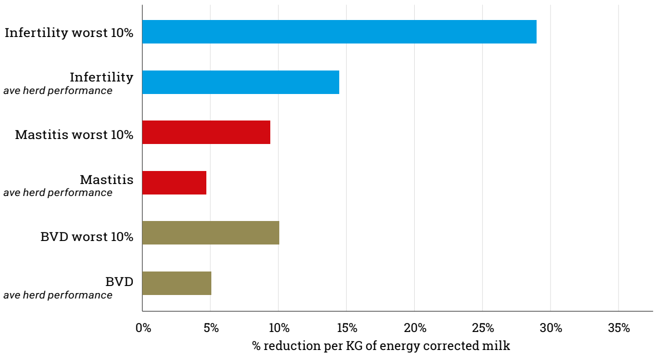

Figure 6: Potential reductions in GHG intensity of milk production in Chile, showing performance of average and worst 10% of herds

Potential reductions in GHG intensity of milk production in Kenya

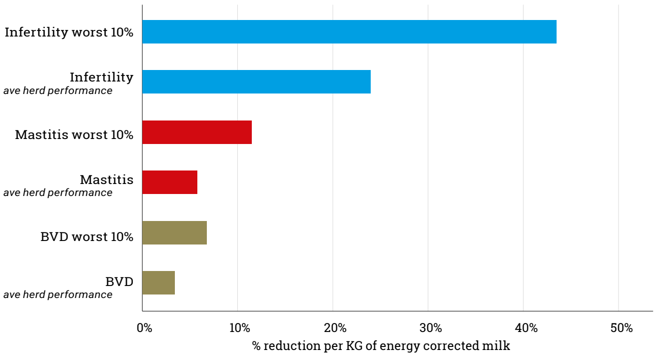

Figure 7: Potential reductions in GHG intensity of milk production in Kenya, showing performance of average and worst 10% of herds

Potential reductions in GHG intensity of milk production in the UK

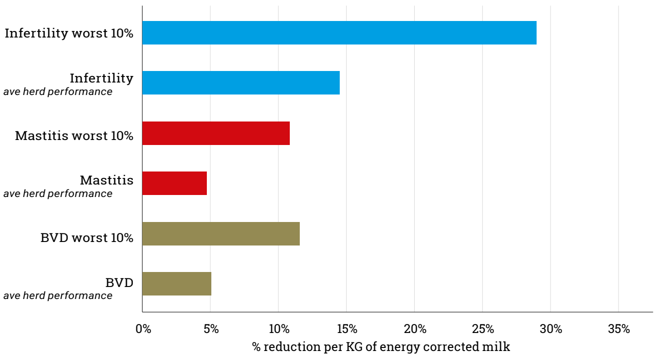

Figure 5: Potential reductions in GHG intensity of milk production in the UK, showing performance of average and worst 10% of herds

How can AHIM be included in Nationally Determined Contributions (NDCs); what are the necessary Measurement, Reporting and Verification (MRV) tools to achieve this ambition?

This pilot study has clearly identified a considerable potential for cost effective mitigation of GHG emissions from the dairy sector through use of targeted AHIMs.

Currently, AHIMs are not explicitly included in Nationally Determined Contributions (NDCs) and we currently lack the necessary standardised Measurement, Reporting and Verification (MRV) tools to achieve this globally or even in a country specific manner in many cases. An approach to MRV for the case examples is outlined below.

Integrating cattle health metrics into greenhouse gas inventories and NDCs

To the best of our knowledge, the explicit integration of AHIM into GHG inventories and MRV has not been carried out anywhere at the time of writing this report. Key questions are:

- What will it show?
- What can be incorporated?
- What further data are needed?

As demonstrated in this pilot study, a key benefit of improving cattle health is reducing GHG emissions intensity (i.e. emissions per unit of milk production); applying interventions to the three generic conditions studied in this report have demonstrated an overall reduction in GHG emissions by the modelling methods used.

In effect, some interventions will in fact increase direct emissions from the individual animal but, will reduce overall farm emissions intensity by preventing the waste associated with reduced production and mitigating the unproductive partitioning of energy and resources to immune responses and fighting disease. Overall, the net effects are to reduce the GHG emissions of unproductive overheads and so reduce emissions intensity per unit milk production (*see Table 2*).

Table 2: Expected effects of the interventions on mastitis, BVD and sub-optimal fertility on GHG emissions from cows (at individual and herd level)

Intervention effect	Consequence for intake	GHG emissions effect per cow	GHG emissions with constant herd milk output	Reason
To reduce extra energy requirement for fighting disease	Reduce intake	Decrease	Decrease	Lower metabolic energy requirements (MER)
To increase milk yield	Increase intake per cow, but fewer cows needed	Increase	Decrease	Reduced overheads
To decrease calving interval	Increase intake per cow, but fewer cows needed	Increase	Decrease	Reduced overheads
To decrease on-farm mortality rate	Reduce intake of the individual, but increases need for other replacement cattle	Decrease for same productivity	Decrease	Reduced overheads
To increase productive cow life	Reduce need for replacements and more beef opportunities	Little on cow herself, apart from time as heifer	Decrease	Reduced overheads
To increase productive lactations per cow	Reduce need for replacements and more beef opportunities	Little on cow herself, apart from time as heifer	Decrease	Reduced overheads

The consequences of interventions will vary between countries and be influenced by many factors such as demand for milk and meat, availability of additional pasture or other feeds, capacity of farmers to manage more stock. If demand for milk is constant or decreasing, then a smaller, more productive dairy herd is plausible in which both GHG emissions intensity *and* total GHG emissions will be reduced. If demand for milk increases, then GHG emissions intensity should still be reduced, but total GHG emissions will increase. This is a plausible scenario in low- and middle-income countries and could inform other aspects of the Sustainable Development Goals (SDGs).

A partial-carbon footprint of milk production can be derived from a **GHG inventory** by summing the GHG emissions from all dairy cows, replacements heifers and breeding bulls and dividing these by the total milk produced. The key assumptions made in this study are outlined in Appendix 1. There are very significant challenges of accounting for AHIMs within current inventory reporting methods. AHIMs are not easy to account within commonly applied inventory systems; they transcend youngstock/adult profiles and are complex beyond effects on simple intake factor corrections in requiring further modifiers.

A Tier 2 inventory approach should enable delivery of this goal, but a more detailed Tier 3 approach may be required that is more country specific in some aspects, and critically facilitates describing the impacts of disease and AHIM beyond those limited by assumptions on intake. This is not a complete carbon footprint, which would also include emissions from feed production, energy use and other upstream inputs. Some allowance must also be made for the production of male calves that enter the beef systems, for example using the allocation system used by the International Dairy Federation.

Using a Tier 2 approach enables tracking change over time. This would allow further assessment of the impact of AHIMs if the key performance indicators (KPIs) such as those identified for the three conditions modelled in this study can be recorded.

Additional data requirements on health related KPIs should include commonly recorded factors such as:

- Age at 1st calving
- Calving interval (CI)
- Number of productive lactations
- Age at death
- Calf mortality rate
- Cow mortality rate
- Milk production per lactation

The original Cranfield University model was parameterised for UK conditions, including data on both cattle management and health conditions (impacts, treatments, capacity for recovery and prevalence). This applied to environmental effects (limited to GHG emissions) and costs for the ten original endemic conditions that were studied (including BVD and mastitis) in Elliot et al. (2015).

The model is a Life Cycle Assessment (LCA) using a metabolizable energy balance and not “simply” an inventory approach, which would only address direct and associated indirect GHG emissions from cattle and not feed production, managerial or veterinary interventions.

The core working of the model depend on calculating; a) the metabolizable energy requirements (MER) for maintenance, growth, gestation and lactation and, (b) the balance of cows and replacement heifers needed to maintain a herd, assuming a steady state population. Modifiers are then applied to address the effects of health on MER of factors such as milk yield, fecundity, mortality, growth rates and fighting infection. These are accompanied by estimates of the GHG emissions of veterinary and managerial interventions.

Key performance indicators (KPIs)

Key performance indicators (KPIs) for each key AHIM measure can form the basis of MRV that would facilitate the inclusion of this endemic disease GHG mitigation approach in NDCs. KPIs are described in Table 3, Table 4 and Table 5 below for each AHIM case example.

These are important in the effective inclusion of AHIM in NDCs, as the dynamics of health and fertility performance prevents an inventory approach alone being adequate, as discussed above. Additional modifiers are required in modelling the effects of AHIM based on metabolizable energy balance and these KPIs offer specific MRV parameters.

Table 3: Reproductive Performance

<table>
<tr><th>Measure (KPI)</th><th>Measure Description</th><th>Progress Indicator</th></tr>
<tr><td>Failure to Conceive Culling (FTC)</td><td>Number of cows transferred out of a herd for failure to conceive in a given period (usually 12 months) as a percentage of the total number of cows calving in the period</td><td>Reduction from 12-18% towards a target of 6% (1) (2)</td></tr>
<tr><td>Calving Interval (CI)</td><td>The amount of time (days or months) between the birth of a calf and the birth of a subsequent calf, both from the same cow. Based on Pregnancy Diagnosis (PD) and calving data</td><td>Reduction from 425 towards 365 days (1) (2)</td></tr>
<tr><th colspan="2">Verification Evidence</th><th>How Progress is Achieved</th></tr>
<tr><td colspan="2">Early Pregnancy Diagnosis (PD) by vet and farm records: PD is usually performed by veterinary surgeons manually palpating the reproductive tract of a cow. This can be augmented by use of ultrasound imaging, and battery powered systems are now readily available, although present capital investment challenges.
Verification and reporting usually includes veterinary certification although milk recording for Dairy Herd Improvement (DHI) and Farm Assurance schemes increasingly include collecting FTC and CI data.</td><td>This AHIM achieves progress by earlier identification of non-pregnant animals, which can either be re-bred or culled for beef and either way mitigate unproductive delayed re-breeding leading to prolonged stale lactations and so reduces FTC and CI.</td></tr>
<tr><td colspan="2">Evidence of use of sensors and tools for heat detection by vet certificate and inspection: Breeding of dairy cattle requires either a fertile bull or more significantly a method of predicting ovulation to facilitate artificial insemination and consequently utilise the superior genetics available on a global germplasm market. Ovulation may be predicted via the behavioural signs of oestrus in cattle, but this is challenging in both systems of high and low production as these signs are compromised in both high metabolic demand or low nutrition. Aids to ovulation prediction support improved submission rate and include tailhead fixed heatmount detectors or paint offering visual signs of oestrus, or similarly vasectomised bulls wearing chin-mark crayons but increasingly sensor systems such as those based on accelerometers are offering ovulation alerts as cows take more steps at or around oestrus.
Verification and reporting could be achieved by examination of breeding records showing that eligible animals had been bred in a target time frame.</td><td>This AHIM achieves progress by increasing the rate at which animals are bred and so reduces FTC and CI.</td></tr>
<tr><td colspan="2">Evidence of the use of fixed-time artificial insemination programmes by veterinary and prescribing records: The challenges of oestrus detection described above may be circumvented using fixed-time insemination programmes where essentially the time of ovulation is controlled artificially by programmes of hormone injections.
Verification and reporting could be achieved by examination of veterinary and farm records of both breeding and medicines use.</td><td>This AHIM achieves progress by increasing the rate at which animals are bred and so reduces FTC and CI.</td></tr>
</table>

(1) Dairy Herd Health – Editor Martin Green, Chapter 4 – 73-116.
(2) Achieving Sustainable Production of Milk – Editor Professor John Webster, Chapter 23 – 551-568

Table 4: Single Agent Infectious Disease (BVDv)

Measure (KPI)	Measure Description	Progress Indicator(s)
Number and percentage of herds with evidence of currently active circulating BVD virus	Evidenced by either positive virus test (PCR or antigen) or positive cohort antibody test controlled for vaccine in a specific year	1) Vaccine compliance by doses administered/ population at risk 2) Persistent Infection (PI) detection and removal/ population at risk 3) Biosecurity and containment status as trading records (number of high or low risk animal movements)

Verification Evidence	How Progress is Achieved
Evidence of vaccine compliance by doses administered: Vaccination to protect breeding animals against BVDv is not universally adopted or delivered. It requires specific timing and route of administration of a biologically active and temperature sensitive product. Vaccine is currently not available in Kenya and this would therefore be a critical first step in adopting this AHIM, but it is available in Chile and the UK. Verification and reporting could be achieved by examining records of vaccines administered on farm and by doses prescribed to a farm by a veterinary surgeon or pharmacist or ultimately pharmaceutical company sales.	This AHIM achieves progress by protecting breeding animals from infection through vaccination that blocks transmission of BVD virus to embryos and foetuses in utero.
Evidence of PI detection and removal by lab results and veterinary certification: Animals persistently infected (PI) with BVD are the key factor in transmission of BVD; removing them is a central pillar of eradication programmes. This requires animals to be sampled and laboratory testing (or pen-side diagnostic testing) to be performed. Verification and reporting could be achieved by examining veterinary and laboratory records.	This AHIM achieves progress by removing the source of infection from herds.
Evidence of biosecurity and containment by veterinary certification: BVDv transmission can be prevented by implementation of biosecurity and biocontainment measures such as boundary fencing or strict policies on purchased stock. Verification and reporting could be achieved by tracing animal movements and visual inspection of boundaries (for example by drone or satellite imagery).	This AHIM achieves progress by preventing the transmission of BVD infection either across the herd unit boundary or across group boundaries within a farm unit.

Table 5: Multifactorial or Management Disease (Mastitis)

Measure (KPI)	Measure Description	Progress Indicator (s)
Clinical mastitis rate as cases/100cows/year	Clinical mastitis infections are those with symptoms like udder swelling or redness that are visible to the naked eye	Clinical mastitis rate reduction from >80 to <50 cases/100cows/year
Subclinical mastitis as Somatic Cell Count (SCC) measured at bulk tank or individual cow level monthly, quarterly or at least annually.	Subclinical mastitis infections don't cause any visible changes in milk or udder appearance, making it more difficult to detect. It is measured as Somatic Cell Count (SCC) in milk samples	SCC falling from >250 000 to <200 000 for more than 10 of 12 months of the year

Verification Evidence	How Progress is Achieved
Milking teat dipping compliance by veterinary certification: Post-milking teat disinfection is a critical aspect of mastitis control, especially contagious pathogens such as staphylococcus aureus and streptococcus agalactiae but also some important environmental pathogens such as streptococcus uberis. Verification and reporting could be achieved by recording usage and purchase of dairy chemicals as well as visual observation of dipping compliance.	This AHIM achieves progress by reducing new intra-mammary infections through disinfecting teats after milking that have been contaminated with mastitis pathogens.
Dry cow therapy (DCT) compliance by veterinary certification: The dry period offers a vital opportunity to achieve cure of existing udder infections and prevention of new infections. Administration of either bismuth subnitrite teat sealants or targeted use of antimicrobials can aid prevention or enhance cure of existing infections. Verification and reporting could be achieved by recording usage of DCT products as prescribed by veterinary surgeons, pharmacists or sold by pharmaceutical companies.	This AHIM achieves progress by cure of existing intra-mammary infections at the end of lactation or by preventing new intra-mammary infections during the dry period.
Milking routine training compliance by veterinary certification: Milk harvesting procedures are an opportunity to reduce the risk of transmission of mastitis infections, for example optimising the time between first preparation of teats and attachment of milking clusters reduces the risk of teat-end damage through overmilking. Verification and reporting could be achieved by certified evidence of training of farmers.	This AHIM achieves progress by delivering optimal compliance with best practice in the milk harvesting process.

It must be recognised that a relatively high investment in recording activity data is needed in middle- and, especially, low-income countries. In recompense, these countries should be able to gain the most in productivity, production and food security, with cattle of a generally lower health status than in high income countries.

It may not yet be seen to be the highest priority for development aid, but there are strong arguments to support it along the simple ethical grounds of helping to improve the health and welfare of millions of cattle, meeting some strategic development goals (SDGs) and helping to reduce GHG intensity.

The economic benefit of AHIMs

The economic benefits for each AHIM in this study in each of the three countries have been explored and these results are shown below. The overarching message is that implementing AHIM across all countries is likely to offer highly significant return on investment at individual farm level as well as for national mitigation of GHG emissions.

Chile

Table 8: Economic Impact and Context of AHIM in Chile

Disease	KPI	Cost of Disease	AHIM	Cost of AHIM
Reproductive Performance	CI 405 days Annual culling rate (without specific reason) 9.6%. Of this 35-40% is estimated to be from reproductive causes. Overall mean values: Heat detection rate 50%, Conception rate 35%, Pregnancy rate 18% [(1)]	Cost per open day US $2-5	Early Pregnancy Diagnosis (PD) by vet and farm records	USD 2.8 (£2.18) per animal
			Use of sensors and tools for heat detection e.g. tail paint, Kamar heat detector and activity meters	Tail paint: US $6.82 – 10.91 (£8.50) Patches: US 1.59 (£1.24) /unit Sensors: USD 157 (£122) (individual sensor for heat detection, activity, rumination and health). The cost of the complete system US $4846.30 (£3800)
			Use of fixed time artificial insemination (FTAI) programmes by vet certificate and prescribing records	Fixed time insemination service: US $29.38 (£22.90) per service
Single Agent Infectious Disease; BVD	No official record. Screening/blood test (serology) – 50% of samples are positive (some herds using vaccines) 40% abortion positive BVD. There is no serological prevalence information in Chile, despite the fact that abortions are mandatory reporting to the "Agricultural and Livestock Service", this service only diagnoses causes of interest to them (Brucella sp). The information we can share is by presumptive diagnoses based on histopathological findings. In the study "Diagnosis of bovine abortion during 2009-2011" at the Institute of Animal Pathology - Universidad Austral de Chile, of 72 samples analysed, 18% corresponded to BVD + Herpes virus and 14% to BVD virus as unique agent.	National information not available yet, but there is an ongoing study. Estimated cost of abortion (Economic effect of bovine abortion syndrome in commercial dairy herds in southern Chile. P. Gadicke, 2010) expressed as the marginal total net revenue for overall parities was US $160. In case of infertility problems the average cost of the open days per cow is US $40.	Total BVD Scheme	In Denmark, a BVD scheme cost US $3.5m (£3m) /year to run but prevented US $20m (£15m) /year losses and subsequently only cost US $0.5m (£0.4m) to run annually.
			Vaccine compliance by doses administered	Two different dead vaccinations available. USD $4.65 – 5.65 (£3.62- 4.40) per animal
			PI detection and removal by lab results and veterinary certification	USD 5.68 (£4.43) ELISA by sample.
			Biosecurity and containment by veterinary certification	National information not available. The absence of an official control and eradication campaign and lack of disease knowledge do not give enough information yet, but there is an ongoing study.
Multifactorial or management disease: Mastitis	From DHI program 60% national milk production SCC 250,000 cells. Incidence Rate of Clinical mastitis = 5 -15/100 cows at risk per month (seasonal, pasture based, and confinement systems) Prevalence of intramammary infections (Subclinical mastitis) = 20-40 % of the milking herd. 2-5% mastitis incidence rate monthly for well managed Mastitis, % 9.3 n (17/183), Prevalence of postpartum diseases between 2- and 21-d postpartum [(2)]	Direct cost US $200 per case plus indirect costs	Milking teat dipping compliance by veterinary certification	Average US $3.13 (£2.44) per litre
			Dry cow therapy (DCT) compliance by veterinary certification	US $0.93 -2.78 (£0.72 -£2.17) per quarter
			Milking routine training compliance by veterinary certification	US $208–485 (£162-£378) per person.

(1) Pinedo et al. (2016)
(2) Brunner et al. (2019)

Chile Case Study - Economic Benefits of AHIM

Chile has an Agriculture and Forestry Census every 10 years (2007 was the last) which is carried out by INE (National Statistics Institute, *www.ine.cl*), and in between there are specific surveys (e.g. for dairy cattle, beef cattle or pigs) by INE or ODEPA (National Office of Agriculture, which belong to the Ministry of Agriculture, *www.odepa.gob.cl*).

Milk yield is around 6000kg/year average. However, there is not serological prevalence information in Chile. Despite the fact that abortion reporting to the "Agricultural and Livestock Service" is mandatory, this service only diagnoses specific causes of interest to them e.g. Brucella sp. Costs of BVD are also not currently estimated on a national basis.

Reproductive performance

The economic benefit of implementing AHIM that improve reproductive performance can be summarised by the reduction in calving interval (CI). If CI is reduced by 10 days in a Chilean herd then the benefit would be estimated at approximately than $20-25/cow/year in the herd, with AHIM such as PD or using heatmount detectors only costing $2-10/cow/year (*see Table 8*). This therefore represents a potential ten-fold return on AHIM investment per year, assuming consistent delivery and that the benefits of implementing AHIM are returned in a uniform manner on all farm businesses over time. On this basis, saving a single day in CI covers the cost of investing in typical reproductive performance AHIM in Chile.

Single Agent Infectious Disease: BVD

The economic benefit of implementing AHIM that improve BVD control can be summarised by the associated reduction in disease, fertility and production impacts. If BVD is prevented in a Chilean herd then the benefit would be estimated at saving more than $68/cow/year in the herd, with AHIM such as vaccination only costing $4-6/cow/year (*see Table 8*).

Specific costs of BVD in Chile are not yet fully recorded but are estimated to be similar to the UK based on comparative fertility and production costs (£2-5/day) comprising the most significant aspect of the economic impact. This therefore represents potentially more than a ten-fold return on typical AHIM investment per year, assuming consistent delivery of e.g. vaccination programmes and that the benefits of implementing AHIM are returned in a uniform manner on all farm businesses over time.

Multifactorial/Management Disease: Mastitis

The economic benefit of implementing AHIM that improve mastitis control can be summarised by the reduction in clinical case rate. If clinical mastitis is reduced in a Chilean herd then the benefit would be estimated at saving more than $200/case/cow/year. A reduction from an average of 40 to 30 cases/cow/year would therefore save more than $2000, with AHIM such as DCT only costing $4-12/cow/year (*see Table 8*). Preventing a single clinical case of mastitis in a Chilean herd potentially saves more than the cost of typical AHIM investment for 50 cows per year, assuming consistent delivery of for example drying-off programmes and that the benefits of implementing AHIM are returned in a uniform manner on all farm businesses over time.

Kenya

Table 9: Economic Impact and Context of AHIM in Kenya

Disease	KPI	Cost of Disease	AHIM	Cost of AHIM
Reproductive Performance	No National figure available. But regional data suggests: 37% of animals would be in calf at any given time (Eastern); 23% (Rift Valley) and 33% (Western). Data is from a small portion of Kenya and may be low. On average 30-40% of animals may be pregnant at any time. Calving Interval national average is 15-17 months but may be lower at 14 months.	No economic costs available.	Early Pregnancy Diagnosis (PD) by vet and farm records	About US $7-15 per cow
			Use of sensors and tools for heat detection by vet certificate and inspection	
			Use of fixed time artificial insemination (FTAI) programmes by vet certificate and prescribing records	On average US $15 per cow/ per insemination. Repeat costs will be lower
Single Agent Infectious Disease; BVD	Same research as above demonstrated prevalence (antibody serum) as: 38% East, 68% Rift Valley, 63% West. Prevalence rates are based on numbers of animals. Despite high prevalence rates no clinical signs of symptoms were shown.	No economic costs available in the public domain.	Total BVD Scheme	
			Vaccine compliance by doses administered	
			PI detection and removal by lab results and veterinary certification	
			Biosecurity and containment by veterinary certification	Fencing per acre US $1500, Foot bath US $400, Housing US $6000, Husbandry US $1200 per year.
Multifactorial or management disease; Mastitis	34% prevalence of clinical mastitis, and 65% prevalence for subclinical mastitis (Published data available). Rates are based on animals sampled. Prevalence of infected animals is estimated to vary between 5 and 75 per cent while infected quarters range from 2 to 40 per cent. This implies that loss of one quarter in 10 per cent of the producing animals would lead to a 2.5 per cent reduction in produced milk. The implication is that in a county where producers earn approximately US $56.4million annually, this translates to a loss of approximately US $1.4million annually. (1)	Costs have not been quantified.	Milking teat dipping compliance by veterinary certification	Cost of teat hygiene/dipping - approximately US $5.6 per litre
			Dry cow therapy (DCT) compliance by veterinary certification	Cost of dry cow antibiotics -approximately US $1.1 per tube (1 tube per quarter)
			Milking routine training compliance by veterinary certification	

(1) *https://www.nation.co.ke/business/seedsofgold/Avoiding-the-unending-losses-due-to-mastitis/2301238-4921804-jqqiyuz/index.html#* ***(2019)***

Kenya Case Study - Economic Benefits of AHIM

The Kenyan dairy industry is segmented into two very distinct parts:

- **Large scale farms** (which are about 20%) at 2800 litres/year on average
- **Small-scale farms** (which are about 80%) at 1700 litres/year on average

Available data is limited in both aspects of the industry, but especially so in the largely subsistence farming segment. However, 2016 survey data showed Kenya's milk prices were the second most expensive in Africa: Expatistan Cost of Living Index (2016) indicated that whole fat milk prices in Nairobi supermarkets stood at an average of approximately US $1 per litre. Official data shows that the volume of milk sold grew 10.9 per cent to 600 million litres in 2015, totalling approximately US $195million. Milk is therefore highly valued and economic benefits of AHIM in Kenya reflect this context.

Reproductive performance

The economic benefit of implementing AHIM that improve reproductive performance can be summarised by the reduction in calving interval (CI). If CI is reduced by 10 days in a Kenyan herd then the benefit would be estimated at approximately $20-25/cow/year in the herd, with AHIM such as PD or using heatmount detectors only costing $7-15/cow/year (*see Table 9*). This therefore represents a potential two-three- fold return on typical AHIM investment per year, assuming consistent delivery and that the benefits of implementing AHIM are returned in a uniform manner on all farm businesses over time. On this basis, saving only 2-3 days in CI covers the cost of reproductive performance AHIM in Kenya.

Single Agent Infectious Disease: BVD

The economic benefit of implementing AHIM that improve BVD control can generally be summarised by the associated reduction in disease, fertility and production impacts. However, these are not currently specifically quantified in Kenya; it is likely that there is much greater impact of BVD on national dairy production than is currently characterised. If BVD is prevented in a Kenyan herd then the benefit would be assumed to be biologically similar and in the context of high milk price similarly estimated at saving more than $68/cow/year in the herd. AHIM such as vaccination or specific laboratory testing and eradication are not currently available commercially, but biosecurity measures are in place in the more developed sector. These are therefore estimated as only costing around $190/cow as a one off or long-term cost (*see Table 9*).

Specific costs of BVD in Kenya are not yet recorded but are assumed to be similar to the UK based on comparative milk price and associated fertility and production costs (£2-5/day) comprising the most significant aspect of the economic impact. Subsistence farming represents a significant and unknown part of the Kenyan dairy sector and no commercial dollar price is associated with milk production here where milk is generally used for own consumption. However, overall this still represents potentially more than a ten-fold return on typical AHIM investment per year, assuming consistent delivery of for example vaccination programmes, when available and that the benefits of implementing AHIM are returned in a uniform manner on all farm businesses over time.

Multifactorial/Management Disease: Mastitis

The economic benefit of implementing AHIM that improve mastitis control can be summarised by the reduction in clinical case rate. If clinical mastitis is reduced in a Kenyan herd then the benefit would be estimated at saving more than $200/case/cow/year. A reduction from an average of 40 to 30 cases/cow/year would therefore save more than $2000, with AHIM such as DCT only costing $4/cow/year (*see Table 9*).

Preventing a single clinical case of mastitis in a Kenyan herd potentially saves around the cost of typical AHIM investment for 50 cows per year, assuming consistent delivery of for example drying-off programmes and that the benefits of implementing AHIM are returned in a uniform manner on all farm businesses over time.

United Kingdom

Table 6: Economic Impact and Context of AHIM in the UK

Disease	KPI	Cost of Disease	AHIM	Cost of AHIM
Reproductive Performance	FTC UK average 12-18% Target 6%	US $160 – 225 (£125 - £175)/cow/year	Early Pregnancy Diagnosis (PD) by veterinary/farm records	Assuming 2 PD tests per year and annual yield of 7500 l/year, the cost of ultrasound is c. US $ 2.1 (£1.60) /cow/year
			Use of sensors and tools for heat detection	Assuming 2 adhesive heatmount detectors used/cow/year, the cost is c. US $2.6 (£2) /cow/year
	CI UK average 425 days Target 365 days	US $2.6 (£2) /day for each day over target For 60 days = US $154 (£120) /cow/year	Use of fixed time artificial insemination (FTAI) programmes	Assuming 1 FTAI used/cow/year, the incremental cost is c. US $19.3 (£15) /cow/year
Single Agent Infectious Disease: BVD		US $68 (£54) /cow in Ireland. US $77m (£61m) in Ireland in total across all dairy herds (1)	Total BVD Scheme	In Denmark, a BVD scheme cost US $3.5m (£3m) /year to run but prevented US $20m (£15m) /year losses and subsequently only cost US $0.5m (£0.4m) to run annually.
			Vaccine compliance by doses administered	US $6.4 (£5)/cow/year
			PI detection and removal veterinary testing and lab results	Lab and sampling costing c. US $12.8 (£10) /cow (only required ONCE in animal lifetime)
			Biosecurity and containment	Double fencing costing c. US $19,300 (£15,000) for the average UK upland 100 cow herd (only required ONCE with some ongoing upkeep and replacement fencing costs)
Multifactorial or management disease: Mastitis		Clinical Mastitis cost per case is c. US $670 (£521) Average of c. 40 cases/100 cows/year in the UK gives a cost of c. US $25,700 (£20,000) /100 cows/year Sub clinical mastitis - various penalty or lost bonus costs of SCC elevation and estimated production impact of c. 2.5% milk production for every rise of 100 000 cells beyond 200 000 threshold	Milking teat dipping compliance by veterinary certification	Costs c. US $3800 (£3000) /100 cows/year
			Dry cow therapy (DCT) compliance by veterinary certification	Intramammary DCT costing c. US $10.3 (£8) /cow/year in the UK
			Milking routine training compliance by veterinary certification	Costing c. US $128 (£100) /milker/herd and may be repeated every 1-5 years

(1) Stott et al (2012) – costs of BVDv is an average of €63/dairy cow in Ireland (a naïve herd costs at €57/cow/year and PI herd costs at €69/cow/year). For 24,267 Irish dairy herds, 1,140,533 cows in total and averaging 47 cows/herd this gives a total cost of €71.7 million. (Exchange rate of EUR 1=£0.85 assumed)

Further work has been carried out in the UK in the form of the Marginal Abatement Cost Curve (MACC) for control of endemic disease in dairy cattle in the UK, shown in Figure 1 (Elliot et al., 2015). This model assumes a static production system for the UK. Sandars et al. (2018) showed that early pregnancy diagnosis by ultrasound reduced GHG intensity on milk production by 2.5% compared with pregnancy diagnosis by manual examination, equivalent to a benefit of 0.026 kg CO_2e/ litre milk. The costs of ultrasound and manual PD were compared with estimates from Statham (2019) and internet research.

Assuming two PD tests per year and an annual yield of 7500l/year, the incremental costs of ultrasound is £1.60/cow/year. With abatement of 2.5% this gives a cost of £8/t CO_2e for the veterinary costs but an increase in milk yield of 0.1% resulting from the earlier diagnosis of pregnancy or intervention by use of ultrasound would turn this into an overall cost benefit. If we assume that this sits in the broad region of ± £10/kg CO_2e abated, it fits into line with the costs calculated by Elliott et al. (2015) for dairy cattle (*see Table 7 and Figure 1*).

Table 7: GHG Emissions Abated and Cost Effectiveness of Mitigation Measures Applied to the UK Dairy Sector as Evaluated for the MACC by Elliott et al. (2015)

MACC reference	Measure	Quantity Abated [ktCO2e]	Cost Effectiveness [£/tCO2e]
MMCF27	MAS: Milking routine	96.0	-£158
MMCF24	MAS: Dry Cow Therapy	86.3	-£51
MMCF04	BVD: Vaccination	73.3	-£20
MMCF05	BVD: Identification of PI animal	70.5	£8
MMCF19	INF: Fixed time AI	135.3	£16
MMCF06	BVD: Double Fencing and Buying Policy	64.1	£28
MMCF18	INF: Tail paint / Kamar and Activity Meters	88.1	£106
MMCF25	MAS: Housing and milking machine maintenance	23.7	£472

United Kingdom Case Study - Economic Benefits of AHIM

Elliot et al. (2015) describe the economic benefits in more detail and this model is used as the basis for comparative AHIM case studies.

Reproductive performance

The economic benefit of implementing AHIM that improve reproductive performance can be summarised by the reduction in calving interval (CI). If CI is reduced by only 10 days in a UK herd then the benefit would be estimated at more than $25/cow/year in the herd, with AHIM such as PD or using heatmount detectors only costing $2-3/cow/year (*see Table 6*). This therefore represents a potential ten-fold return on typical AHIM investment per year, assuming consistent delivery and that the benefits of implementing AHIM are returned in a uniform manner on all farm businesses over time. On this basis, saving a single day in CI covers the cost of investing in reproductive performance AHIM in the UK.

Single Agent Infectious Disease: BVD

The economic benefit of implementing AHIM that improve BVD control can be summarised by the associated reduction in disease, fertility and production impacts. If BVD is prevented in a UK herd then the benefit has been estimated at saving more than $68/cow/year in the herd, with AHIM such as preventative vaccination only costing $2-3/cow/year (*see Table 6*). This therefore represents potentially more than a twenty-fold return on typical AHIM investment per year, assuming consistent delivery of e.g. vaccination programmes and that the benefits of implementing AHIM are returned in a uniform manner on all farm businesses over time.

Multifactorial/Management Disease: Mastitis

The economic benefit of implementing AHIM that improve mastitis control can be summarised by the reduction in clinical case rate. If clinical mastitis is reduced in a UK herd then the benefit would be estimated at saving more than $670/case/cow/year. A reduction from an average of 40 to 30 cases/cow/year would therefore save more than $6700, with AHIM such as DCT only costing $10/cow/year (*see Table 6*). Preventing a single clinical case of mastitis in a UK herd potentially saves around the cost of typical AHIM investment for 70 cows per year, assuming consistent delivery of for example drying-off programmes and that the benefits of implementing AHIM are returned in a uniform manner on all farm businesses over time.

Conclusion

Despite incomplete data being available, the evidence from this study shows very strongly that delivering AHIMs offers some clear cost benefit advantages to farmers as well as climate change benefits in all three countries studied. Proactive health management offers a clear economic benefit, as also evidenced by the negative magnitude of the columns in Figure 1 (Elliot et al., 2015). Proactive health management can contribute to reducing GHG emissions in the cattle farming sector. This study provides evidence that AHIMs associated with improving reproductive performance, controlling single agent infectious diseases such as BVD and multifactorial/management diseases such as mastitis offer reductions in GHG emissions intensity in the order of 5-40%, with some striking similarities that reach out across countries and regions across the globe.

There are very significant challenges of accounting for AHIMs within current inventory reporting methods (see Appendix 1). AHIMs are not easy to account within commonly applied inventory systems; they transcend youngstock/adult profiles and it is proposed that specific KPIs should be collected to effectively include AHIM effects. The measurement, reporting and verification (MRV) implications of different AHIMs are significant. Authenticated data will be required, and this may only really be achieved by national co-ordination of the collection of targeted key performance indicator (KPI) data to templates as discussed above, designed to most cost-effectively and robustly monitor the mitigation outcomes of different AHIMs. There are currently significant gaps in the data in many countries of the world.

This pilot study provides a stepping-stone to further, more complex studies that will enable the cattle sector to make increasingly informed management and policy decisions on a wide range of cattle health challenges in a number of different geographies and to determine where MRV can be used to supplement inventories to disaggregate the impact of policies to improve animal health.

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Acknowledgements

The authors would like to thank the following industry experts for their involvement in the Delphi panel methodology:

Kenya

- Samuel Mbuku, Kenya Agricultural & Livestock Research Organization
- Moses Olum, Kenya Agricultural & Livestock Research Organization
- Alexander Kipronoh, Kenya Agricultural & Livestock Research Organization
- Robin Mbae, Ministry of Agriculture, Livestock and Fisheries

Chile

- Natalie Jones, Consorcio Lechero
- Octavio Oltra, Consorcio Lechero
- Francisco Lanuza, Sociedad Chilena de Buiatría and Asociación Latinoamericana de Buiatría
- Francisco Salazar, Instituto de Investigaciones Agropecuarias (INIA)
- Jorge Lama, Cooprinsem
- Mario Olivares, Cooprinsem
- Luis Poo, Independent veterinary advisor
- Marco Muñoz, Universidad de Concepción
- Mario Loyola, Servicio Agrícola y Ganadero (SAG)

UK

- The XLVets group, including RCVS specialists in the UK
- Defra

This project was undertaken by:

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This work was funded by the New Zealand Ministry for Primary Industries and the Global Dairy Platform

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Appendix 1. Inventory Assumptions and Structures

The original Cranfield University model was parameterised for UK conditions, including data on both cattle management and health conditions (impacts, treatments, capacity for recovery and prevalence). This applied to environmental effects (limited to GHG emissions) and costs for the ten original endemic conditions that were studied (including BVD and mastitis).

The model is a Life Cycle Assessment one and not "simply" an inventory approach, which would only address direct and associated indirect GHG emissions from cattle and not feed production, managerial or veterinary interventions.

The enteric emissions of methane and Nitrogen excretion (leading to eventual N2O emissions) use a metabolizable energy balance to calculate dry matter intake and hence methane emissions and Nitrogen excretion. Emissions factors for Nitrogen use the Intergovernmental Panel on Climate Change (IPCC) Tier 1 factors, except for ammonia, which follows the UK approach of the Nitrogen flow model from excretion to land application.

The core working of the model depends on calculating; a) the metabolizable energy requirements (MER) for maintenance, growth, gestation and lactation and, (b) the balance of cows and replacement heifers needed to maintain a herd, assuming a steady state population. Modifiers are applied to address the effects of health on MER of factors such as milk yield, fecundity, mortality, growth rates and fighting infection. Feeds to meet MER are based on grazed grass, conserved forage and concentrates, with the proportions derived from available activity data, including feed composition. For want of better data, the manure management practices are all assumed to be the average of those modelled for the UK. The environmental of veterinary interventions were calculated from previous work in the UK and were applied in the same way in Chile and Kenya.

The available data for Chile and Kenya were less complete across all areas. Hence, the results for these are more uncertain. Those for Kenya are yet more uncertain in that the most milk production is on smallholder farms with very different management systems from those in the UK or Chile (with the approaches in Chile being recognisable from a typical European perspective).

Estimates of the effects of sub-optimal health and reproductive performance were based on a herd average and the worst performing 10%. The factor for the latter was derived from data presented in the Cattle Health and Welfare Group (CHAWG) (2018) report for the prevalence of mastitis across a large sample of herds in the UK. This was 2.3 times the median for mastitis and we assume a multiplier of two for BVD and PD.

Given these factors, we must regard the outputs as being estimates that are at least indicative for Kenya and robust for the UK. Uncertainties were not derived explicitly in this work, but we suggest these bands, based on previous work.

- **Chile** ± 30% of presented result
- **Kenya** ± 35% of presented result
- **UK** ± 25% of presented result

Table 11: Data for Chile from GHG emission modelling

Condition	Health State	GHGE, GWP100, kg CO2e	GHGE reduction to reach reference	CI, months	Productive life, lactations	Cow weight, kg	Cow Mortalities, %	Milk yield per lactation, kg FP corrected milk	Calf mortality, %	Dry matter intake, kg / lactation	Heifers needed per lactation
Mastitis	Reference	990	0%	13.1	3.5	503	3.0%	6400	4%	5670	0.33
	Average	1050	6%	13.1	3.3	503	3.0%	6300	4%	5650	0.33
	Worst 10%	1100	10%	13.1	3.0	503	3.0%	5900	4%	5620	0.34
BVD	Reference	990	0%	13.1	3.5	503	3.0%	6400	4%	5670	0.33
	Average	1000	5%	13.1	3.3	503	-0.2%	6100	4%	5630	0.33
	Worst 10%	1080	9%	13.1	3.1	503	-0.2%	5760	4%	5604	0.33
PD	Ideal target	810	0%	12.0	3.5	503	3.0%	6100	4%	5110	0.34
	Average (current)	870	7%	12.2	3.3	503	3.0%	6200	4%	5290	0.34
	Worst 10%	900	10%	12.4	3.1	503	3.0%	6200	4%	5380	0.34

Table 12: Data for Kenya from GHG emission modelling

Condition	Health State	GHGE, GWP100, kg CO2e	GHGE reduction to reach reference	CI, months	Productive life, lactations	Cow weight, kg	Cow Mortalities, %	Milk yield per lactation, kg FP corrected milk	Calf mortality, %	Dry matter intake, kg / lactation	Heifers needed per lactation
Mastitis	Reference	3100	0%	16	3.0	410	5.0%	1800	20%	3700	0.33
	Average	3300	6%	17	2.9	410	5.6%	1800	20%	3700	0.35
	Worst 10%	3500	11%	19	2.8	410	6.2%	1700	20%	3690	0.36
BVD	Reference	3100	0%	16	3.0	410	5.0%	1800	20%	3700	0.33
	Average	3200	4%	17	2.8	410	6.2%	1800	23%	3700	0.36
	Worst 10%	3400	8%	18	2.6	410	7.4%	1700	26%	3690	0.38
PD	Ideal target	2500	0%	12	4.0	410	4.8%	2000	19%	3710	0.19
	Average (current)	3100	24%	16	3.0	410	5.0%	1800	20%	3700	0.33
	Worst 10%	4500	44%	20	2.5	410	5.5%	1600	21%	4610	0.40

Table 10: Data for UK from GHG emission modelling

Condition	Health State	GHGE, GWP100, kg CO2e	GHGE reduction to reach reference	CI, months	Productive life, lactations	Cow weight, kg	Cow Mortalities, %	Milk yield per lactation, kg FP corrected milk	Calf mortality, %	Dry matter intake, kg / lactation	Heifers needed per lactation
Mastitis	Reference	1130	0%	12.7	3.8	631	2.0%	7300	4%	6820	0.27
	Average	1200	6%	13.7	3.0	631	2.8%	7100	4%	6800	0.35
	Worst 10%	1290	12%	14.7	2.7	631	3.8%	6700	4%	6760	0.39
BVD	Reference	1130	0%	12.7	3.8	631	2.0%	7300	4%	6820	0.27
	Average	1200	4%	13.1	3.7	631	3.0%	7200	10%	7010	0.28
	Worst 10%	1300	11%	13.4	3.6	631	4.0%	7100	16%	7170	0.29
PD	Ideal target	960	0%	12.0	5.0	631	1.5%	7500	4%	6520	0.23
	Average (current)	1030	7%	12.5	4.4	631	1.8%	7500	4%	6740	0.25
	Worst 10%	1130	16%	12.7	3.8	631	2.0%	7300	4%	6820	0.27