Reducing Livestock Production and Consumption as a Mitigation Strategy against Agricultural Methane and Nitrous Oxide Emissions

Abstract

Livestock are a significant source of greenhouse gas emissions in the UK, contributing to the increasing problem of global warming. Methane is emitted from enteric fermentation and both methane and nitrous oxide are emitted from the anaerobic breakdown of manure. Ruminants, especially cattle, are the primary source of emissions from agriculture. This study explores how reducing livestock production and consumption could mitigate livestock methane and direct nitrous oxide emissions, and help meet emission reduction targets in the livestock sector, of 20% set by the Kyoto protocol and 34% set by the Climate Change Act. A number of scenarios that involved reducing consumption of animal products were formulated, based on drivers, which included human health and international emission targets. The resulting emissions were calculated using the IPCC methodology and compared to a baseline of 1990. The results demonstrate cattle's large contribution to emissions with potential reductions in direct emissions of livestock of 28%, if all cattle numbers were halved. Alternative human dietary protein sources to beef were investigated and the results showed that legumes were a successful replacement with negligible effects on emissions and an overall reduction of 17%. Replacing beef with other sources of animal protein, such as poultry and pork, was found to be much less effective due to increases in nitrous oxide emissions of 28% and 2%, with an overall increase of 2% and an overall reduction of 10%, respectively. Reducing consumption of all animal products by 50%, equivalent to half the UK population becoming vegetarians, showed the largest reduction of 40% in emissions, meeting both emission reduction targets. In order for higher reduction targets set by the Climate Change Act to be met, it was calculated that animal numbers in all livestock categories needed to be decreased by at least 58% and simply decreasing cattle numbers was not enough. Although some of the scenarios would be acceptable to the public, those with the greatest effect may be unrealistic. There would therefore be a requirement for additional mitigation strategies such as improved manure management, livestock diet manipulation, switching to grassland grazing systems, and reducing waste of livestock products.

Introduction

The animal agriculture sector makes up a significant portion of all greenhouse gases emitted globally. It contributes 18% of all greenhouse gas emissions, with 12% coming directly from livestock and their manure, 60% of which is from beef and dairy cattle, and a further 6% from deforestation for grazing land (Dewhurst, 2013). Livestock production produces more greenhouse gas emissions than the whole of the transport sector, making it the leading industry contributing to pollution and global warming (Steinfield, 2006).

The FAO publication "Livestock's Long Shadow" (Steinfeld, 2006) was written to draw attention to the contribution of animal agriculture to climate change and global warming, and to reinforce the pressing need to mitigate the resulting environmental damage. Deforestation to grow feed crops and for grazing land is resulting in areas of forest that serve as important carbon sinks, such as the Amazon rainforest, to be cleared (Hecht, 1993). Animal agriculture now accounts for 70% of all agricultural land and 30% of the planet's land surface (Steinfeld, 2006). Intensification of livestock farming is increasing in an attempt to maximise yields and reduce the required land area, using methods such as increasing stocking densities and confinement indoors. Large amounts of energy are needed for heating, cooling, ventilation, increased feed production and transportation (Ilea, 2008). This type of farming produces more waste and concentrates pollution in a smaller area, as well as producing more greenhouse gases from increased inputs.

One of the most harmful aspects of animal agriculture is its contribution to two of the main greenhouse gases contributing to global warming - methane and nitrous oxide. Livestock are the most significant source of anthropogenic methane emissions, responsible for 35-40% of global methane emissions (Ilea, 2008). Methane is extremely efficient at trapping radiation from the sun, resulting in heating of the Earth's atmosphere and has a global warming potential 25 times more destructive than carbon dioxide (Brander, 2012). It is primarily released as a by-product from enteric fermentation, during the complex digestive process where carbohydrates are broken down by microorganisms in to smaller molecules in the gastrointestinal tract. Ruminants such as cattle and sheep have stomachs containing a rumen that possesses intensive microbial fermentation, benefitting them as they are able to digest tough material such as cellulose. However this means they have higher methane emissions compared to non-ruminants such as chickens (IPCC, 2006). Methane is also released from manure (dung and urine) during decomposition by bacteria under anaerobic conditions during storage and treatment. Emissions from manure are smaller than enteric emissions, most coming from confined animal management operations where manure is in a liquid based form, where a higher proportion decomposes anaerobically. When manure is handled as a solid or deposited on pastures it decomposes under more aerobic conditions and less methane is produced (IPCC, 2006)

The other main greenhouse gas associated with animal agriculture is nitrous oxide (Ji & Park, 2012). Nitrous oxide is emitted directly during the nitrification and denitrification of nitrogen by bacteria in the manure of livestock (Rees, R. et al 2014). When there is a sufficient supply of oxygen, nitrification takes place which involves the oxidation of ammonia nitrogen to nitrate nitrogen. Denitrification occurs in anaerobic conditions where nitrites and nitrates are transformed in to nitrous oxide. Indirect emissions can also occur from volatile nitrogen losses in the form of ammonia and through the addition of nitrogen fertilisers to land due to deposition and leaching (IPCC, 2006). The livestock sector emits 68% of anthropogenic nitrous oxide in the UK, which stays in the atmosphere for up to 150 years and has a global warming potential 296 times more harmful than carbon dioxide (Ilea, 2008).

A number of legislative initiatives are placing more pressure on animal agriculture to reduce greenhouse gas emissions. The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which commits its parties by setting internationally binding greenhouse gas emission reduction targets (United Nations Framework Convention on Climate Change (UNFCCC, 2014). It was adopted in 1997 and entered force in February 2005 and had a first commitment period 2008-2012 to reduce all greenhouse gas emissions by 8% from the 1990 base level. UK emissions of the basket of greenhouse gases covered by the Kyoto Protocol were an average 600.6 MtCO2e per year over the first commitment period, 23% percent lower than base year emissions. The second commitment period is from 2013-2020 with a target to reduce emissions by 20% from the 1990 base level (Department for Business, Energy & Industrial Strategy, 2017). The Climate Change Act 2008 also sets emission reductions, with a target to reduce greenhouse gas emissions in the UK by 80% by 2050 and 34% by 2020. It introduced carbon budgets that limit the total amount of greenhouse gas emissions the UK can emit over 5 year period. The first budget (2008-2012) was met with emissions 36MtCO2e below the cap of 3018MtCO2e. The UK is on track to reach the second (2013-2017) and third (2018-2022) budget however is set to be above the cap for the fourth budget (Department for Business, Energy & Industrial Strategy, 2017).

The need for mitigation strategies to be put in place to prevent the detrimental environmental impacts from greenhouse gases and meet emission reduction targets, increases constantly as the global population continues to rise (Nardone et al., 2010). The demand for food and animal products is increasing, with meat and dairy production expected to more than double by the year 2050 (Steinfeld, 2006). Many proposed mitigation strategies advocate making modifications to agricultural systems. Soussana (2009) suggests encouraging grass-fed production systems increasing carbon sinks from grazing land through improved grassland management. Composition of livestock diet and feed intake has a significant impact on levels of methane emitted. Therefore more intensive agricultural systems are associated with higher emissions, due to an increased quality of diet compared to grazing animals and imports of high protein feed (Johnson & Johnson, 1995). Manipulation of ruminant diets has also been proposed as a mitigation strategy to help reduce methane and nitrous oxide emissions; through the provision of forages with higher digestibility, increasing feed conversion efficiencies (Eckard, Grainger & de Klein, 2010). The addition of plant secondary metabolites, such as tannins and lipids, have also been shown to reduce methane (Herrero et al., 2016). Different animal waste management approaches have also been identified as a way to reduce methane and nitrous oxide emissions, by decreasing nitrogen losses. Storing slurry or manure more effectively minimizes losses due to volatilization and runoff.

A reduction in the consumption of meat and dairy products, as well as decreasing waste of livestock products, is another strategy with potential to reduce methane and nitrous oxide emissions associated with animal agriculture (Bellarby et al., 2012). Campaigns to have “meat free days” have been put forward to encourage the public to reduce their consumption of animal products and to start replacing meat in the diet with alternatives, such as plant protein (de Boer, Schösler & Aiking, 2014). Dietary greenhouse gas emissions in meat eaters have been reported to be approximately twice as high as those in vegans and 35% higher than vegetarians. Moving from a high meat diet to a vegetarian diet could reduce an individual’s carbon footprint by 1,230kgCO2e/year (Scarborough et al., 2014). If meat and dairy consumption was to be reduced, protein and other nutrients would have to be obtained from other sources. Plant based food sources such as legumes, have the potential to replace meat in the diet due to their high protein content and range of health benefits, such as low fat content, being slow to digest so provide energy for long periods, high levels of fibre and can help reduce blood cholesterol (The Andersons Centre, 2015). Legumes also require little or no nitrogen fertiliser as they use nitrogen fixation to obtain their nutrients, also adding nitrogen to the soil for following crops (Pankievicz et al., 2015). Nitrogen fixation is a process that changes nitrogen in to a useable ammonia form, to manufacture components such as amino acids. This is done by nitrogen fixing rhizobia bacteria, located in nodules on roots, and when these bacteria die, nitrogen is released in to the surrounding environment which can then be transformed in to nitrous oxide.

Cereals, such as wheat and barley, provide an excellent source of carbohydrate, fibre and protein (Williams, Grafenauer & O'Shea, 2008) and when combined with legumes, can help form part of a well-balanced diet and possible meat substitutes. However, unlike legumes, cereals need the addition of fertiliser ,also contributing to nitrous oxide emissions from agriculture. Despite greenhouse gas emissions still being emitted from crop agriculture, animal products have generally been seen have greater emissions than plant based diets (Caro, Kebreab & Mitloehner, 2016), due to inefficiencies of growing crops to feed the animals, when these crops could just be used to feed people directly.

The aims of this study are to formulate a number of scenarios involving a reduction in livestock production and consumption that could be adopted in the UK, as a mitigation strategy against agricultural methane and nitrous oxide emissions. Alternative plant based food sources are to be selected as meat and dairy substitutes, in order to still obtain enough protein in the diet. Potential reductions in methane and nitrous oxide emissions associated with the proposed dietary changes, will be calculated using the IPCC (2006) methodology. Comparisons of different scenarios will be made, to determine which are the most effective at reducing emissions, potentially meeting emission reduction targets, and which propose realistic mitigation approaches.

Methods

Scenarios were formulated according to particular driving factors and involved reductions in livestock numbers and animal product consumption. Horse numbers were not reduced in any of the scenarios as they are not associated with the consumption of livestock products in the UK. Greenhouse gas emissions and animal population data from 1990 (Baggot et al., 2004) were used as a baseline scenario to allow comparisons of outcomes from other scenarios, as this is the reference year for all emission reduction targets. Final scenarios, along with their associated percentage reductions in animal numbers are presented in Table 1. Reductions are assuming the change in numbers was from the domestic livestock sector only, excluding imports and exports.

Scenario	Scenario number	Reduction in animal numbers	Livestock category affected
1990 baseline	1	0%	N/A
NHS protein recommendation	2	25%	All
Meat free Monday	3	15%	All
Half livestock consumption & replace with legumes & cereals	4	50%	All
Half dairy consumption	5	50%	Dairy
Half beef consumption	6	50%	Beef
Half beef & dairy consumption	7	50%	Beef & Dairy
Replace beef with legumes	8	50%	Beef
Replace beef with poultry	9	50%	Beef
Replace beef with pork	10	50%	Beef
Kyoto protocol all livestock	11	25%	All
Kyoto protocol beef	12	60%	Beef
Kyoto protocol dairy	13	82%	Dairy
Kyoto protocol all cattle	14	35%	Beef & Dairy
Climate Change Act all livestock	15	58%	All
Waste	16	17%	All

Table 1: Scenarios formulated as mitigation strategies against livestock methane and nitrous oxide emissions, allocated scenario numbers, the percentage reductions in animal numbers and the livestock category affected.

Human health concerns were the main driving factor for scenarios 2, 3 and 4. Scenario 2 consisted of reducing the average human protein intake from the current 66g person/day (Department for Environment, Food & Rural Affairs, 2016), to the NHS recommended intake of 50g (NHS, 2014); therefore reducing animal numbers in all categories by 25% (scenario 2). The recommendation of one meat free day per week suggested by de Boer (2014), as a step towards reducing emissions from livestock production and also advocated for health reasons by Friel (2009), formed the basis of scenario 3 a "meat-free Monday" could be adopted, with the assumption that meat is not eaten one day a week by the whole UK population. Another scenario involving reducing demand for animal products, with the assumption that 50% of the UK population became vegetarians, therefore reducing livestock numbers in all categories by 50% (scenario 4). This scenario involved replacing meat protein that would be lost from reduced consumption with a combination of peas (15%), beans (15%), wheat (10%) and barley (10%) to make up to 50% lost meat protein. Legumes and cereals were chosen due to their variety of health benefits and high protein contents (The Andersons Centre, 2015). The average daily intake of animal protein per person/day, 40g (Department for Environment, Food & Rural Affairs (DEFRA), 2016) was used to calculate the amount of meat protein that would be lost, and the protein contents of peas (5%), beans (8%), wheat (15%) and barley (12%) (USDA, 2017) were used to calculate the crop biomass needed to replace it. Yields per hectare (The Andersons Centre, 2015) were used to calculate the extra area of agricultural land needed in order to produce this protein. Fertiliser use per hectare (The British Survey of Fertiliser Practice, 2016) determined the additional fertiliser needed for cereals.

A significant driving factor behind a number of scenarios was to target just cattle (scenario 5, 6 and 7), because of their high contribution to livestock methane and nitrous oxide emissions due to their ruminant digestion and large populations (IPCC, 2006). Cattle numbers in the relevant category were reduced by 50% in these scenarios to compare the potential to reduce methane and nitrous oxide emissions between beef (scenario 6), dairy (scenario 5) and all cattle (scenario 7). In reality, at least some of this reduction in cattle – derived protein would be met by a shift in diet towards other sources of protein. Scenarios 8-10 were formulated to explore the effects on emissions of replacing 50% of beef protein with plant based food sources (scenario 8), poultry (scenario 9) or pigs (scenario 10). Peas (25%) and beans (25%) were used, as only a relatively small proportion of protein needed to be replaced and no fertiliser would need to be applied. Beef production in the UK (DEFRA, 2016), and protein contents (USDA, 2017) were used to calculate the proportion of the average daily intake of animal protein (Department for Environment, Food & Rural Affairs, 2016) that came from beef; to determine the amount that would be lost and to determine the required increase in production of peas and beans. Protein from poultry was chosen as a replacement to beef, as they are non-ruminants with the lowest emission factors per head (Table 2). Pork was also chosen as a replacement due to pig's' relatively low emission factors as they are pseudo-ruminants. The number of extra pig or poultry individuals that would be needed to obtain the same amount of meat protein was calculated using average dressed carcass weights (DEFRA, 2016), and protein contents (USDA 2017) for each animal.

Compliance with greenhouse gas emission reduction targets of 20% by 2020 set by the Kyoto Protocol (UNFCCC, 2014) and 34% by 2020 set by the Climate Change Act (Department for Business, Energy & Industrial Strategy, 2017) were the drivers for scenarios 11-15. These scenarios were assuming that all other sectors also reduced their emissions – effectively reducing all greenhouse gas emissions in the UK to meet the reduction targets. It was calculated that in order to meet the Kyoto protocol reduction target from the livestock sector, by manipulating all livestock categories, animal numbers would need to be reduced by 25% (scenario 11). Other scenarios targeted only cattle (scenario 12, 13, 14), to determine whether the target for the livestock sector could be met if just cattle numbers were decreased. It was calculated that beef cattle numbers would need to be reduced by 60, dairy cattle numbers would need to be reduced by 82% and all cattle numbers would need to be reduced by 35%. Similarly, it was calculated that all animal numbers in all categories would need to be reduced 58% in order to meet the reduction target set by the Climate Change Act (scenario 15). Unlike the Kyoto Protocol scenarios, it was calculated that emissions could not be reduced to meet the target by only reducing beef, dairy or both.

The final scenario was based upon reducing the amount of food waste in the UK. Animal products were found to have a waste rate of 14% (WRAP 2009) in the UK in relation to the amount of food supplied. Therefore it was calculated that if waste of animal products was eliminated, animal numbers in all livestock categories could be reduced by 17% (scenario 16).

The IPCC methodology (IPCC 2006) was used to estimate potential reductions in methane emissions from enteric fermentation in livestock and methane and nitrous oxide emissions from manure waste management. In order to estimate enteric methane emissions, livestock populations (Baggot et al., 2014) are divided in to subgroups with different emission factors for each subgroup (Table 2). Subgroup emission factors are multiplied by populations to estimate total subgroup emissions. Emission factors for different livestock categories vary due to feed intake, feed characteristic assumptions, animal size and population structure. A Tier 1 methodology is sufficient for most animal species in most countries, however Tier 2 is used for dairy cattle in the UK, as more detail such as feed intake and further characterization is required. This is due to their varying productivity and enteric fermentation being a key source of emissions, representing a large portion of the UK's total emissions. Estimating methane emissions from manure management requires livestock population data by animal species/category (Baggot et al., 2014) and climate region or temperature, in combination with IPCC default emission factors (Table 2).

Table 2: Methane emission factors for livestock categories

Livestock category	Enteric methane kg/CH4/head/year	Methane from manures kg/CH4/head/year
Dairy(1)	88	22
Beef(2)	48	2.74
Others >1	48	6
Others < 1	32.8	2.96
Pigs	1.5	3
Breeding sheep	8	0.19
Other sheep	8	0.19
Lambs <1 year	3.2	0.076
Goats	5	0.12
Horses(3)	18	1.4
Poultry	NE	0.078
Deer: Stags & Hinds	10.4	0.26
Deer: Calves	5.2	0.13

(1) Dairy cattle emission factors obtained from Baggot et al (2004)
(2) All other livestock categories emission factors obtained from IPCC (2006)
(3) Horse numbers were not decreased in any scenarios as they are not associated with the consumption of livestock products in the UK

Direct nitrous oxide emissions from manure management are also calculated with the IPCC methodology (IPCC 2006), using emissions factors and total amount of nitrogen excretion from livestock categories in each type of manure management system. Baseline figures for direct N2O emissions from the livestock sector were taken from Baggot et al (2004). Indirect nitrous oxide emissions were not calculated in this study. Nitrous oxide emissions from nitrogen fixation in legumes was also calculated with the IPCC methodology, using emissions factors, crop biomass, dry matter and nitrogen content. Emissions from fertiliser applied to cereal crops was also calculated with emission factors, the extra area needed to grow the crops and the amount of fertiliser applied per hectare. In scenarios that involved the replacement of meat protein with plant based food sources, these increases in emissions, together with the changes in N2O emissions from livestock, were used to calculate the overall emission change of the scenario.

Emission reductions from 1990 agricultural livestock emissions were analysed and emission savings were calculated for each scenario. Total UK emissions of both methane and nitrous oxide in 1990 (Department for Business, Energy & Industrial Strategy, 2017) were obtained and the contributions of both gases from agriculture, to total emissions were also calculated; to determine if there were any significant impacts. The implications for each scenario were examined and compared, to determine the most effective, and scenarios that met emission reduction targets were identified.

Results and Discussion

For the baseline 1990 scenario (Table 3) beef and dairy cattle have the highest methane and nitrous emissions of all animal categories, with methane emissions from beef cattle of

10.8MtCO2e and 3.1MtCO2e of nitrous oxide and methane emissions from dairy cattle of 7.8MtCO2e and 2.3MtCO2e of nitrous oxide. It can also be seen that sheep have a relatively large contribution to livestock methane and nitrous oxide emissions and goats, horses and deer have the lowest emissions. Poultry and pigs also have relatively low methane and nitrous oxide emissions with total emissions of 0.9MtCO2e and 1.5MtCO2e, respectively. It was found that methane from animal agriculture contributes to nearly all methane emissions from agriculture, whereas direct nitrous oxide from animal agriculture contributes a much smaller portion.

Table 3: Methane and nitrous oxide emissions for categories of livestock, all animals and all agriculture in 1990

Category	CH4 emissions 1990 (MtCO2e)	N2O emissions 1990 (MtCO2e)(1)	Total
Dairy	7.8	2.3	10.1
Beef	10.8	3.1	13.9
All cattle	18.6	5.4	24.0
Pigs	0.8	0.7	1.5
Sheep	5.3	2.2	7.5
Goats	0.01	0.0	0.0
Horses	0.1	0.1	0.2
Poultry	0.3	0.6	0.9
Deer	0.01	0.0	0.0
All animals	25.2	9.0	34.2
All agriculture	25.4	17.7	43.1

(1) From Baggot et al (2004)

It can be seen in Table 4 and Fig 1 that in all scenarios, direct livestock methane emissions have a more significant reduction and savings in emissions, from 1990 baseline emissions, than nitrous oxide.

Table 4: Methane and nitrous oxide emissions for each scenario and percentage reductions from 1990 baseline direct emissions in the livestock sector of agriculture.

Scenario number	CH4 emissions MtCO2e	N2O emissions MtCO2e	Total	Reduction in CH4 emissions	Reduction in N2O emissions	Total reduction
1	25.4	17.1	43.1	0%	0%	0%
2	18.9	15.4	34.3	25%	13%	20%
3	21.3	16.1	37.4	16%	9%	13%
4	12.6	13.2	25.8	50%	25%	40%
5	21.2	16.3	37.5	17%	5%	13%
6	19.8	16.1	35.9	22%	6%	16%
7	15.9	15	30.9	37%	12%	28%
8	19.8	16.1	35.9	22%	6%	17%
9	22.2	21.9	44.1	13%	-28%	-2%
10	21.3	17.4	38.7	16%	-2%	10%
11	19	15.4	34.4	25%	10%	20%
12	18.7	15.8	34.5	26%	8%	20%

13	18.7	15.8	34.5	26%	8%	20%
14	18.7	15.8	34.5	26%	8%	20%
15	14.6	13.8	28.4	43%	19%	34%
16	21	16	37	17%	6%	14%

Table 4: scenario 1: 1990 baseline, scenario 2: NHS recommendation, scenario 3: meat free Monday, scenario 4: half livestock consumption and replace with cereals & legumes, scenario 5: half dairy consumption, scenario 6: half beef consumption, scenario 7: half beef and dairy consumption, scenario 8: replace beef with legumes, scenario 9: replace beef with poultry, scenario 10: replace beef with pork, scenario 11: Kyoto protocol all livestock, scenario 12: Kyoto protocol beef, scenario 13: Kyoto protocol dairy, scenario 14: Kyoto protocol all cattle, scenario 15: climate change act all livestock, scenario 16: waste

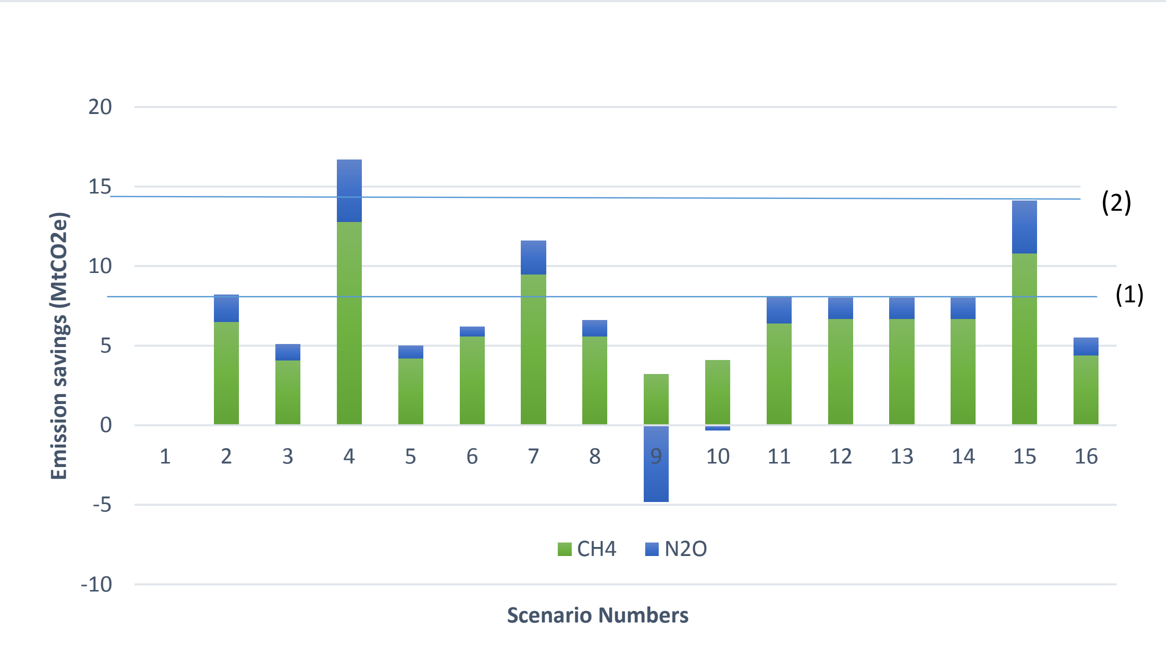

Fig 1: Combined methane and nitrous oxide emission savings for scenarios with Kyoto protocol target (1) and Climate Change Act target (2)

Scenario 1: 1990 baseline, scenario 2: NHS recommendation, scenario 3: meat free Monday, scenario 4: half livestock consumption and replace with cereals & legumes, scenario 5: half dairy consumption, scenario 6: half beef consumption, scenario 7: half beef and dairy consumption, scenario 8: replace beef with legumes, scenario 9: replace beef with poultry, scenario 10: replace beef with pork, scenario 11: Kyoto protocol all livestock, scenario 12: Kyoto protocol beef, scenario 13: Kyoto protocol dairy, scenario 14: Kyoto protocol all cattle, scenario 15: climate change act all livestock, scenario 16: waste

When protein intake is reduced by 25% to the NHS recommended intake (scenario 2), there is a total reduction in emissions of 20%, therefore meeting the emission reduction target set by the Kyoto protocol, however not meeting the Climate Change Act target. It can be seen that a “meat free Monday” (scenario 3) only has a 13% reduction in total agricultural emissions and reducing emissions from wasted livestock products by 14%, meets neither emission reduction targets.

The largest reductions in both methane and nitrous oxide emissions is demonstrated in Table 4 and Fig 1, when animal product consumption was halved and replaced with legumes and cereals (scenario 4), if half the UK population became vegetarians. There was a total reduction in agricultural emissions of 40% with a total saving in emissions of 16.7MtCO2e, complying with both emission reduction targets. Methane emissions were reduced 50%, however nitrous oxide emissions only reduced by 25%. Additional nitrous oxide emissions from nitrogen fixation in legumes and fertiliser applied to cereals can be seen in Table 5. An increase of 0.91MtCO2e was found to be insignificant in comparison to livestock emission reductions. Emissions from fertiliser application to cereals were found to be higher than from nitrogen fixation in legumes.

Table 5: Nitrous oxide emissions from fertiliser application and nitrogen fixation, percentage increases in agricultural nitrous oxide emissions and percentage decreases in livestock emissions, for different scenarios.

Scenario number	N2O from fertiliser (MtCO2e)	N2O from N fixation (MtCO2e)	Total N2O	% increase in N2O	% decrease in livestock emissions
4	0.54	0.37	0.91	1.54	40
8	0	0.09	0.09	0.15	17

Table 5: scenario 4: half consumption and replace with legumes & cereals, scenario 8: replace beef with legumes

If beef and dairy consumption were reduced by the same proportion (scenario 5 and 6), it can be seen in Fig 1 and Table 4, that reducing beef cattle numbers has a stronger potential to mitigate emissions from agriculture, with a 16% reduction and savings in emissions of 6.2MtCO2e, compared to a 13% reduction and savings in emissions of 5MtCO2e for dairy cattle. However neither of these scenarios meet the emission reduction targets. Decreasing both beef and dairy consumption (scenario 7) shows a more considerable decrease of 28% and savings in emissions of 11.6, exceeding the Kyoto protocol target of 20% although not meeting the Climate Change Act target. Methane emissions show a noticeably larger reduction of 37% compared to only a 12% reduction in nitrous oxide emissions.

In the beef replacement scenarios (Table 4 and Fig 1), poultry was found to be the worst alternative to beef (scenario 9) and there was in fact a 2% increase of 1.6MtCO2e in total emissions from agriculture, with a significantly large increase in nitrous oxide emissions of 28%. Methane emissions were still found to have a decrease of 13%. Comparably, when beef is replaced with pork (scenario 10), there is a reduction of 10% in total emissions with savings of 3.8MtCO2e. Although there is an overall reduction in emissions, replacing beef with pork still increases nitrous oxide emissions by 2%, but decreases methane emissions by 16%. Legumes were found to be the best alternative to beef (scenario 8), with the greatest reduction in emissions of 16% with savings of 6.6MtCO2e, although still meeting neither of the emission reduction targets. Nitrous oxide emissions from nitrogen fixation in legumes had an insignificant increase of less than 1% as shown in Table 5, therefore had a negligible effect.

It was calculated that in order to meet the Kyoto protocol reduction target from the livestock sector, animal numbers in all livestock categories would need to be reduced by 25% (scenario 11), therefore reducing methane emissions by 25% and nitrous oxide emissions by 10% to give an overall reduction of 20% and savings in emissions of 8.1MtCO2e, as shown in Table 4 and Fig 1. It was also calculated that beef cattle numbers would need to be reduced by 60% (scenario 12), dairy cattle numbers would need to be reduced by 82% (scenario 13) and all cattle numbers would need to be reduced by 35% (scenario 14), resulting in a 26% reduction in methane emissions and an 8% reduction in nitrous oxide emissions. Similarly, it was calculated that animal numbers in all livestock categories would need to be reduced 58% in order to meet the reduction target set by the Climate Change Act (scenario 15), resulting in a 43% decrease in methane emissions and a smaller 19% decrease in nitrous oxide emissions to give an overall reduction of 34% and savings in emissions of 14.1MtCO2e. Unlike the Kyoto Protocol scenarios, it was calculated that emissions could not be reduced to meet the target by only reducing beef, dairy or both.

Total UK emissions of both methane and nitrous oxide in 1990, and the contributions to total emissions of both gases from agriculture is presented in Table 6. Methane released from agriculture was found to contribute 18.84% of total UK methane emissions and direct nitrous oxide was found to have a larger contribution of 33.40% of total UK direct nitrous oxide emissions.

Table 6: Agricultural methane and nitrous oxide as a proportion of total UK emissions

Scenario number	Proportion of all UK CH4 emissions	Proportion of all UK N2O emissions
1	18.84%	33.40%
2	14.02%	30.08%
3	15.80%	31.45%
4	9.35%	25.78%
5	15.73%	31.84%
6	14.69%	32.23%
7	11.80%	29.30%
8	14.69%	31.45%
9	16.47%	42.77%
10	15.80%	33.98%
11	14.09%	30.08%
12	13.87%	30.86%
13	13.87%	30.66%
14	13.87%	30.86%
15	10.83%	26.95%
16	15.58%	31.25%

Table 6: scenario 1: 1990 baseline, scenario 2: NHS recommendation, scenario 3: meat free Monday, scenario 4: half consumption and replace with cereals & legumes, scenario 5: half dairy consumption, scenario 6: half beef consumption, scenario 7: half beef and dairy consumption, scenario 8: replace beef with legumes, scenario 9: replace beef with poultry, scenario 10: replace beef with pork, scenario 11: Kyoto protocol all livestock, scenario 12: Kyoto protocol beef, scenario 13: Kyoto protocol dairy, scenario 14: Kyoto protocol all cattle, scenario 15: climate change act all livestock, scenario 16: waste

When consumption of animal products was halved (scenario 4), the contribution of agricultural methane emissions was significantly reduced to 9.35% whereas nitrous oxide emissions only decreased to 25.78%. Reduced beef consumption and replacement with poultry (scenario 9) shows a small decrease to 14.69% in agricultural contribution to methane emissions however nitrous oxide emissions increase to 42.77%. Replacement of beef with pork (scenario 10) shows a slightly smaller decrease in methane to 15.8%, however still also shows a very small increase in nitrous oxide emissions to 33.98%. Legume replacement (scenario 8) indicates a larger decrease in contributions of agricultural methane and nitrous oxide emissions. Reducing both beef and dairy cattle consumption (scenario 7) and reducing all animal numbers in order to meet the emission reduction target of the Climate Change Act (scenario 15), also shows significant decreases in the proportion of both agricultural methane and nitrous oxide from agriculture.

All scenarios, except scenario 9, showed an overall reduction in emissions. Methane emission reductions in all scenarios were considerably greater than nitrous oxide reductions, as enteric fermentation in ruminants and anaerobic animal waste processing are the principle sources of methane from agriculture contributing to 98% of all methane emissions from agriculture (Baggot et al). A small portion of the remaining agricultural methane emissions come from biomass burning (Cole et al., 1997). Whereas nitrous oxide emissions come from many sources in agriculture, with a large portion (Baggot et al., 2004) coming from the application of synthetic nitrogen fertiliser to crops, as well as small amounts from nitrogen fixation. Indirect emissions from nitrous oxide were not calculated in this study but nitrous oxide emissions also come from leaching and run off of fertilisers and manure applied to and deposited on agricultural lands, in to nearby water bodies and soils, and from ammonia volatilization. Nitrates from these sources are eventually denitrified and transformed in to nitrogen and nitrous oxide (Mosier et al., 1998). Direct nitrous oxide emissions from the livestock sector only make up 50% of overall direct nitrous oxide emissions from agriculture (Baggot et al., 2014), therefore methane reductions are greater when animal numbers are manipulated. This was reflected in the findings of this study: if consumption and production of animal products was reduced, the contribution of agricultural methane emissions to total UK methane emissions could be significantly decreased (as demonstrated in scenario 4), compared to a less significant decrease in the contribution of agricultural nitrous oxide emissions.

It has been previously proposed that reducing meat consumption and replacement with plant proteins, is key to achieving sustainable agriculture and food security, mitigating the harmful environmental effects from greenhouse gases (de Boer, Schösler & Aiking, 2014). A number of scenarios (2, 4, 6, 7, 8, 11, 12, 13, 14 and 15) in this study show that reducing meat and dairy consumption has the potential to significantly decrease methane and, to a lesser extent, nitrous oxide emissions from agriculture. Bellarby et al (2012) note that a reduction in consumption would need to be linked to production, resulting in a decrease in livestock numbers and a reduction agricultural greenhouse gas emissions. This was the approach that was adopted in this study. However, it has been demonstrated that reducing meat consumption would not necessarily result in equal changes in production (Wolf *et al.,* 2010) due to an increase in exports. If production was decreased without consumption reducing at the same time, this would encourage an increase in imports with potentially more greenhouse gases being emitted. It is therefore key that both consumption and production go hand in hand in order to decrease greenhouse gas emissions.

Inherently, a major problem associated with meat consumption is the low efficiency of converting feed crops in to meat protein to be consumed by humans. It has been reported that 80-96% of all protein in cereal and leguminous grains fed to animals are wasted and not converted in to edible protein (Smil, 2002), whereas land required to grow these feed crops could therefore be used to grow crops to feed directly to humans, with little or no harmful effects as demonstrated in this study. Halving the consumption of animal products (scenario 4) demonstrated the potential for the livestock sector to meet both emission reduction targets set by the Kyoto protocol and the Climate Change Act. Replacing meat protein in the diet with plant protein, such as legumes and cereals, still resulted in considerable reductions in emissions. Therefore this reinforces the potential for a change in human diet to a more plant based diet, to be adopted as a justifiable mitigation strategy against agricultural greenhouse gas emissions. There is strong evidence for the potential of nitrogen fixing legumes, such as peas and beans, to replace meat protein, due to their extremely small contribution to nitrous oxide emissions (scenario 4 and 8), as well as a lack of fertiliser induced emissions. These scenarios represent the equivalent UK dietary change of half the population becoming vegetarian. A switch from the UK-average diet, to a vegetarian or vegan diet was estimated to result in potential greenhouse gas savings of 22% and 26%, respectively (Berners-Lee et al., 2012).

It is recognised that meat protein consumption in the UK and other developed countries is much higher than necessary for human health, therefore a reduction in animal product consumption would also have major health benefits as well as environmental. Animal products are major sources of saturated fats, which are extremely detrimental on human health if consumed in large quantities (Friel et al., 2009). There is a strong positive association with the consumption of meat (especially red meat and processed meat) and the risk of developing a range of chronic diseases, such as colorectal cancer, cardiovascular disease, and type 2 diabetes (Van Hecke, Van Camp & De Smet, 2017). As protein in takes in the UK are currently higher than the recommended intake by the NHS (NHS, 2014) therefore there is the potential to reduce consumption without negative health impacts. Simply reducing consumption of animal protein in the UK to the NHS recommended amount (scenario 2) demonstrated strong mitigation potential against livestock greenhouse gases with a total reduction of 20% in methane and nitrous oxide emissions with total savings of 8.2MtCO2e, meeting the emission reduction target set by the Kyoto protocol for the livestock sector.

Several non-governmental organisations (NGO's) have promoted campaigns for "meat less days" as a way of reducing the consumption of livestock products and encouraging people to find alternative protein sources and change their dietary behaviours (de Boer, Schösler & Aiking, 2014). The same approach was used in this study with a meat – free Monday scenario (scenario 3), which demonstrated how simply not eating meat one day a week can help reduce livestock greenhouse gas emissions, with the possibility of progressing to more days a week not eating meat, which would show further reductions in emissions. Laestadius et al (2013) found the public more likely to reduce their meat consumption, without the pressure of totally eliminating meat from the diet and if they were better educated on the impacts of meat consumption. The scenario of a meat – free Monday (scenario 3), and a 50% reduction in livestock consumption (scenario 4) is therefore more feasible as a mitigation strategy than the vegetarianism advocated by Berners-Lee et al (2012).

Beef and dairy cattle make the greatest contribution to livestock greenhouse gas emissions due to their ruminant digestion and high emissions per unit of meat producing between 64% and 78% of emissions (Bellarby et al., 2012). Herrero et al (2016) estimated cattle to contribute to 46 $MtCO_2e$ a year globally, with 25$MtCO_2e$ from beef and 2.1$MtCO_2e$ from dairy (Herrero et al., 2016). Consuming less beef and dairy products and using less agricultural land, allowing regrowth of natural vegetation has been projected to possibly reduce this to 33$MtCO_2e$, with substantial benefits of spare land for other uses and afforestation (Soussana et al 2010). It is apparent that targeting the beef and dairy sector for has strong greenhouse gas mitigation potential therefore a number of the scenarios in this study focus on the reduction of cattle (scenarios 5-10). It can be seen that beef cattle have a higher reduction potential in total emissions (scenario 6) than dairy cattle (scenario 5) due to their larger populations, despite dairy cattle having much higher emission factors based on a Tier 2 approach (Baggot et al., 2014). However, neither of these scenarios meet the emission reduction targets set by the Kyoto protocol and the Climate Change Act. It was found there would be a much more significant decrease in emissions if both dairy and beef consumption were reduced with a 28% reduction in total emissions and savings of 11.6$MtCO_2e$, meeting the emission reduction target of 20% set by the Kyoto protocol.

Replacing beef with other protein sources would necessitate a change in land use since e.g. 212,228 hectares of land would be required to grow enough legumes to replace the protein not obtained from beef. This should not contribute to environmental impacts of agriculture such as deforestation for land to grow crops because a reduction in the farming of beef cattle would result in spare land from where pastures are no longer needed for grazing, therefore providing land that can either be used to grow crops if it is productive enough, or afforestation and regeneration of natural habitats (Bellarby et al,. 2012). Nitrous oxide emissions from fertiliser applied to grassland land was not taken in to account in this study, but produces large quantities of indirect nitrous oxide through the conversion of ammonia, leeching and runoff. Therefore a reduction in beef and dairy farming would also result in less fertiliser induced nitrous oxide emissions applied to their grazing lands. Unexpectedly poultry was found to be the worst alternative to beef of the scenarios, despite being non-ruminants and having methane enteric emission factors of 0 and waste emission factors of only 0.078 kg/CH_4/head/year (IPCC, 2006). Direct nitrous oxide emissions from livestock increased by 28% due to the number of extra individuals that would be needed to replace the same amount of beef protein, each with nitrous oxide emissions of 0.02kg per/head. Such a large increase in poultry numbers would produce 21kt of waste that can then be decomposed and denitrified. Although replacing beef with protein from pork gave an overall reduction of 10% with savings in emissions of 3.8$MtCO_2e$, nitrous oxide emissions were also increased by a smaller 2%. Similarly, this is due to the extra number of pigs needed to obtain the same amount of protein and the amount of extra waste that would be produced. Although pigs have a larger nitrous oxide emission per head than poultry (0.3kg/N_2O/head/year)g and higher methane emission factors of 1.5kg/CH_4/head/year for enteric emissions and 3kg/CH4/head/year for waste (IPCC, 2006), fewer individuals are needed as one pig produces more meat per kg.

The contribution of beef and dairy cattle to greenhouse gas emissions from agriculture, can also be seen in the scenarios that involve reducing emissions to meet the emission reduction target of 20% set by the Kyoto protocol (scenario 11, 12, 13). This target can be met within the livestock sector by simply reducing overall cattle numbers by 35%, a relatively small decrease and if it was to be met by reducing animal numbers across all livestock categories the reduction would be a smaller 25%. In order to meet the target by changes to the dairy category alone, numbers would have to be reduced by 82%, a less realistic scenario for a mitigation strategy as it is unlikely consumption of dairy products would be reduced by that amount. Similarly, although not as high, beef cattle numbers would need to be reduced by 60%. Again this is an unrealistic scenario as it is unlikely beef consumption would be reduced by that proportion. Therefore it can be seen it is more effective to reduce both cattle numbers as they don't need to be reduced by such a high amount, a more realistic scenario that could potentially be adopted as a mitigation strategy against greenhouse gases from agriculture. Comparably, the higher emission reduction target of 34% set by the Climate Change Act, cannot be met by only reducing cattle numbers. If this target was to be met in agriculture by reducing animal numbers, all animals across all livestock categories would need to be decreased by at least 58%. This is a relatively high and unrealistic reduction in livestock production therefore indicating that if higher emission reduction targets are to be met, other mitigation strategies will need to be put in place as well as reducing livestock production and consumption. Friel et al (2009) identified that a combination of agricultural technological improvements as well as a 30% reduction in livestock production would mean this target would be met (Friel et al., 2009), a larger reduction than predicted in this study. Scenario 16 demonstrates how much emissions could potentially be reduced from reducing food waste and when done in combination with reducing production, could provide significant savings on greenhouse gas emissions and possibly meet reduction targets.

Although reducing consumption and production of livestock products shows potential decreases in greenhouse gas emissions from agriculture, most scenarios in this study involve a relatively substantial reduction in consumption and production, perhaps an unrealistic proposal. However, they could be used in conjunction with other mitigation strategies in order to meet emission reduction targets. Soussana et al (2010) proposes raising animals on grasslands which has the advantage of acting as a carbon sink. However grassland production systems have lower feed conversion efficiencies therefore could potentially produce more greenhouse gases per unit of meat due to a slower growth rate (Bellarby,. 2013). Eckard (2010) proposes dietary manipulation and improving forage quality of livestock as a mitigation strategy against emissions. The addition of plant secondary compounds such as condensed tannins, plant saponins and salt supplements can also potentially reduce methane emissions (Beauchemin et al., 2007) and balancing the protein to energy ratios in the diets of ruminants is important for minimizing nitrous oxide emissions (Misselbrook et al., 2005). Greenhouse gas emissions from agriculture can also be mitigated through various animal waste management systems such as: Composting of manure, anaerobic digestion of waste, compacting and covering (Herrero et al., 2016).

There were a number of limitations encountered in this study, one main problem being that only direct nitrous oxide emissions from livestock were taken in to account. Indirect nitrous oxide emissions contribute to a significant proportion of agricultural emissions (Mosier et al., 1998), therefore predicted reductions in nitrous oxide emissions from manipulating livestock numbers could potentially be reduced further. This also applies to fertiliser applied to grasslands lands which was not taken in to account and again contributes a relatively large proportion of indirect nitrous oxide emissions (Baggot et al., 2014), which would be significantly decreased if cattle production was reduced. Therefore, if this study was to be furthered to achieve more detailed and accurate results, the effect of reducing consumption and production on indirect nitrous oxide emissions from agriculture could also be measured and analysed. This study also assumes that consumption is directly linked to production which is not necessarily true (Wolf *et al.,* 2010). Therefore imports and exports have not been taken in to account which could also affect potential reductions or increases in greenhouse gas emissions from agriculture. Many scenarios propose a high and possibly unrealistic reduction in livestock product consumption and production and were done on the basis of analysing the potential of reducing consumption and production as a mitigation strategy.

Future work could possibly examine the difference in emissions between livestock production systems as possible differences between these wasn't investigated. This could to determine which system produces the highest emissions and therefore, which system has the highest potential to reduce emissions, if production and consumption was decreased. Because beef cattle were found to be the main source of methane and nitrous oxide emissions from agriculture in the UK, they therefore warrant a Tier 2 approach to determine more accurate estimates on how they contribute to emissions (IPCC, 2006). Although it has been demonstrated in this study that reducing livestock production can help mitigate the harmful effects from methane and nitrous oxide emissions, some scenarios propose a high and possibly unrealistic reduction in livestock product consumption and production. However, the public could be encouraged to significantly reduce their consumption of livestock products through more campaigns such as a "meat free Monday" and through better education on the harmful impacts of animal agriculture, so more informed choices can be made. It has been found in one study that the main motivations for vegetarianism were health benefits (Fox & Ward, 2008). These benefits could be promoted further and healthier alternatives, such as plant based food sources, could be offered. However, it is apparent that other mitigation strategies are likely to be needed as well as a reduction in consumption and production, if emissions are to be significantly decreased from agriculture, and to meet emission reduction targets set by legislative initiatives, such as the Kyoto protocol and Climate Change Act.

Conclusion

It can be concluded that a reduction in consumption and production of cattle, of all the livestock categories, has the highest mitigation potential against agricultural methane and nitrous oxide emissions. Beef cattle have been proven to have higher overall emissions than dairy cattle due to their larger populations, therefore show the most significant reduction in emissions as their numbers are reduced by a greater amount. In scenarios that investigated the best alternative source of protein to beef, it was found that replacing with other animal sources, such as pork and poultry, was not as effective at mitigating emissions as using plant based food sources. Pork replacement gave an emission reduction of 10% and poultry an increase of 2%, whereas legumes gave a reduction of 17% and the increase in nitrous oxide emissions from nitrogen fixation was found to be negligible. Similarly, cereals were also found to be good alternatives to animal protein, as fertiliser induced nitrous oxide emissions only increased 1.5% compared to an overall reduction of 40%. However, none of these scenarios met the emission reduction target within the direct livestock sector of 20% set by the Kyoto protocol, therefore cattle numbers needed to be reduced further if these targets were to be met. It was found that the reduction target of 34% set by the Climate Change Act was not possible to be met by simply reducing cattle numbers, therefore animal numbers in all categories needed to be reduced. A reduction in the waste of livestock products showed a small decrease in emissions although not meeting emission reduction targets. This demonstrates potential to help mitigate greenhouse gas emissions from agriculture further, if combined with a reduction in consumption. Not eating meat one day a week also showed potential to reduce emissions and, if progressed to two or three days a week, could show more significant reductions and meet emission reduction targets.

It can also be concluded that reducing livestock consumption and production has higher potential to reduce methane emissions in agriculture than those of nitrous oxide, as animal agriculture is the primary source, emitting nearly all of the methane emitted from agriculture. Nitrous oxide emissions occur from other sources such as fertiliser and indirect emissions from leaching and run off. Nitrous oxide emissions from fertiliser applied to grassland and indirect nitrous oxide emissions would also need to be evaluated for more detailed and accurate results on how much all nitrous oxide emissions could potentially be reduced, following a reduction in livestock numbers.

The scenarios which enabled the Kyoto protocol and Climate Change act target to be met in the livestock sector were 11, 12, 13, 14 and 15. Although scenarios 11 and 14 may be acceptable, 12, 13 and 15 were perhaps not likely to be adopted in the UK. This is perhaps an unrealistic proposal therefore it can be concluded that reducing consumption and production has the potential to be an effective mitigation strategy if implemented alongside other mitigation strategies, such as different manure management approaches, livestock dietary manipulation, converting from intensive production systems to grazing systems, although this may incur emission increases in other ways, and a reduction in waste of livestock products.

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