AN INVESTIGATION OF GREENHOUSE GAS EMISSIONS THAT ARISE FROM VENISON PRODUCTION IN SCOTLAND

BY

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ABSTRACT

Deer farming originally began in Scotland in 1973. While it is currently a small industry, demand is expected to grow 10% annually from 2016. Farming deer can result in emission of various greenhouse gases (GHG). Deer are ruminants and produce methane through enteric fermentation. Farming also results in emissions from manure management, energy use and feed production.

The threat of climate change has resulted in growing global collaboration. The Kyoto Protocol requires Annex 1 parties to provide an emissions inventory, quantifying the level of GHG emissions from different sources. Currently, Scotland quantifies emissions from deer farming through Tier 1 Intergovernmental Panel on Climate Change (IPCC) default methodologies. A wider understanding of the efficiency of production in terms of emissions can also be achieved by determining emissions intensity (EI).

This study aims to create a Tier 2 model using Scotland specific data and calculations from IPCC and New Zealand (NZ) Ministry for Primary Industries (MPI) to quantify emissions from farmed deer. It also aims to consider the EI of venison, per kilogram live weight (LW), carcass weight (CW) and protein, and compare it to other livestock commodities.

The study estimated that deer contribute 8.52kt of CO_2 equivalent to Scotland's greenhouse gas inventory. Of this, methane (CH_4) comprises the largest fraction of emissions at 5.32ktCO_2eq followed by nitrous oxide (N_2O) with 2.07ktCO_2eq and finally carbon dioxide (CO_2) with 1.13ktCO_2eq. The average enteric and manure management CH_4 emission per head was found to be 25.87kgCH_4/head/year and 0.60kgCH_4/head/year respectively. This suggests that the IPCC Tier 1 defaults currently used of 20kgCH_4/head/year and 0.22kgCH_4/head/year from enteric fermentation and manure management do not accurately capture the true level of emissions from farmed deer.

EI of venison per kg LW was determined as 28.74 kg CO2eq / kg LW, per kg CW as 51.31 kg CO2eq / kg CW and per kilogram protein as 381.04 kg CO2eq / kg protein. This results in venison having higher EI than all other Scottish meats including beef and lamb. Reasons for this are concluded to be due to deer having a low feed conversion ratio (FCR) and naturally high general energy requirements. They also have a lower output per tonne dry matter consumed than other livestock.

Venison as a product poses positive health and economic benefits for Scotland. However, development of accurate emissions reporting as well as lowering the EI will be imperative in the future, particularly if the industry grows as planned.

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ABBREVIATIONS

GHG= greenhouse gas

IPCC= Intergovernmental Panel on Climate Change

CH_4= methane

N_2O= nitrous oxide

CO_2= carbon dioxide

UK=United Kingdom

NZ= New Zealand

MAF= Ministry of Agriculture and Forestry

MPI= Ministry for Primary Industries

DMI= dry matter intake

ME= metabolisable energy

EI= emissions intensity

MJ= megajoule

ME_m= energy required for maintenance

ME_{con}= metabolisable energy from pasture

ME_{graze}= additional Energy Requirements for Activity

ME_g= energy required for growth

NEMI= national Enteric Methane Inventory Methodologies

GE= gross energy requirements

N_i= nitrogen intake

N_{lwg}=nitrogen retention from live weight gain

N_{rm}= nitrogen retention from milk

N_{ex}= nitrogen excretion

VS= volatile solids

FCR= feed conversion ratio

LW= live weight

CW= carcass weight

1 INTRODUCTION

Concentrations of many GHGs, such as CO_2, are at record levels. Increasing scientific agreement shows that the consequences of climate change pose drastic effects for humanity and other forms of life (Hughes, 2000). A decrease in these is therefore essential to prevent further global temperature increases. Effective mitigation of climate change and its consequences is dependent on global efforts and collaboration. The United Nations Framework Convention on Climate Change (UNFCCC), combined with the Kyoto Protocol, have led the way in concentrating these global efforts. As a result, each member party must provide a detailed inventory of their greenhouse gas emissions from different sources and then consider ways to reduce their emissions. The Kyoto Protocol also requires each member state to commit to reducing their emissions by a specific amount based on the 1990 baseline period (UNFCCC, 2014). Scotland as part of the UK must adhere to these requirements. Furthermore, Scotland has its own ambitious emissions reductions targets and a key component of developing strategies for reduction is to first determine the current level of emissions (The Scottish Government, 2012).

Agriculture remains a primary source of GHG emissions. Enteric fermentation is a digestive process undergone by animals named ruminants (such as cattle and sheep) and is one of the main sources of anthropogenically-produced methane (CH_4). Furthermore, other gases such as nitrous oxide (N_2O) and carbon dioxide (CO_2) are produced as a result of manure management, feed production and energy use in livestock upkeep (Gerber, et al., 2013).

Deer are becoming increasingly popular to farm and have been farmed in Scotland for decades, with the first farm opening in 1973 (SAC Consulting, 2017). They are ruminant animals and so contribute to agricultural CH_4 as well as N_2O and CO_2. The farmed deer industry is currently small in Scotland however given the nutritional qualities and growing popularity of deer meat, commonly known as venison, there is a push to increase the number of deer farms to several hundred and the number of annual farmed deer to over 25000 (Playfair, 2015).

Presently, the UK GHG inventory and therefore the inventory of each devolved country (in this case Scotland) solely use Tier 1 IPCC recommendations in order to determine CH_4, N_2O and CO_2 emissions that arise from deer farming (MacCarthy, et al., 2015). While deer farming may not currently contribute much to Scotland’s greenhouse gas inventory, it has the potential to rapidly expand and become an important aspect of agricultural emissions in the country. Considering the planned growth of the industry, use of only Tier 1 defaults may affect the accurate reporting of Scottish and UK GHG emissions under the Kyoto Protocol.

It is also important to consider the EI of venison. This is the level of emissions that arise as a result of producing one kilogram of different functional units such as LW, CW and protein. This allows a comparison to be made between species as to what meat contributes the most and least emissions per kg output, thus giving greater understanding of what has the biggest environmental impact (Macleod et al, 2017).

This study will use calculations from the New Zealand MPI detailed methodologies for agricultural GHG emission calculation and IPCC Guidelines for National Greenhouse Gas Inventories, combined with data from Scotland and Scottish deer farms, to quantify the contribution of deer farming to Scotland’s greenhouse gas inventory through Tier 2 processes (Ministry for Primary Industries, 2016)(IPCC, 2006). It will also assess the EI of venison and draw comparisons between it and other livestock meats.

2 LITERATURE REVIEW

2.1 Greenhouse Gases and the Need for Quantification

Global warming and climate change both pose an increasingly major threat to the future of humanity. Global warming is an increase in the average temperature of the Earth and climate change is the resulting effect of global warming, with a change in long-term climate patterns. While historical records show the climate has naturally fluctuated in the past, there has been a marked increase in temperature in the past 100 years. This can be linked with increased industrialisation causing the release of excess GHGs in the atmosphere. The main GHGs include CO_2, CH_4, N_2O and water vapour. GHGs cause the greenhouse effect where heat is trapped within the atmosphere. This is a necessary process, which makes the Earth habitable (Latake et al, 2015).

However, anthropogenic activity has caused the greenhouse effect to accelerate due to excessive GHGs in the atmosphere. The effects of this overabundance are expected to impact on global processes for a long time span, perhaps centuries. Climate change is expected to have multiple impacts, some of which are already being seen globally. These include rising temperatures, changing weather patterns of higher frequency and severity, loss of arctic ice, ocean acidification and sea level rise. From a biodiversity perspective, the physiology, phenology and distribution of many species are altering. From a human perspective, effects of climate change may affect our food and water supplies, air quality and the livelihoods of many communities (Hughes, 2000).

Many of the gases (particularly CO_2) come from the burning of fossils fuels, industrial processes, transportation and buildings but another major contributor is agriculture (EPA, 2017). This can be due to land use change where forests (an important carbon sink) are removed to make way for agricultural developments or from agricultural processes themselves such as crop production (NASA, 2018). Another key contributor to agricultural emissions is the production and maintenance of livestock, which will be the focus of this investigation.

2.2 Emissions from Livestock

Livestock cause the emission of CH_4, CO_2 and nitrous oxides (NO_x). They account for approximately 37% of anthropogenic CH_4 and 65% of anthropogenic NO_x. CH_4 has 26x more Global Warming Potential (GWP) than CO_2 and NO_x has 296x more (Steinfield et al, 2006). Sources of livestock emissions are primarily from feed production (CH_4, N_2O and CO_2), accounting for approximately 45% of the overall sector emissions. Fertilisers, manure deposition on pasture and land use change for feed crops all contribute. Other sources of emissions include direct and indirect energy use at the on-farm and post-farm stages (Gerber, et al., 2013).

Enteric fermentation causes CH_4 production and results in approximately 40% of sector emissions. Enteric fermentation is a digestive process that occurs in the gut of ruminant animals including cattle, sheep and deer. These animals have a four-chambered stomach and fermentation occurs due to the presence of one large area of the stomach named the rumen, where microbial fermentation takes place. Here, microbes break down consumed food, enabling the animal to utilise the nutrients within. The presence of a rumen allows ruminants to effectively digest coarse plant matter, which monogastric organisms cannot do. A by-product of this fermentation process is $CH_{4,}$ which is then exuded by the animal along with CH_4 produced in the large intestine. Factors that are considered to most affect enteric fermentation are the physical/chemical traits of feed as well as feed amount and digestibility (Van Amstel and Swart, 1994).

A comparison of different ruminants showed there were differing emissions between species, related to animal size and dry matter intake (DMI) shown in Table 1.

Table 1: Comparison of Different Ruminant Species (Swainson Et Al, 2008)

Methane Production	Cattle	Deer	Sheep
Daily CH_4 Production (gCH_4/day)	140	31.5	18.3
Daily CH_4 Production/kg DMI (gCH_4/kgDMI)	20.6	16.5	18.4

Daily CH_4 production differed quite considerably however when considered with the DMI, the difference became smaller. Another reason for differences in CH_4 production between species is feed utilisation and what level of feed gross energy (GE) is lost in the form of CH_4. A study comparing bison, wapiti and white-tailed deer showed that bison were the least efficient in that they expelled the biggest fraction of GE feed intake as CH_4 in comparison with wapiti and white-tailed deer. A seasonal difference was also seen in bison and wapiti with higher emissions in February/March than in April/May yet white tailed deer had little difference. However, there was only a difference of 6°C between the two periods so results may not be significant (Galbraith et al, 1998).

Manure management (N_2O and CH_4) accounts for 10% of sector emissions. CH_4 is produced during anaerobic decay of manure (Gerber, et al., 2013). Nitrogen from grazing animal excreta accumulates on soil and results in N_2O emissions, which are in turn affected by soil compaction and the diet of the animal (de Klein, 2003). Grazing animals accumulate nitrogen when ingesting plant matter, which means conversion to atmospheric N_2O is more likely upon excretion (Davidson, 2009).

2.3 Greenhouse Gas Emissions from Venison Production

Deer farming is related to the production of three GHGs. Deer are ruminant animals and therefore expel CH_4 during enteric fermentation. There are also emissions associated with feed production, such as silage and concentrates, and energy use on farm in the form of CO_2 and N_2O. CH_4 and N_2O are emitted through manure management. Intensive deer farming can also have other environmental impacts such as soil compaction and affecting water and soil quality of nearby areas due to nutrient leaching and eutrophication (de Klein et al, 2003).

IPCC Tier 1 recommendations state that the expected CH_4 emission for enteric fermentation in deer is 20kgCH_4/head/year. CH_4 from manure management is expected to be 0.22kgCH_4/head/year (IPCC, 2006). In comparison New Zealand (NZ) Tier 2 emissions factors state 22.3kgCH_4/head/year from enteric fermentation however the country has no studies on emissions from manure management (Ministry for the Environment, 2017).

N_2O emissions from manure management are calculated via species nitrogen excretion rates of which IPCC has no default indicator for deer. Previous UK studies state a value of 13kg N/head/yr (Patton et al, 2010). However NZ states a value of 30.41kg/head/year (Ministry for the Environment, 2017). Currently, deer are seen to have better cycling of nitrogen in their excretions than beef. This means less nitrogen is present in faeces resulting in lower nitrous oxide emissions (de Klein et al, 2003).

A study showed that of bison, wapiti and white-tailed deer, the deer species had the lowest CH_4 emissions. However, the farmed deer population is mainly red deer and is larger than white-tailed deer so emissions values may be closer to wapiti (Galbraith et al, 1998). Indeed comparison of Western Europe default emissions factors shows cattle produce 57-117kgCH_4/head/year, sheep 5kgCH_4/head/year and swine 1kgCH_4/head/year from enteric fermentation. Manure management values are 6-21kgCH_4/head/year for cattle, 0.19kgCH_4/head/year for sheep and 6-9kgCH_4/head/year for swine (IPCC, 2006). This shows deer to produce less enteric CH_4 than cattle (but more than sheep and swine) and less manure management emissions than all except sheep.

2.4 Emissions Intensity

While studies suggest that deer compare quite favourably with other livestock in regards to emissions per head, it is also important to consider emissions intensity (EI) of the meat. EI is the level of GHG emissions produced per unit of economic activity (Baumert et al, 2005). In this case, it is the level of emissions per different functional units of an animal such as LW, CW and edible protein.

Quantification of EI is useful as it can better determine the efficiency of a farming system and how it alters across a timespan. A decrease in emissions may occur due to the sector itself declining rather than the system becoming more emissions efficient. EI aids in the understanding of the emissions impact of an industry (Macleod et al, 2017).

A NZ comparison of beef, sheep and deer systems found deer to have the highest EI at 33.6kgCO_2eq/kg output whereas a sheep and beef mixed system was 19.1kgCO_2/kg output. A higher the proportion of deer on a farm resulted in a higher EI. This was due to deer producing less output per hectare and per tonne dry matter consumed (Duchemin, 2011).

From an economic perspective, while there was a low output for deer farms, the products have a high value. Furthermore, a NZ MAF report showed that venison production resulted in twice the profit per unit of GHG emissions than both sheep and beef farming (de Klein et al, 2003). However, this could be due to the difference in value of deer products and other livestock so may not accurately represent their efficiency in terms of emissions.

Overall, it is in the interest of sustainability both in the broader global sense and for the deer industry itself in Scotland to ensure the EI is quantified and the lowest emissions per unit of finished product is achieved (Deer Industry New Zealand, 2018).

2.5 Deer Farming In Scotland

There are two different venison production systems in Scotland and these are the park and the traditional farm system. Park systems are where the deer are enclosed in large parks but largely left untouched. These deer can only be shot by free bullet and do not receive any handling. As such, these enterprises are classed as wild deer and so are not considered in this study. In contrast, deer farms are where deer are routinely handled and must be slaughtered by a licensed slaughter-man. Venison from farmed deer is also of higher value than wild/park venison (Fletcher, 2015).

The deer species in farming systems in Scotland is almost exclusively red deer (*Cervus elaphus*). This is due to the species being easier to handle and having a natural herd forming ability so may be kept in large herds, which is beneficial for farming. They are also a larger deer species and so have greater output per head. The majority of deer in Scotland are kept on pasture however calves and young hinds may be wintered due to the wet climate as seen in Figure 1 (Venison Advisory Service Ltd., 2016).

Figure 1: Wintered Calves at Glensaugh Farm (Authors Own, March 20th, 2018)

Deer farming in Scotland is currently a small industry with only 50 out of 3500 tonnes of produced venison coming from farmed deer. The majority of venison produced in Scotland comes from annual wild culls. However wild culls have become static in recent years and may even decline (Scotland Food and Drink, 2012).

Farmed deer numbers in Scotland remained relatively stable from 2007 to 2013 at around 6000 deer each year (Fig.1.). However, recent years have seen a significant population increase with a 15% rise (7005 to 8039) from 2016 to 2017 (The Scottish Government, 2017).

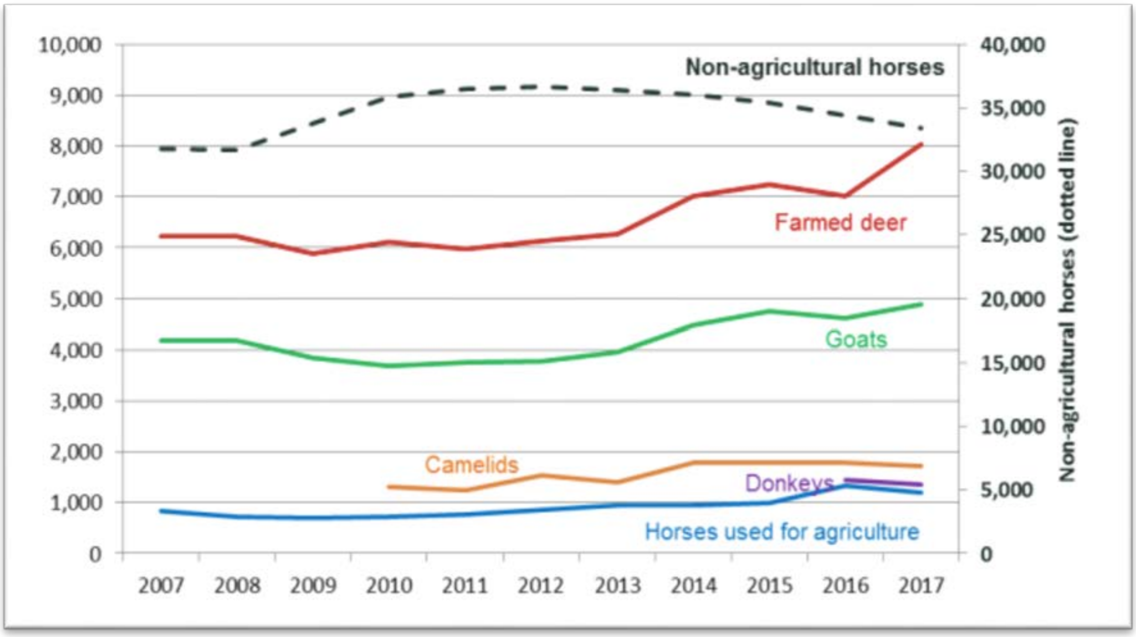

Figure 2: Scottish Agricultural Census 2017 (The Scottish Government, 2017)

In 2016, there were approximately 89 farm holdings in Scotland that were farming deer. Of these, 55% were located in the South of Scotland with the biggest percentage of farms being in the South West. Scottish agricultural land is approximately 86% Least Favourable Area (LFA) denoting poor soil and low agricultural income. In 2015, 5822 of 7236 farmed deer were kept on LFA land. This equates to 80% of the population (The Scottish Government, 2016).

2.6 Background of Quantification and International Agreements

International collaboration and action on climate change was first recognised with the introduction of the UNFCCC. It was introduced in 1992 at the Rio Summit and the overarching aim of the convention was to prevent dangerous anthropogenic influences on the global climate. With 197 ratifications, including the United Kingdom, it had near universal support (UNFCCC, 2014). There was a call for GHG emissions to be stabilised within a time frame sufficient enough to allow climate change adaptation to take place. This would allow ample global food availability and allow economic development to occur sustainably (van Amstel and Swart, 1994). The framework included the goal to decrease emissions to 1990 levels by 2000. Many parties of the convention have achieved that goal, the UK included. Total UK greenhouse gas emissions show a continual overall decrease 1990 to 2016 (Fig.3.) (GOV.UK, 2018).

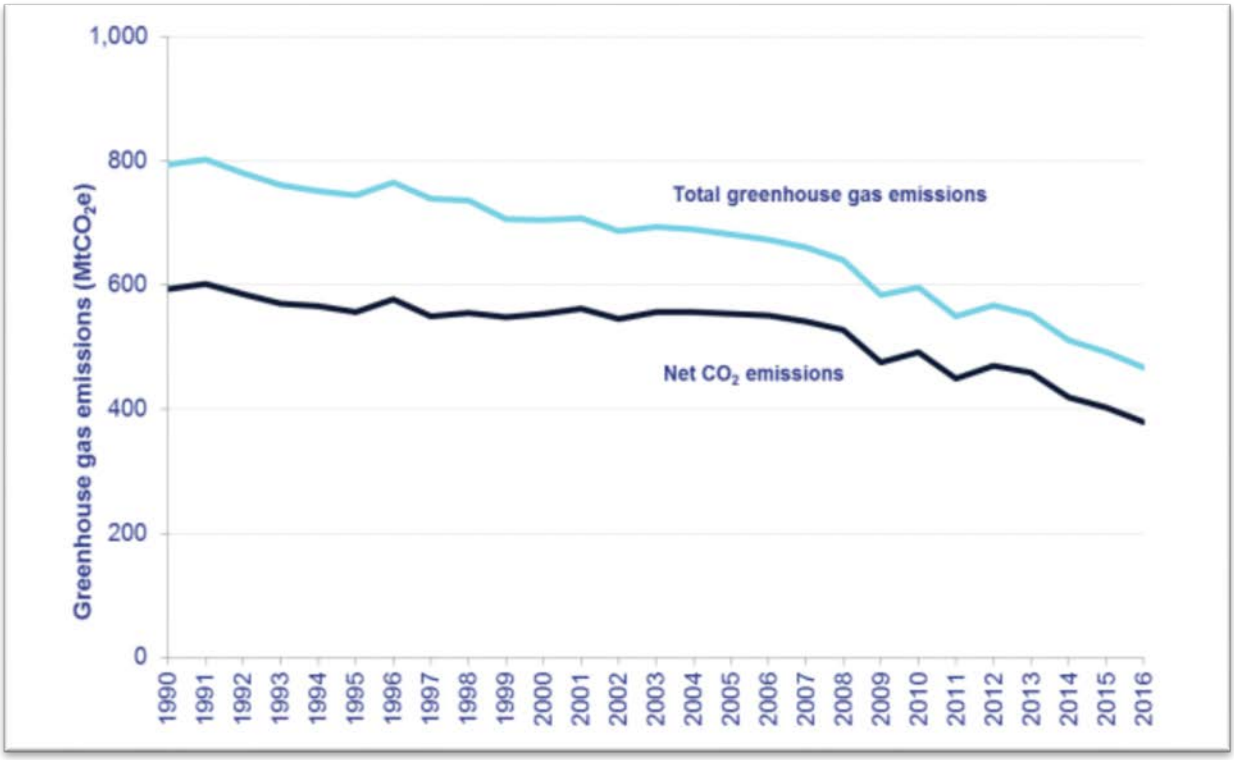

Figure 3: Total UK Greenhouse Gas Emissions 1990-2016 (MtCO$_2$eq) (GOV.UK, 2018)

The Kyoto Protocol was a continuation of the UNFCCC commitments. It was introduced in 1997 but did not fully come into effect until 2005 due to complications in ratification. The UNFCCC represents an encouragement for ratified parties to control emissions levels however the Kyoto Protocol makes it a commitment. It set out emissions targets for 37 industrialised countries that must be met. For example, the UK target was to reduce emissions to 12.5% lower than the baseline level in the first period of the Kyoto Protocol however a 22% reduction was actually achieved (GOV.UK, 2015).

Due to the UNFCCC and the Kyoto Protocol, all Annex 1 parties are required to submit regular reports on any policies introduced to combat climate change and also must create a yearly inventory of the greenhouse gas emissions produced by that party. The inventory must include the baseline year of 1990 and be updated for each year thereafter. The United Kingdom is an Annex 1 party and so emissions monitoring is essential for the UK and each devolved nation (United Nations Framework Convention on Climate Change, 2018).

2.7 Scotland and its Greenhouse Gas Targets

Scotland, as part of the United Kingdom, faces the same requirements for greenhouse gas monitoring and reductions. As a result, the Climate Change (Scotland) Act (2009) was introduced in order to apply measures to decrease the overall emissions. This bill is described as the most expansive environmental related act that Scotland has introduced as a devolved government (The Scottish Government, 2012).

This is due to the particularly ambitious target of an 80% reduction on baseline emissions (1990 level) by 2050. An interim target of 42% reduction by 2020 was also introduced and in 2015 the net emissions reduction was 41% of baseline levels. This showed Scotland to be comfortably on way to the target. As a result, a stricter target is being proposed of up to 90% emissions reduction by 2050. The Act also requires Scottish Ministers to create yearly emissions targets from 2010 through to 2050 and reports detailing policies that will achieve these reduction targets (The Scottish Government, 2012).

In order to meet the target of at least 80% reductions, Scotland must be particularly conscientious from where emissions are being exuded. Emissions targets reductions in Scotland have been focussed on the power industry as can be seen with its marked decrease in Figure 4 (The Scottish Government, 2017).

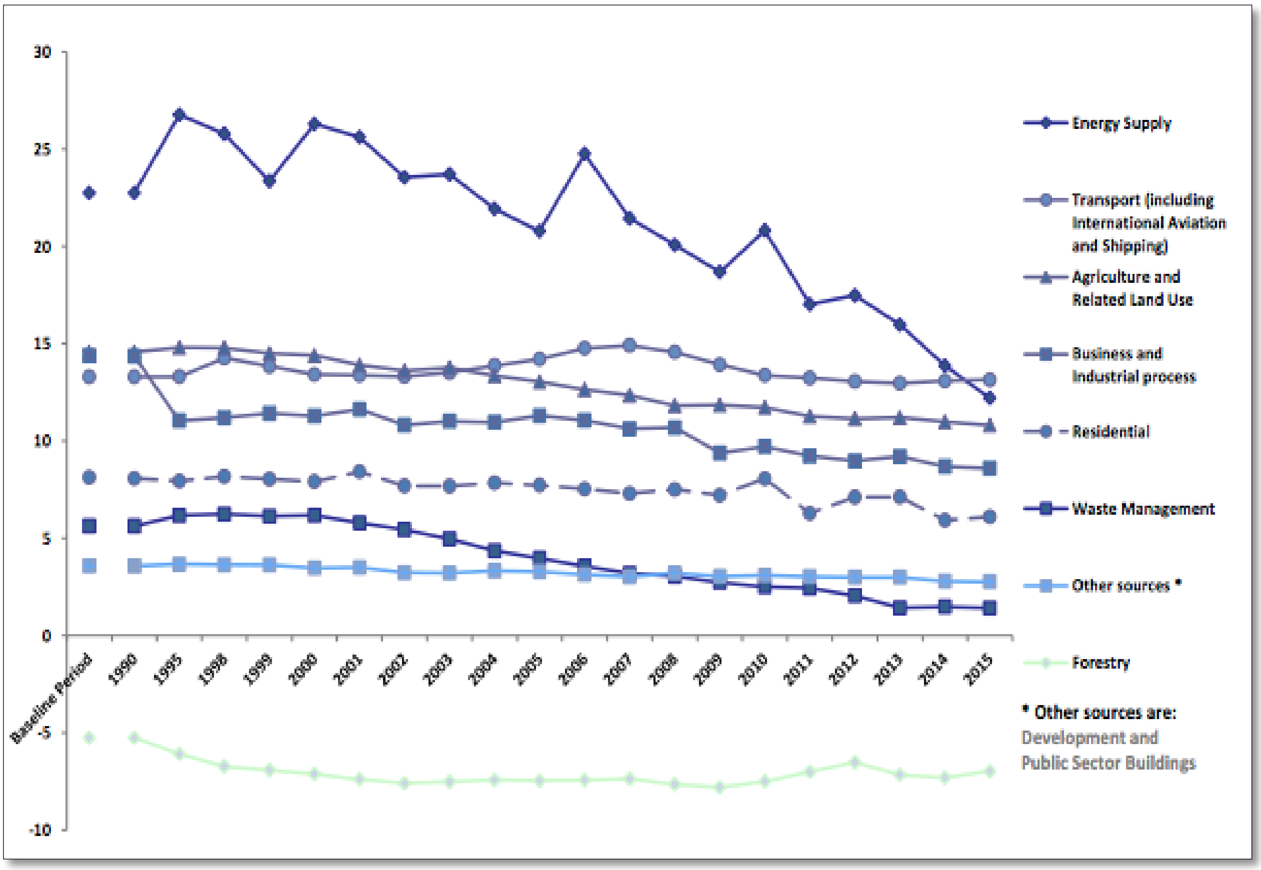

Figure 4: Main Scottish Emissions Sources 1990-2015 (The Scottish Government, 2017).

Emissions on sectors outside of energy production have not shown a marked decrease in recent years. Agriculture is one of the areas where insufficient progress has been made. As a result, it is recommended that more focus be put on this area (combined with transport) or reaching Scotland's ambitious reduction targets could be threatened (Committee on Climate Change, 2017).

2.8 Quantification Methodologies

The IPCC is an international group with the purpose of analysing the science behind climate change and related policy. It aids policymakers in decisions, assesses the potential impacts of climate change and researches potential mitigation options (IPCC, 2013). It was created in 1988 by the World Meteorological Organisation and the United Nations Environment Programme and currently has 195 members. The IPCC has three different working groups each with a different focus: the basis of the physical science, climate change impacts and vulnerabilities and mitigation methods. In addition to this, there is a Task Force on National Greenhouse Gas Inventories (TFI) where the methodologies used to quantify and report greenhouse gas emissions are developed. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories were approved for use from 2015 (IPCC, 2006).

The IPCC methodology functions on different Tiers, each with a different level of detail. The most basic level is Tier 1 where the IPCC have developed default equations and emission factors for different animal species. Data from the specific country is used but it is not particularly detailed. For example, the entire deer population would be used and no distinction would be made between gender or age. Tier 2 methodologies use more detailed country population statistics determine the energy requirements for a species, their level of dry matter intake and the nitrogen excretion. This information is used to calculate resulting CH_4 and N_2O emission from enteric fermentation and manure management. The IPCC guidelines are based on cattle and sheep and so New Zealand Ministry for Primary Industries developed a Tier 2 methodology for cattle, sheep and deer. It determines more specific calculations for their energy requirements and resulting emissions. The methodologies comply with the IPCC good practice guidelines and provide more factual quantification of emissions. Parts of this study are also based on these methodologies (Ministry for Primary Industries, 2016).

2.9 Venison Demand Outstrips Supply

While the farmed deer sector of Scottish agriculture may currently be small, it represents a unique economic opportunity due to the demand for venison being significantly higher than the supply. As a result, the Scottish Venison Partnership was developed in 2012. This group aims to implement a framework towards increasing venison production in Scotland. It is also now possible for deer farmers to gain support through the EU Common Agricultural Policy under the Basic Payments Scheme but the future of this is unclear with Brexit. Non-EU venison is tariff free for European markets so no longer being in the EU may allow the UK deer industry to flourish. However future deductions cannot be made as Brexit agreements are still being discussed (SAC Consulting, 2017).

During 2013, the UK imported approximately 26000 carcasses from New Zealand alone. Venison demand increased approximately 34% between 2006 and 2009 (Scotland Food and Drink, 2012). It is expected to further increase by 10% year on year from 2016. It is therefore estimated that our venison imports will have to increase by 5x in order to keep up with this projected growth (SAC Consulting, 2017).

In order to reduce the reliance on imports and meet the continuing demand for venison products, the aim is to increase the amount of venison produced by 1200 tonnes. As approximately 25 deer produce 1 tonne, slaughtering at least 25000 additional deer annually will be necessary. This represents a 24-fold increase in the industry and requires a further 3-400 farms being developed in Scotland compared to the current 89 (Scotland Food and Drink, 2012). Furthermore, producing 25000 more carcasses a year requires an established breeding herd and therefore an overall population that is much larger. Clearly, this increase in the number of deer being farmed has implications for Scotland's greenhouse gas inventories and future emissions targets. In recent NZ inventory reports, the emissions arising from deer farming increased by 17% from 1990 to 2015 due to the growth of the industry (Ministry for the Environment, 2017).

In the 2016 to 2017 period, the total export revenue from deer related products in NZ was $266million (Deer Industry New Zealand, 2018). Additionally, their wild deer population were initially considered pests and so were captured. This led to deer becoming one of NZ's biggest exports (Hoffman and Wiklund, 2006). Scotland has a large wild population (approximately 400000) and so the New Zealand industry represents a path that Scotland could follow (Edwards & Kenyon, 2013). However, increasing greenhouse gas emissions threaten farming methods due to climate change. Thus, quantification of emissions from deer farming not only aids in meeting the international requirements of greenhouse gas reporting more accurately, but also aids in the sustainability of what could be an important Scottish industry.

3 AIMS AND OBJECTIVES

The overall aim of this study is to quantify the greenhouse gas emissions that arise from the deer farming industry in Scotland and investigate the emissions intensity associated with the meat.

This will be completed by the following objectives:

1. Quantify the total greenhouse gas emissions including CH_4, N_2O and CO_2 that arise from the farmed deer population in Scotland.
2. Quantify the emissions intensity of deer meat using different functional units including live weight, carcass weight and protein.
3. Compare the resulting emissions intensity with those of other livestock meats and consider reasons for the differences between commodities.

4 METHODS

4.1 Overview of Methods

This study was completed via a desk-based study using Microsoft Excel to create the model. A blank Excel model template was provided by Dr Michael MacLeod to allow for input of deer specific calculations. The other software programme used was Microsoft Word in write up and to create results tables.

The first stage of the study was to utilise the MPI detailed methodologies on agricultural GHG calculation and the IPCC 2006 Guidelines for National GHG Inventories, to determine the net energy requirements and nitrogen intake of different subcategories of deer (Ministry for Primary Industries, 2016) (IPCC, 2006). The results of these were then used to determine the emissions related to the animal compartment (including enteric fermentation, manure management and nitrous oxide manure management systems (MMS)) and the emissions related to feed production (kgCO_2eq/animal/year) for each subcategory. Calculations were completed using collected Scotland-specific data on deer farming.

The second stage was to use the results from each subcategory combined with herd data to determine the emissions that arise from the total population. This included the total N_2O, CH_4 and CO_2 emissions from the different sources (enteric fermentation, MMS and emissions from feed).

The third stage was to calculate the production from the population in terms of LW, CW, bone-free meat and protein yield (kg/subcategory/year). This was then used in conjunction with calculated emissions to determine the EI of each product and by each emissions source from Scottish farmed deer.

4.2 Source of Calculations

The MPI approach was used in conjunction with the IPCC approach due to there being equations only for different subsets of cattle and sheep and no detailed equations for deer in the IPCC approach. New Zealand has a global reputation as the primary source of farmed venison with a population of just less than 1 million deer (Suttie Consulting Ltd, 2012). As such, the methodologies were deemed the most accurate in the calculations within this study. Details of the calculations used are given in each section.

Furthermore, The MPI approach has been developed to consider the changing productivity and demographics of the livestock population. This allows for greater accuracy than using fixed emissions standards that do not count for variables within the country or its livestock population.

4.3 Data Collection

Data for the study came from a variety of sources. Some values came directly from the MPI methodologies report. Other data was collated through a literature review of relevant studies on farmed deer. Attendance of a Knowledge-Transfer-Exchange research meeting at Glensaugh Research Station allowed information on Scottish deer farms to be collected directly from key players of the industry including representatives from James Hutton Institute, the Venison Advisory Service and large deer farms. Specifics of what data was used where are detailed throughout the results in the corresponding equations.

4.4 Herd Data

The deer population was split into six sub-categories: adult hind, replacement hind, adult stag, replacement stag, hinds bred for slaughter and stags bred for slaughter to account for differing energy requirements.

As Scotland (or the UK) does not have specific population statistics for farmed deer, a herd model was created to estimate the number of deer per subcategory. It accounted for Scottish herd specific data including the replacement rate and fertility rate of adult females, the age and weight of each subcategory at slaughter and the mortality rates of each subcategory. The ratio of stags to hind in a herd was also considered. Details of the inputs are listed in Appendix 1. The resulting herd numbers were calculated and provided by MacLeod, M (personal communication, March 29th, 2018).

This also allowed estimations of the numbers from each subcategory that went to slaughter and that were culled/died of other circumstances. The resulting LW contributed by each category to slaughter was determined by multiplying the average weight by the slaughter number. The CW sent to slaughter was then derived by application of a killing out percentage of 56% (SAC Consulting, 2017). The same process was followed for animals dying/culled. The numbers used (assuming a steady state population) are detailed in Table 2.

Table 2: Total Number Of Overall Animals, Slaughtered Animals And Animals Dying/Culled In The Population

Subcategory	Overall Animal Numbers	Finished Animals To Slaughter	Animals Dying/Culled
Adult Hinds	3238	243	49
Replacement Hinds	642	25	34
Adult Stags	81	12	1
Replacement Stags	28.	0	1
Hinds Bred For Slaughter	1783	1143	91
Stags Bred For Slaughter	2267	1453	116

All animals that die of other causes than slaughter are incinerated and not used for venison production as indicated by Stagison Abattoir (Prentice J, personal communication April 4, 2018).

4.5 Energy Requirement Estimation

The energy requirements were calculated on a megajoule (MJ) per day basis. This was later converted to a per year basis for purposes of emissions calculations. Deer are predominately field kept but calves are housed over the winter months due to Scotland's wet climate. Adult hinds and stags are predominately left to winter on grass. Supplementary feeding of silage occurs throughout the winter and concentrates may be fed to calves or young hinds that require extra energy for growth (Venison Advisory Service Ltd., 2016).

When considering parameters for pasture, values for rough grazing in Scotland were used due to the majority of deer being kept on LFA land (The Scottish Government, 2016).

4.5.1 Maintenance Energy Requirements (ME_m) (MJ/animal/day)

The energy requirements for maintenance (ME_m) for each subset of the deer population were calculated using the same equation as is used for cattle. The equation used is described in the MPI methodologies report in section 1.4.1 (equation 4) and shown in detail in Appendix 5 (Ministry for Primary Industries, 2016).

The age (years) and LW (kg) of the different subcategories of the deer population are detailed in Appendix 2. The values for age and LW were taken as the average for each subcategory. The ME_{con} is described as the metabolisable energy of the pasture on which the deer are feeding from and is shown in Appendix 3.

4.5.2 Additional Energy Requirements for Activity (ME_{graze}) (MJ/animal/day)

In order to calculate the additional energy requirements for activity (ME_{graze}) of each subcategory, the equation described in MPI methodologies report section 1.4.2 (equation 10) is used. Similarly to $ME_{m,}$ it is the same equation used for cattle but with key differences. It is fully described in Appendix 5 (Ministry for Primary Industries, 2016). The LW and ME_{con} were included as above (Appendix 2) (Appendix 3).

4.5.3 Energy Requirements for Growth (ME_g) (MJ/animal/day)

The energy required for LW gain (ME_g) for each subcategory was determined by using the following values (Table 3). These values are originally from the National Enteric Methane Inventory Methodologies (NEMI) report (Ministry for Primary Industries, 2013):

Table 3: Energy Requirements for Growth per Gender (Ministry for Primary Industries, 2013).

Category	Energy Requirement For Growth (ME_g) (MJ ME/kg)
Hinds	56
Stags	37

The values given for the energy requirement were then multiplied by the growth rate for each subcategory. The growth rate was determined by the following calculation:

$$Growth\,rate = \frac{W_{exit} - W_{entry}}{A_{exit} - A_{entry}} * 365$$

Where:

W_{exit}= the weight of the animal upon leaving the subcategory (kg)

W_{entry}= the weight of the animal upon entering the subcategory (kg)

A_{exit}= the age of the animal upon leaving the subcategory (years)

A_{entry}= the age of the animal upon entering the subcategory (years)

Weight and age on entry and exit per subcategory is shown in Appendix 2 as well as the resulting growth rates. The NEMI value was multiplied by the growth rate due to it being the MJ ME/kg of LW gain. Multiplying by the growth rate allows the ME requirement to be determined for the actual amount of LW gain per day for each category.

4.5.4 Energy Requirements for Gestation (ME_c) (MJ/animal/day)

The equation used to calculate the additional energy requirements of adult hinds during pregnancy (ME_c) is detailed in section 1.4.6 of the MPI methodologies report (Equation 22) (Ministry for Primary Industries, 2016). The calculation includes use of a different trimester factor for each month. In this study, the average between all trimester factors was found and used in the calculation so to account for differences in each month. This then allowed an average daily requirement to be calculated. The detailed calculation and trimester factors are shown in Appendix 5.

4.5.5 Energy Requirements for Lactation (ME_l) (MJ/animal/day)

Additionally, the energy required by adult hinds for lactation (ME_l) must be considered. This was calculated as per guidelines in the MPI methodologies report section 1.4.4 (equation 20) and is shown in detail in Appendix 5 (Ministry For Primary Industries, 2016).

4.5.6 Energy Requirements for Velvet Production (ME_{velvet}) (MJ/animal/day)

Velvet growth begins at 10 months of age. The energy value required for velvet production (ME_{velvet}) is taken to be 0.5 MJ/day (Suttie, 2012). Male subcategories are estimated to produce velvet for approximately 65 days per year. The energy requirement is found by multiplying 0.5 MJ/day by 65 as shown in MPI methodologies report section 1.4.7 (Ministry for Primary Industries, 2016). This study divided the result by 365 to find the average daily energy requirement over the period of a year.

4.5.7 Total Net Energy Needs (MJ/animal/day)

The total net energy needs per day for an animal in each subcategory was calculated by finding the sum of each energy calculation that was pertinent to that subcategory. The deer subcategories and the relevant energy parameters are displayed in Table 4.

Table 4: Net Energy Calculation For Each Deer Subcategory

Subcategory	Net Energy Equation
Adult hind	$ME_m + ME_l + ME_c + ME_g + ME_{graze}$
Replacement hind	$ME_m + ME_g + ME_{graze}$
Adult stag	$ME_m + ME_{graze} + ME_g + ME_{velvet}$
Replacement stag	$ME_m + ME_{graze} + ME_g + ME_{velvet}$
Hinds bred for slaughter	$ME_m + ME_g + ME_{graze}$
Stags bred for slaughter	$ME_m + ME_{graze} + ME_g + ME_{velvet}$

4.5.8 Gross Energy Need (GE) (MJ/animal/day)

The gross energy requirements (GE) of each subcategory were calculated using the IPCC Guidelines equation 10.16 (IPCC, 2006). Two parameters of the calculation (REM and REG) each have a separate calculation to discover their value, described in IPCC equation 10.14 and 10.15 respectively (IPCC, 2006). Details of all three equations are shown in Appendix 6.

The gross energy calculation considers both the total net energy requirements of each category combined with the energy available in the feed. Two changes were made to the calculation for this study. The IPCC calculation 10.16 contains a value for NE_{work} and NE_{wool}. NE_{work} is not applicable to farmed deer as they are not used for any additional work and so this parameter was removed. Furthermore, as deer do not produce wool, the calculation was adapted so that the energy required for velvet production was included in place of NE_{wool}.

4.5.9 Dry Matter Intake (DMI) (kgDMI/day)

After the gross energy intake is determined, it is then possible to find the total dry matter intake (DMI) for each subcategory. This is calculated by dividing the gross energy intake by the energy present in the feed. As per IPCC guidelines a value of 18.45 MJ/kg was used for the energy present in the feed, as the actual energy content specific to the feed was not available (IPCC, 2006).

4.6 NITROGEN EXCRETION ESTIMATION

An estimation of the nitrogen excretion for each subcategory can be used to determine the nitrous oxide emissions from manure management systems. It was calculated in terms of kg/animal/day.

4.6.1 Nitrogen Intake (N_i) (kg/animal/day)

In order to determine the amount of nitrogen ingested (N_i) by each subcategory, the process described in section 2.4.1 (equation 40) of the MPI methodologies report was followed (Ministry for Primary Industries, 2016). The calculation takes the feed intake and the nitrogen content of the feed into account and is shown in detail in Appendix 8. The dry matter intake was taken from the initial calculation in the energy estimations section and the nitrogen content of the feed is shown in Appendix 4 (Ministry for Primary Industries, 2013).

4.6.2 Nitrogen Retention from LW Gain (N_{lwg}) (kg/animal/day)

The nitrogen retained in LW gain (N_{lwg}) was based on the MPI methodologies report section 2.4.4 (equation 42) (Ministry for Primary Industries, 2016). It considers the daily weight gain (growth rate) for each subcategory and the nitrogen present in body tissue. The body tissue nitrogen is shown in Appendix 4 and a detailed description of the calculation in Appendix 8.

4.6.3 Nitrogen Retention from Milk (N_{rm}) (kg/animal/day)

For breeding hinds, it was also necessary to consider the nitrogen retained in the milk (N_{rm}) that they produce. This was based on the MPI methodologies report section 2.4.2 (equation 42) but with some differences (Ministry for Primary Industries, 2016). The NZ model splits the milk yield into monthly proportions however this study uses a milk yield averaged across the entire year as a value for Y.

The altered equation is as follows:

$$N_{rm} = \frac{Y \times P}{6.25}$$

Where:

N_{rm}= the nitrogen retained in milk of breeding hinds

Y= average daily milk yield (kg)

P= the protein content of milk, detailed as 0.036kg/kg of milk (Ministry for Primary Industries, 2013).

The value of 6.25 is used due to the fact that 6.25kg of protein is known to contain 1kg of nitrogen (Pierce and Haenisch, 1947). The value for annual milk yield was 204kg/head/year (Ministry For Primary Industries, 2016).

4.6.4 Nitrogen Retention from Velvet

The nitrogen retention of velvet (N_{vevlet}) with regards to stag subcategories was also considered. This was based on the MPI methodologies report section 2.4.3 (equation 43) but with some differences (Ministry for Primary Industries, 2016). The NZ model was split into months and the velvet yield considered on a monthly proportion. However in this study, the annual velvet yield was divided by 365 to find a daily average and then multiplied by the velvet in nitrogen:

$$N_{velvet} = \frac{V}{365} \times N_v$$

Where:

N_{velvet} = the nitrogen level present in velvet

V= the velvet yield (kg/hd/year)

N_v= the nitrogen level present in velvet (shown in Appendix 4).

The velvet yield was determined from NZ annual velvet yields (Ministry for Primary Industries, 2016).

4.6.5 Nitrogen Excretion (N_{ex}) (kg/animal/day)

The next step was to determine the nitrogen excreted by each subcategory dependent on the amount they retain. This was found by subtracting the nitrogen intake by the nitrogen retained as follows:

$$N_{ex} = N_i - (N_{rm} + N_{lwg} + N_{velvet})$$

Where:

N_{ex} = the nitrogen excretion (kg/animal/day)

N_i = the nitrogen intake (kg/animal/day)

N_{rm} = the nitrogen retained in milk (kg/animal/day)

N_{lwg} = the nitrogen retained in LW gain (kg/animal/day)

N_{velvet} = the nitrogen retained in velvet (kg/animal/day)

The parameter N_{velvet} applied only to the three stag subcategories and the N_{rm} parameter applied only to the adult hind subcategory.

It was then possible to determine the annual nitrogen excretion from an animal in each subcategory by multiplying the daily nitrogen excretion result by 365 (the number of days in a year).

4.7 EMISSIONS RELATED TO ANIMAL COMPARTMENT

4.7.1 Methane Emissions from Enteric Fermentation (kgCH_4/animal/day)

The next step was to calculate the methane emissions as a result of enteric fermentation. The emissions are calculated by taking into consideration the gross energy estimation and the methane conversion factor. The equation used was followed as per IPCC Guidelines equation 10.21 and is shown in detail in Appendix 7 (IPCC, 2006).

However, no methane conversion factor is fully developed for deer and so the conversion factor for sheep was used. IPCC guidelines state that if a conversion factor is not available for a particular species then one should be chosen from the species that has the closest similarity. The value for mature sheep is 6.5% ± 1.0%. The ± represents a range dependent on the quality of the feed (1.0% higher for lower quality feed and vice versa) however the value of 6.5% is deemed suitable for the majority of situations thus was the value used in this study (IPCC, 2006).

4.7.2 Methane Emission from Manure Management (kgCH_4/animal/day)

The emissions from manure management were calculated in two steps. First, it was necessary to determine the manure management systems (MMS) used for deer farming in Scotland. This was determined to be primarily deposition on pasture but due to wintering calves some manure was considered solid storage. Pasture manure is considered under emissions related to feed however solid storage is calculated under nitrous oxide emissions from manure management. The fractions used are shown in Table 5.

Table 5: Fraction of Manure Management Systems in the Scottish Farmed Deer Herd

Manure Management System	Proportion
Pasture/Range	0.884
Solid Storage	0.116

The proportion of each manure management type in the population was calculated by determining the percentage of manure that is produced by the wintered calves (bred for slaughter subcategories). These subcategories spend 3 months every winter indoors, which overall accounts for 6 months of their 1.5-year lifespan (one-third).

The overall volatile solids excreted (VS) (kgVS/day) by each subcategory were found by following IPCC guidelines equation 10.24 (IPCC, 2006). Dividing the total by three then allowed the level of VS excreted indoors to be determined. The total VS produced by the whole population were summed and the proportion of this that the indoor excretion represented was found.

It was now possible to calculate the CH_4 emissions from manure management with regards to the MMS in place. This was determined by following IPCC guidelines equation 10.23 with parameters for sheep (developed countries) being used (IPCC, 2006). Detailed descriptions of both equation 10.23 and 10.24 are shown in Appendix 7.

4.7.3 Total Methane Emissions (kgCH_4/animal/day)

It was then possible to calculate the total methane emissions from the deer herd. This was found by summing the emissions from enteric fermentation and manure management for each subcategory. This was transferred to CO_2equivalent and the sum of each subcategory was found to determine total emissions for the entire population.

4.7.4 Nitrous Oxide Emissions (kgN_2O/animal/day)

The N_2O emissions were calculated in two steps. First, the proportions of manure management systems as described in section 4.7.2 were taken and inputted in the Herd and Manure Sheet in the supplied model template. The values were then used in calculations to determine 3 types of N_2O emissions, which were supplied by Dr Michael Macleod (personal communication, April 3rd, 2018):

- N_2O direct MMS
- N_2O indirect NH_3/N_{ox} MMS
- N_2O indirect leaching MMS

4.7.5 On-Farm Energy Estimation and Emissions (kgCO_2/subcategory/year)

Due to a lack of data regarding deer farm energy use in the UK, statistics from sheep were used. These state that 500kWh of diesel is used per 1000kg of CW produced (Warwick HRI, 2007). The main source of energy use in sheep farming is diesel during pasture upkeep and given deer primarily are field kept, this was determined as a suitable alternative. The MJ and resulting kgCO_2eq/kg CW and LW were then determined. The resulting value was multiplied by the LW output of each subcategory to determine the emissions related to energy use for each.

4.8 Emissions from Feed

The emissions from feed were considered by calculating the rations fed to deer. The rations used are shown in Table 6.

Table 6: Feed Rations for the Scottish Farmed Deer Herd

Ration Type	Adult Hinds	Adult Stags	Replacement Hinds	Replacement Stags	Hinds Bred For Slaughter	Stags Bred For Slaughter
Rough Grazing	0.59	0.59	0.51	0.51	0.51	0.51
Silage	0.41	0.41	0.39	0.39	0.39	0.39
Barley	-	-	0.07	0.07	0.07	0.07
Soymeal	-	-	0.02	0.02	0.02	0.02
Rapemeal	-	-	0.01	0.01	0.01	0.01

Ration calculations for adult hinds and stags were based on a winter supplement period of 150 days (SAC Consulting, 2017). Additional feed for mature animals in winter is generally silage according to input from various deer farmers (Venison Advisory Service Ltd., 2016).

Ration calculations for all other categories were based on a winter supplement period of 180 days (SAC Consulting, 2017). Calves and growing young deer are fed concentrates throughout winter, generally sheep meal as there is no specific deer feed developed yet in Scotland. Composition of sheep concentrate feed was provided via SRUC (Macleod M, personal communication, 26 February 2018).

Rations were inputted into the Input Variables sheet of the model template and the pre-calibrated Feed Sheet gave values for emissions associated with each feed. These emissions were then multiplied by the annual feed intake of each subcategory to determine yearly emissions related to feed per animal.

4.9 Total Greenhouse Gas Overview

The total GHG emissions from the animals were now considered. The emissions in kgCO_2equivalent/head/year were derived by the sum of the total nitrous oxide emissions MMS, the total methane emissions and the total CO2eq from feed intake. The overall population was considered in 3 categories: country level, adult + replacements and meat animals. The emissions from different sources were summed as N_2O, CH_4 and CO_2 and then transferred to CO_2equivalent by multiplication of their corresponding GWP.

4.10 Production and Emissions Intensity

Additionally, the EI of produce from the population was considered. The total LW and CW produced by each subcategory of the overall population was summed. For this, only the number of finished animals to slaughter was considered as 100% of animals that are culled or die of other causes are incinerated (Prentice, J. Personal communication, April 4th 2018). The total bone-free meat was found by multiplying the CW by 0.67 (Schmidt, 2000). The protein yield (kg/subcategory/year) was then determined by finding the protein percentage of the bone-free meat, found to be 20.1% (based on 201g protein per kg venison) (Aidoo & Haworth, 1995).

The EI per kg LW, CW and bone free meat was determined for 3 categories: country level, adult + replacement and meat animals. The total emissions for the 3 categories were divided by the total kg of LW, CW and bone free meat to give the EI of each respectively. For CW, it was calculated both with and without allocation to the co-products as data on co-product value is limited for the UK. Co-products consist of hide, antlers, tail, leg tendons and pizzle. Stomach, intestine, head and legs below the knee are considered waste. Co-products are estimated to consist of approximately 2% of the overall carcass in both weight and value as indicated by Dovecote Park (Bunn, R. Personal communication, April 10th 2018).

Once these were quantified for each of each of the 3 categories, it was possible to determine the EI of the meat protein depending on the source of emissions. The sources were broken down into 6 categories (kgCO_2eq/kg protein):

- Enteric CH_4
- Manure CH_4
- Feed N_2O
- Manure N_2O

- CO_2 (feed energy)
- CO_2 (direct energy)

The EI for each was determined by summing the emissions depending on the source and overall category (country level, adult + replacement, and meat animals) and dividing by the protein yield of the meat (kg/subcategory/year) relevant to the overall category.

Other parameters to aid in analysis were calculated including the feed conversion ratio (FCR) and protein production (per kg standing LW). FCR was calculated by dividing the total annual feed intake by the total number of animals. Protein production was calculated by dividing the sum of the protein yield by the sum of the average weights of the population.

5 RESULTS

5.1 Energy Requirement Estimation (MJ/animal/day)

The energy requirements for each subcategory including energy required for maintenance and additional energy required for growth, grazing activity, pregnancy, lactation and velvet production are detailed in the following table. The net energy requirements for each subcategory are also listed (Table 7).

Table 7: Energy Requirement Estimation per Subcategory (MJ/animal/day)

ME (MJ/animal/day)	Adult Hinds	Replacement Hinds	Adult Stags	Replacement Stags	Hinds Bred For Slaughter	Stags Bred For Slaughter
ME_m	15.4	10.9	25.3	15.3	10.2	13.5
ME_{graze}	1.8	0.9	2.6	1.2	0.8	1.0
ME_g	0.3	7.0	1.2	6.3	8.3	6.8
ME_{velvet}	-	-	0.1	0.1	-	0.1
ME_c	4.4	-	-	-	-	-
ME_l	5.2	-	-	-	-	-
Total Net Energy	27.1	18.8	29.2	22.9	19.3	21.4

Stags were found to have the higher overall energy requirements in comparison to hinds of similar subcategory, likely due to their greater size. Adult hinds had a higher energy requirement than replacement hinds due to the extra energy required for pregnancy and lactation. Slaughter stags had higher requirements than slaughter hinds.

5.2 Gross Energy Need (MJ/animal/day) and Feed Intake (kgDM/animal/day)

The gross energy needs and resulting feed intake for each subcategory are detailed in Table 8.

Table 8: Gross Energy Needs and Feed Intake per Subcategory (MJ/animal/day) (kgDM/animal/day)

Parameter	Adult Hinds	Replacement Hinds	Adult Stags	Replacement Stags	Hinds Bred For Slaughter	Stags Bred For Slaughter
GE Need (MJ/animal/day)	54	61	61	67	67	66
Feed Intake (kgDM/animal/day)	2.9	3.3	3.3	3.6	3.6	3.6

GE need ranged from 54 to 67 MJ/day with a weighted average of 61 MJ/day for the population. The feed intake ranged from 3 to 3.6 kgDM/animal/day. Replacement stags and slaughter hinds had the same and highest gross energy need whereas adult hinds had the lowest requirement.

5.3 Nitrogen Intake, Retention and Excretion (kg/animal/day)

The results from the nitrogen intake via feed, the nitrogen retained in LW, milk and velvet and the resulting nitrogen excretion are shown in Table 9.

Table 9: Nitrogen Intake, Retention And Excretion (kg/animal/day)(kg/animal/year)

Nitrogen Retention/Excretion (kg/animal/day)	Adult Hinds	Replacement Hinds	Adult Stags	Replacement Stags	Hinds Bred For Slaughter	Stags Bred For Slaughter
N_i	0.0745	0.0846	0.0849	0.0928	0.0924	0.0913
N_{lwg}	0.0002	0.0046	0.0012	0.0063	0.0055	0.0068
N_{rm}	0.0033	-	-	-	-	-
N_{velvet}	-	-	0.0001	0.0001	-	0.0001
N_{ex}	0.0711	0.0800	0.0836	0.0864	0.0869	0.0844
Annual N_{ex} (kg/animal/year)	25.9	29.2	30.5	31.5	31.7	30.8

Nitrogen intake ranged from 0.0745-0.0924kg/animal/day. N_{lwg} ranged from 0.0002 (adult hinds) to 0.0068 (slaughter stags). N_{rm} applied only to adult hinds and had a value of 0.0033 and N_{velvet} had a value of 0.0001 for all males. As a result, N_{ex} ranged from 0.0711 to 0.0869 kg/animal/day with annual results ranging from 25.9 to 31.7kg/animal/day. The weighted average annual N_{ex} was determined as 28.9kg/animal/year.

5.4 Methane Emissions from Subcategories

The methane emissions contributed by each subcategory for enteric fermentation, manure management and the resulting total methane emissions are detailed in Table 10.

Table 10: Methane Emissions (Enteric Fermentation And Manure Management) And Resulting Total Emissions (kgCH_4/animal/year)

Emission Source (kgCH_4/animal/year)	Adult Hinds	Replacement Hinds	Adult Stags	Replacement Stags	Hinds Bred For Slaughter	Stags Bred For Slaughter
Methane Emissions (Enteric Fermentation)	22.90	25.99	26.08	28.51	28.38	28.05
Methane Emissions (Manure Management)	0.54	0.61	0.61	0.66	0.66	0.65
Total Methane Emissions	23.45	26.60	26.69	29.17	29.04	28.71

Enteric CH_4 emissions ranged from 22.90 to 28.51kgCH_4/animal/year with a weighted average of 25.87kgCH_4/animal/year. Manure management CH_4 emissions were significantly smaller at 0.54 to 0.66kgCH_4/animal/year depending on the subcategory with a weighted average of 0.60kgCH_4/animal/year.

Individually, adult hinds were found to have the lowest enteric CH_4 emissions with replacement stags having the highest level of emissions. This was repeated with manure management calculations however slaughter hinds had equal emissions to replacement stags.

The weighted average total CH_4 emission was 26.47kgCH_4/animal/year.

5.5 Nitrous Oxide Emissions from Manure Management

The nitrous oxide emissions from different sources (manure management system) for each subcategory are detailed in Table 11.

Table 11: Nitrous Oxide Emissions from Direct/Indirect MMS, Indirect Leaching MMS And Total Nitrous Oxide (kgN_20/animal/year)

Emission Source (kgN_2O/animal/year)	Adult Hind	Replacement Hind	Adult Stag	Replacement Stag	Hinds Bred For Slaughter	Stags Bred For Slaughter
Nitrous Oxide Direct MMS	0.047	0.053	0.056	0.057	0.058	0.056
Nitrous Oxide Indirect NH_3/N_{ox} MMS	0.014	0.016	0.017	0.017	0.017	0.017
Nitrous Oxide Indirect Leaching MMS	0.001	0.001	0.001	0.001	0.001	0.001
Total Nitrous Oxide Emissions	0.063	0.070	0.074	0.076	0.076	0.074

Nitrous oxide direct MMS values were between 0.047 and 0.058 kgN_2O/animal/year, indirect between 0.015 and 0.017kgN_2O/animal/year and indirect leaching was 0.001kgN_2O/animal/year for all subcategories. The overall total emissions ranged between 0.063 and 0.076 kgN_2O/animal/year and had a weighted average of 0.070kgN_2O/animal/year. Replacement stags and slaughter hinds had the highest emissions but adult hinds the lowest.

5.6 Emissions Related To Feed Production

The emissions related to feed including N_2O from feed and energy use for each subcategory in CO_2equivalent are detailed in Table 12.

Table 12: N_2O Emissions (Feed and Energy Use) and the Overall Total (KgCO_2eq/animal/year)

Emission Source (kgCO_2eq/animal/year)	Adult Hind	Replacement Hinds	Adult Stag	Replacement Stag	Hinds Bred For Slaughter	Stags Bred For Slaughter
CO_2eq N_2O from Feed	218.1	231.5	248.4	253.9	252.8	249.8
CO_2eq N_2O from Energy Use	104.2	149.6	118.6	164.1	163.4	161.5
Total CO_2eq From Feed Intake	322.3	381.1	367.0	418.0	416.1	411.3

The total emissions related to feed ranged from 322.3 to 41.0 kgCO_2eq/animal/year for each subcategory. Replacement stags had the highest overall emissions of the subcategories and adult hinds the lowest.

For the overall population, a breakdown of the sources of emissions related to feed in comparison to the total is shown in Figure 5.

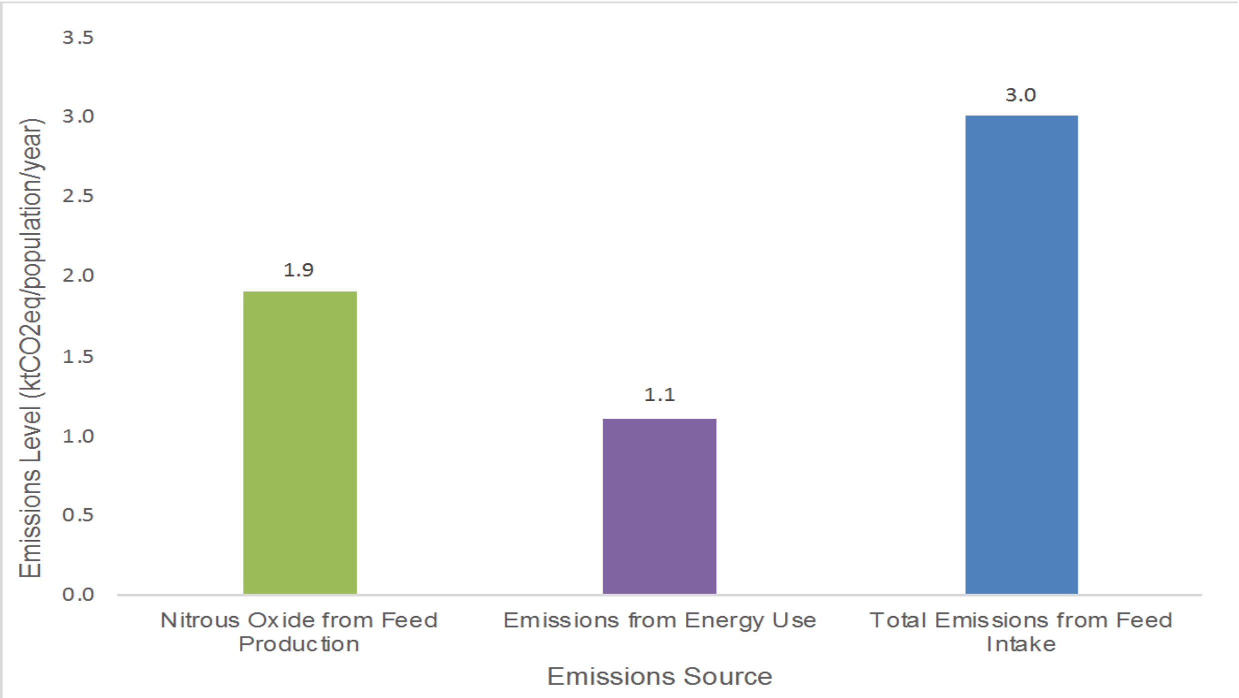

Figure 5: Emissions Sources of Feed Related Emissions (kgCO_2eq/population/year)

As can be seen, N_2O from feed production contributes the most to overall feed emissions with 1.9ktCO_2eq annually. Emissions from energy use in feed production contributed 1.1ktCO_2eq per year. The total population emissions associated with feed were 3.0ktCO_2eq.

5.7 Total Greenhouse Gas Emissions

Total greenhouse gas emissions from the whole Scottish farmed deer population from N_2O, CH_4 and CO_2 are shown in Figure 6. They are shown in kilotonnes (kt) CO_2equivalent per year by the three overall categories: country level, adult + replacement and meat animals.

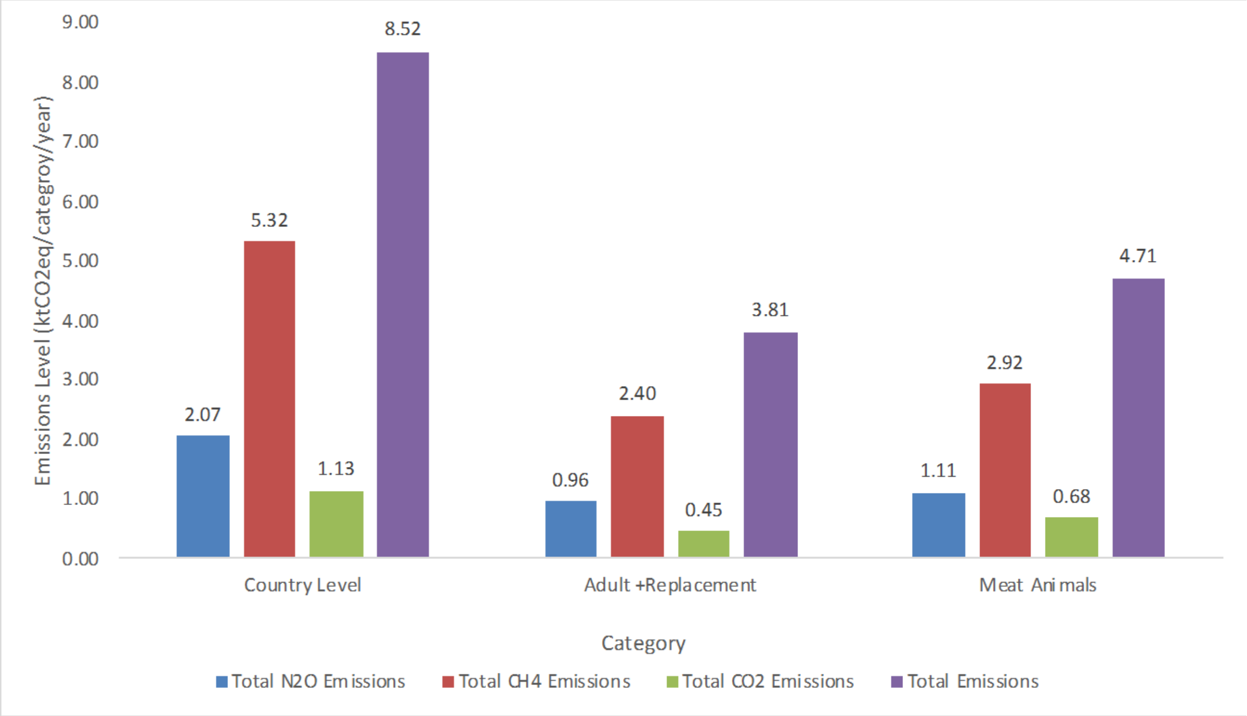

Figure 6: Total Greenhouse Gas Emissions from the Population (ktCO$_2$eq/Year)

It is clear that overall, CH_4 contributes the most to overall deer farming emissions whereas CO_2 contributes the least to the total emissions. The overall population total was 8.52ktCO$_2$eq/year. Meat animals contributed the most at 4.71ktCO$_2$eq/year and adult+replacements emitted less at 3.81ktCO$_2$eq, simply due to meat animals comprising a larger portion of the population. Overall CH_4 emissions were 5.32ktCO$_2$eq/year with N_2O and CO_2 emissions being 2.07ktCO$_2$eq/year and 1.13ktCO$_2$eq/year respectively.

The contribution of different sources of the emissions to the overall total shows the reasons for differences between the gases. A breakdown of the contribution of each source (enteric fermentation, manure management (CH_4), N_2O MMS, emissions related to feed and emissions from direct energy use) is shown in Figure 7.

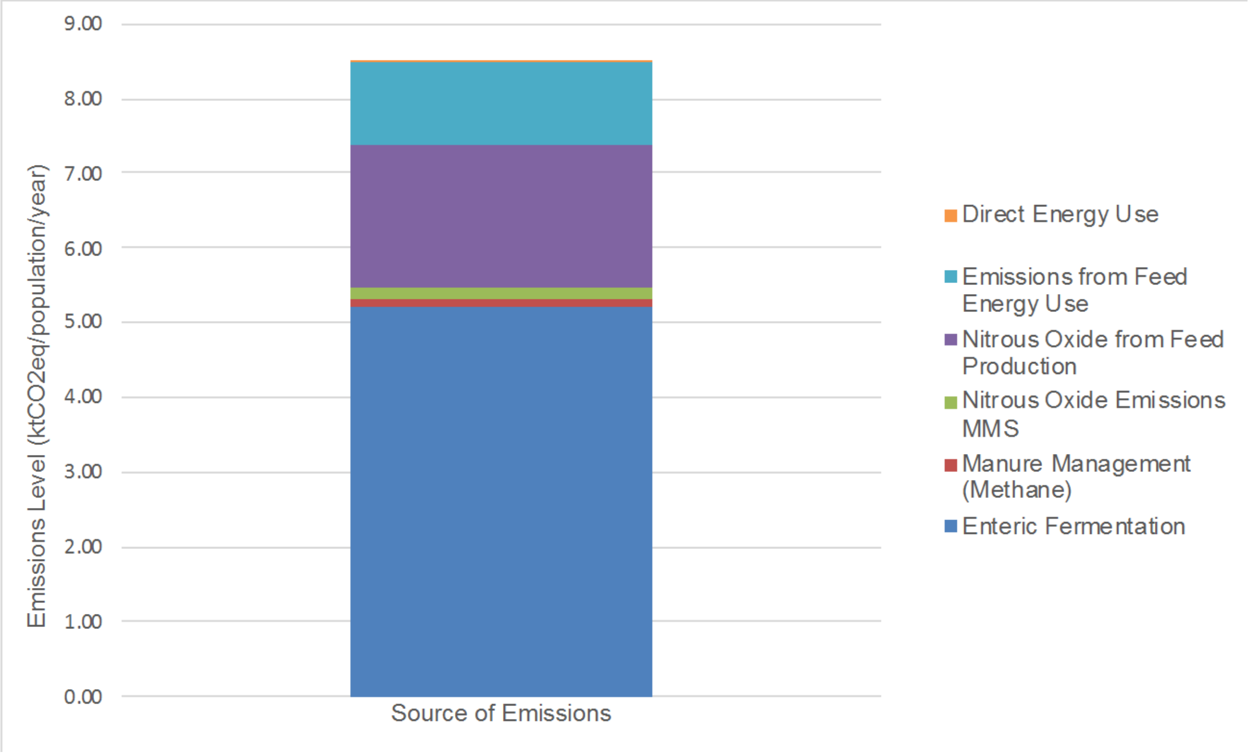

Figure 7: Comparison Of Contribution of Emissions Sources to Overall Total (ktCO$_2$/population/year)

It is clear that enteric fermentation dominates the sources of emissions from the population, which links to CH_4 having the highest overall level of emissions of the three gases. The next biggest contributors are N_2O from feed production and emissions from feed energy use. Manure management (both CH_4 and N_2O) as well as direct energy use comprised only a small amount of the overall emissions.

5.8 Production and Emissions Intensities

The calculated production level for each subcategory in terms of LW, CW, co-products, bone free meat and protein yield are detailed in Table 13.

Table 13: Production Levels per Subcategory for the Population

Production (kg/year)	Adult Hind	Replacement Hind	Adult Stag	Replacement Stag	Hinds Bred For Slaughter	Stags Bred For Slaughter	Total (tonnes/year)
Live weight	29142	2461	2210	0	102858	159859	297
Carcass Weight	16320	1378	1238	0	57600	89521	166
Co-products	326.4	27.6	24.8	0	1152	1790.4	3
Bone free meat	10934	923	829	0	38592	59979	111
Protein Yield	2198	186	167	0	7757	12056	22

The LW produced by the population ranges from 0kg by replacement stags (as none are sent to slaughter) to 159859kg by stags bred for slaughter. The resulting CW again is from 0kg to 89521kg for the same subcategories. Co-products comprise a small amount of the carcass and so the highest contribution is slaughter stags with 1790kg annually. The bone free meat yield is 0-59979kg and protein yield 0-12056kg annually.

In total, the population is estimated to produce 297t of LW, 166t of CW, 3t of co-products, 111t of bone-free meat and 22t of protein.

The EI for the above production parameters are detailed in Table 14.

Table 14: Emissions Intensity per Functional Unit

Emissions Intensity	Country Level	Adult + Replacement	Meat Animals
Live weight (kgCO2eq/kgLW)	28.7	112.6	17.9
Carcass Weight (kgCO2eq/kgCW)	51.3	201.2	32.0
Co-products (kgCO2eq/kgCW)	1.0	4.0	0.6
Carcass Weight (with allocation to co-products) (kgCO2eq/kgCW)	50.3	197.1	31.4
Bone-free meat (kgCO2eq/kg bone-free meat)	76.6	300.2	47.8
Protein (kgCO2eq/kg protein)	381	1493.7	237.8

Co-products, due to having a small proportion of the carcass, had a small EI 1.0 kgCO2eq/kgCW. The largest EI was for protein with a value of 381kgCO2eq/kg protein. Overall, EI for CW was 51.3 (50.3 with allocation to co-products), bone-free meat was 76.6kg CO2eq/kg bone-free meat. Individually, adult + replacement had higher EI than meat animals for all parameters due to the category having less output in terms of product than meat animals.

The EI breakdown dependent on the source of emissions in kgCO2eq/ kg protein was also considered. The results of this are detailed in Table 15.

Table 15: Emissions Intensity per Different Gas Source

Emissions Intensity (kgCO2eq/kg protein)	Country Level	Adult + Replacement	Meat Animals
Enteric CH_4	232.5	919.2	144.1
Manure CH_4	5.4	21.7	3.3
Feed N_2O	84.9	345.9	51.3
Manure N_2O	7.5	29.9	4.6
CO_2 (feed energy)	49.4	175.5	33.2
CO_2 (direct energy)	1.3	1.5	1.3

Enteric CH_4 had the highest breakdown EI with a value of 232.5kgCO2eq/kg protein. Manure CH_4 and CO_2 (direct and embedded energy) were lowest with 5.4kgCO2eq/kg protein and 1.3kgCO2eq/kg protein respectively. Again, adult + replacement category had higher EI for all breakdown EI than meat animals.

Other production parameters calculated included protein production per kg standing LW and the feed conversion ratio for each category. These are detailed in Table 16.

Table 16: Additional Production Parameters

Parameter	Country Level	Adult + Replacement	Meat Animals
Feed Conversion Ratio	32.5	128.7	20.2
Protein Production (per kg standing LW)	0.036	0.006	0.089

9 DISCUSSION

The aim of this project was to determine the GHG emissions that arise from farmed deer in Scotland and consider the EI of venison produced. Overall, there is little research from the perspective of the environmental impacts of farmed deer in Scotland and their contribution to the greenhouse gas inventory. A higher number of studies have been completed in NZ however these are still limited. The emissions per head of deer were expected to be lower than other species due to their smaller size. However with regards to results of EI of this study, it is clear that a move to increase deer farming and its intensity could impact the environment. Growth of the deer industry is also tightly linked to consumer perspective. Farming practices associated with intensification threatens the image of venison as a sustainable and naturally produced meat (Hoffman and Wiklund, 2006).

9.1 Energy Requirements Estimation

With regards to the energy requirements calculations that inform the emissions calculations, results appear to show similarity to other studies. For example, the energy required for maintenance was calculated to be 19.7MJ ME for a 100kg hind and 29MJ ME for a 140kg stag (Ministry for Primary Industries, 2013). Results of this study were 15.4MJ ME for adult hinds (average weight 110kg) and 25.3MJ ME for stags (average weight 156.7kg). The results for the Scottish population were lower however this could be attributed to the difference in pasture ME content as the values in the NZ MPI methodologies report ranged from 10.61-12.56MJ whereas this study used a blanket average of 10MJ. Another factor could be the age and weights of animals as NZ deer are generally larger (Suttie Consulting Ltd, 2012). Furthermore, the 2013 MPI evaluation calculated ME_m and ME_{graze} together whereas this model had a separate calculation for additional activity energy.

Similarly, the energy requirements for growth by a red deer hind up to 120kg were determined as 5.6MJ ME/100g LW gain. The value for a growing hind in the model was 7.0MJ ME/120g LWgain, which equates to 5.8MJ ME/100g LW gain showing close similarities. When considering conception/gestation, this model used a NEMI equation, which determined overall annual ME_c to be 1316MJ (Ministry for Primary Industries, 2013). Multiplication of ME_c by the gestation period (historical average of 233 days) gives a value of 1016MJ, which is lower than the NZ value. However, NZ hinds are larger than Sottish hinds and achieve a higher weight at a younger age. The daily ME_c value in this study is also an average, which may have an effect (Asher, 2007).

Energy requirements and thus feed intake were calculated in this model based on an overall average basis for the year. Therefore in reality the values stated in the model will not be a constant requirement, rather an average of a fluctuating value that changes with seasonal deer requirements. NZ data shows feed intake to be between 1.2 and 5.2 kgDM/day depending on the weight of the deer, gender and ideal LW gain (Deer Industry New Zealand, 2018). Adult hinds are likely to have higher energy and feed requirements during summer where they are pregnant and lactating. Stags instead have higher requirements during spring however in autumn during the rut, they will voluntarily only consume approximately half of their feed requirements (Mulley, 2003).

With regards to nitrogen excretion, the UK inventory assumes that the excretion from deer has not changed in the period 1990-2016. It also gives values in kg/animal place/year and so direct comparisons cannot be made with kg/head/year. The value that is stated is 13 kg N/animal place/year (MacCarthy, et al., 2015). The NZ inventory states that in 2015, deer were calculated to have on average an annual excretion rate of 29.7 kg N/head/year. The results of the model in this study range from 25.9-31.7kg N/head/year with a weighted average of 28.9. This is close to the NZ value (Ministry for the Environment, 2017).

Overall, the values for energy requirements calculated in this model bear some resemblance to results of NZ calculations using similar methodologies. However some of the calculations themselves are disputed. For example, the NEMI equation used for ME_c is considered a possible overestimation due to an inaccurate trimester factor. The ME_g equation is limited due to it not considering changing body composition of the animals (Ministry for Primary Industries, 2013). More accurate estimations may be possible in future with better data and further development of calculations.

9.2 Greenhouse Gas Quantification

Currently, the UK GHG inventory (and therefore the Scottish GHG inventory) does not split the deer population into subcategories and uses the IPCC default of 20kgCH_4/head/year (IPCC, 2006). However this study finds a weighted average of 25.9kgCH_4/head/year. As a result, the Scottish government greenhouse gas inventory estimations states that from enteric fermentation, the CH_4 emissions were 3.62kt/CO_2eq (Jones et al, 2017). This study calculates emissions to be 5.2kt/CO_2eq showing a potential underestimation of 1.58ktCO_2eq per year.

Similarly, in the inventory CH_4 emissions from manure management were calculated via IPCC default methodology and detailed as 0.22kgCH_4/head/year. Yet, this study finds a weighted average of 0.6kgCH_4/head/year (IPCC, 2006). The total emissions from manure management stated in the inventory are 0.15kt of CO_2eq (Jones et al, 2017). This study finds the value to be 0.12ktCO_2eq from CH_4 and 0.17ktCO_2eq from N_2O, showing the inventory having a potential underestimation of 0.14kt CO_2eq overall.

Between enteric fermentation and manure management, the total underestimation was 1.72ktCO_2eq/year. Total emissions in Scotland in 2015 were estimated as 45687.16ktCO_2eq and so the underestimation comprises only a small part of the overall emissions total. However, given that farmed deer production is aimed to increase to 1000 tonnes by 2020 (from 50 tonnes), the underestimation could represent a much larger contribution to the overall inventory in the future (Playfair, 2015).

The underestimation is due to the difference between IPCC default emissions factors and the values determined in this study. Indeed, this study suggests that IPCC defaults do not accurately capture emissions from farmed deer. This finding is supported by NZ calculations finding a value of 22.3kgCH_4/head/year for enteric fermentation. There are no NZ studies on manure management (Ministry for the Environment, 2017). Furthermore, this study has given estimations of feed emissions for deer, which are not specifically allocated in the inventory. Overall, the 2015 inventory states a value of 3.77ktCO_2eq that is directly attributed to farmed deer. However estimates from this study state 8.52ktCO_2eq, suggesting that revision of allocation of emissions to deer farming should be revised.

9.3 Emissions Intensity

With regards to EI, the total value was found to be 381kgCO2eq/kg protein. A breakdown of emission sources is displayed in Figure 8.

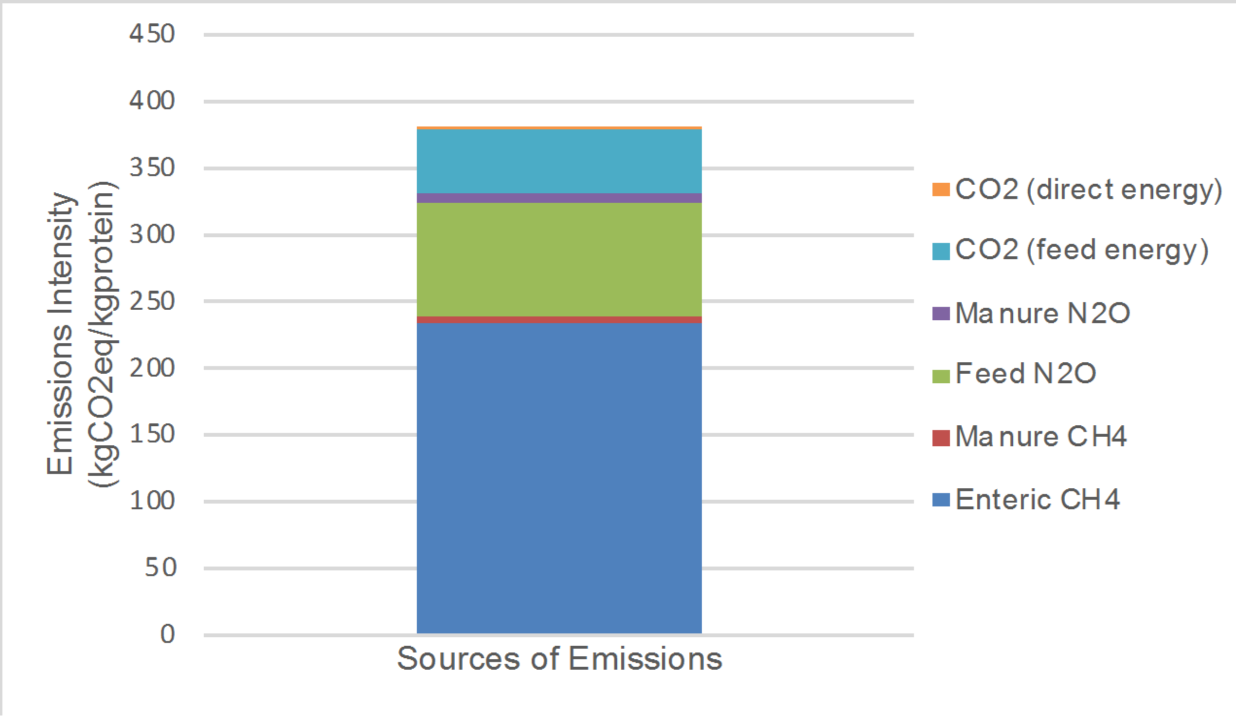

Figure 8: Breakdown Of Emissions Intensity By Sources Of Emissions (kgCO$_2$eq/kg protein)

Enteric CH_4 is, as expected, the predominant contributor to EI with 232.5kgCO2eq/kg protein (approximately 61% of total). Feed production is the second largest contributor to EI where N_2O from feed and related energy use accounts for approximately 35% of the overall EI with a contribution of 84.9kgCO2eq/kg protein for N_2O from feed and 49.4kgCO2eq/kg protein from energy use to the overall total of 381kgCO2eq/kg protein. Emissions from feed arise due to fertiliser and soil nutrient application as well as energy use in farm buildings and in production/processing of commodities (Gerber et al, 2013).

Other factors such as emissions from manure (CH_4 and N_2O) comprise only a small part. This is due to the majority of manure being deposited to pasture thus are included in the feed N_2O category. CO_2 (direct energy) is small as the main energy input to deer farming is assumed to be diesel for vehicles whereas other operations such as dairy cows require additional energy inputs including electricity (Warwick HRI, 2007). More accurate estimations of deer farming energy use would be possible with more detailed farm data.

9.4 Comparison of Venison Emissions Intensity with Other Livestock

The overall EI for the population was calculated as 381 kgCO$_2$eq/kg protein, which was unexpectedly high. Comparison with other animal commodities shows beef to be 295 kgCO2eq/kg protein, small ruminants (i.e. goats) as 201 kgCO$_2$eq/kg protein and meat from poultry as 36 kgCO2eq/kg protein (FAO, 2018). Scottish specific data shows beef and sheep to have a weighted average EI of 157 and 148.8kgCO_2eq/kg protein respectively (Macleod et al, 2017). This suggests that production of venison is significantly more emissions intensive than other meats.

Reasons within the model for this difference have been considered. The feed conversion ratio (FCR) is how effectively an animal converts feed to edible protein. It has an effect on emissions from feed production as well as enteric and manure emissions as a higher feed intake results in higher excretion and emissions expelled. For deer in this study, FCR for meat animals was determined as 20.2 kgDM.kgLW. In comparison, a UK hill lamb has an average FCR of 8 kgDM.kgLW (Hybu Cig Cymru, 2012). Beef of similar age have FCR value of 12 kgDM.kgLW (Vickers & Stewart, 2016). This indicates that deer are less efficient at transferring feed into LW gain and edible protein thus increasing intake and overall emissions. FCR is in turn affected by the growth rate of an animal with slower growth resulting in higher FCR. Digestibility of the feed can also affect emissions however the digestibility used in this model was assumed to be 65%. In comparison with digestibility of beef and sheep, values ranged from 66.3-68.3% for hill/upland beef and 66.3-67.4% for hill/upland sheep (Macleod et al, 2017). Thus, the conclusion is that the difference is not likely due to digestibility.

Another reason for higher emissions may be that deer simply have naturally higher energy requirements than other animals. For example, in NZ calculations, an adult 500kg cow that was gestating and lactating required in total 122.5MJ ME. In comparison, an adult 120kg hind of similar assumptions required 49.5MJ ME (Ministry for Primary Industries, 2013). This equates to 0.25MJ/kg for the cow and 0.41MJ/kg for the deer, suggesting deer may have higher natural energy requirements. However, there is a lack of real evidence of this and so conclusions cannot decisively be made.

In general, a significant reason for the higher EI found with venison is the low meat output per unit DM intake. This is found to be 24kg output/t DM whereas beef/sheep produce approximately 38kg output/t DM (Duchemin, 2011). Productivity of the animal also has an effect as higher productivity means the feed intake goes towards production rather than maintenance. Fertility, mortality, growth rates and feed digestibility also play a part as they link to how productive a herd may be. With regards to feed digestibility, climate can have an effect. Herds in different areas of Scotland may have altering quality of pasture or silage available, which in turn will alter digestibility and feed intake (Food and Agriculture Organisation, 2013).

The dynamics of the herd can alter EI. Herds with a higher breeding population results in a higher level of feed is being used for breeding than for output of produce thus increasing the EI. As such, there are concentrated efforts in Scotland currently to grow the farmed deer population. The model in this study is based on a steady state population however in future years the EI may be higher due to stock being kept for breeding instead of sending to slaughter (Food and Agriculture Organisation, 2013).

9.5 Opportunities for Emissions Intensity Reduction

Studies into how EI can be lowered have been performed in NZ. For example, deer carcass productivity is considered to have an important effect on overall EI. In the study, slaughter animals replaced 129 velvet stags resulting an in increase of the number of finished animals. This led to a 20% decrease in emissions. However, less revenue was made due to the high value velvet being replaced. Thus, productivity must also be linked to efficiency otherwise farmers will not be incentivised to include mitigation measures on their farms. GHG intensity per kg output for solely deer farms was determined as 33.6 EI/kg output due to the low ouput per hectare of deer. Yet, mixed beef, sheep and deer systems had an intensity of 20.2, showing that mixed farms have a lower EI (Duchemin, 2011).

As emissions level is linked to the feed intake of an animal, the solution to reducing EI lies in increasing the product output per kg DM consumed. The first and second largest contributors to EI found in this study (enteric fermentation and N_2O from feed production) are both affected by feed intake. Increasing the output while keeping the same level of feed will mean the same N_2O emissions from feed production are divided over a larger output. The level of CH_4 produced in enteric fermentation is altered by feed intake. Furthermore, increasing the meat yield per head, decreasing the age at slaughter and increasing the finished slaughter weight of deer are considered to lower the overall EI. Increasing herd productivity also allows fewer animals to be farmed while keeping the same output therefore reducing emissions (New Zealand Agricultural Greenhouse Gas Research Centre, 2017). A NZ carbon footprinting of venison from farm to restaurants in Germany found that 93% of emissions were attributed to the on-farm stage indicating this as an area of focus. Scenarios that most affected EI were switching to a once-bred system where hinds are sent to slaughter after first calving (11% decrease of EI) and in finishing deer at a younger age (10% decrease of EI) (Lieffering et al, 2011).

9.6 Benefits of Venison Consumption

While this study shows there to be high EI associated with venison production, consumption of the meat does provide some benefits. A study found that venison had 25% of the fat content of beef. Venison also had a better ratio of polyunsaturated and saturated fatty acids and a lower atherogenic index. This means consumption resulted in less fat deposition in arteries than beef.

Furthermore, the study found venison to be more flavourful, easier to chew and a better texture than beef (Bureš et al, 2015). Another aspect is the positive protein-fat ratio found in venison. The meat provides a high level of protein coupled with a lower fat content in comparison to other species. For example, venison steak was found to have 22.5% of protein compared to 0.7% of fat whereas beef had 17.6% of protein to 7.9% of fat and lamb 17.9% of protein to 9.1% of fat (Aidoo & Haworth, 1995).

Deer co-products (particularly antlers), often from farmed deer, are used throughout Asia in traditional medicines mainly used for kidney and hormonal function. This shows both a potential health and cultural benefit. However, the true mechanisms behind traditional medicines are not backed by scientific evidence. Scientific trials have been conducted where the effect of antler treatment was considered with regards to blood pressure and cholesterol levels. Cholesterol was found to decrease in the brain, liver and spleen (but increase in kidneys) and blood pressure was found to decrease in 26 out of 32 patients. Furthermore, the FDA approves velvet antler for use in arthritis treatment. While studies are limited, there may be a potential future contribution of deer products to medicine (Kawtikwar et al, 2010).

Deer are also particularly adept at survival on low quality ground therefore pose an option for agricultural land that cannot be used for other purposes. Given the high incidence of LFA land in Scotland, this could be particularly beneficial. Red deer generally calf on their own without major problems and calf mortalities are often related to insufficient herd management (Shaw, R. Personal Communication, January 26 2018).

9.7 Issues with Methodology

The primary issue throughout the study was developing a Tier 2 model without optimal detailed population data. For example, New Zealand studies have detailed data on the amount of animals per subcategory however in this model, assumptions had to be made to derive these values. This data is available for cattle and sheep in Scotland but not deer. The New Zealand model splits the population into more subcategories by age, which allows for better estimation of emissions from young deer. It was still possible to develop a more accurate representation of Scottish deer farm emissions than with using default Tier 1 methodology however continual revision of the model would be beneficial as the deer industry grows and better population data becomes available. Better population data would also allow more subcategories to be included enabling the differing requirements of younger animals to be more effectively captured.

Furthermore, the IPCC and MPI guidelines are missing specifics for deer resulting in parameters for sheep being used as these were deemed to be most similar. Indeed, studies suggest that there are some small differences in that sheep appear to digest dry matter and cellulose slightly more efficiently than red deer. However the conclusion is that digestion in sheep has close similarities to digestion in red deer (Maloiy & Kay, 1971). The use of data from sheep is therefore deemed acceptable for use in these calculations however more accurate representation would be reached with further research into calculations for deer.

The methodologies for energy requirements and emissions estimation calculations undergo regular review and development. As such, the calculations included in this report are considered the most appropriate at the time of writing in terms of current recommendations on calculations and the available raw data for the Scottish population. As the equations and the values used for constants within them are evaluated, it is recommended for the model used in this report to also be developed. This will allow for better estimation of the energy requirements for the deer population with regards to their seasonal and annual changes in terms of their physical characteristics.

9.8 Future Study

A potential option for further investigation would be to consider the wild deer population in Scotland. An SNH study conducted to determine this estimated that wild venison might have a carbon footprint approximately 38% lower than beef and 49% lower than lamb. However it only considered a small proportion of the overall population and used the 1997 IPCC emission factor (10.4kg CH_4/head/year), which is almost half of the current emission factor of 20kg CH_4/head/year (IPCC, 2006). It also did not consider N_2O from excretion. Consideration of the overall population that are not stalked for deer hunting was also not included. Thus use of this study and comparison of the carbon footprint to other agricultural commodities is therefore not recommended (Natural Capital Ltd., 2009).

The wild population is considerably bigger than the farmed deer population and so is likely to have a larger impact in terms of total emissions. They may also have a higher EI than farmed deer due to poorer diet and higher activity levels (so greater feed intake) (Natural Capital Ltd., 2009). However, some differences are present between the two groups that will render the model created in this study inaccurate for comparison. For example, the wild deer population have a large impact on biodiversity and forestry, therefore their impact on carbon sequestration would also have to be considered (Holland, et al., 2017). The grazing and birth/death rates of a wild population are also more variable and difficult to discern. Emissions from manure would also be more difficult to estimate. As such, this remains an area of limited knowledge that would benefit from further research with regards to reducing Scotland’s impact on global greenhouse gases.

Another potential option is to consider the best way to grow the deer industry in Scotland whilst keeping emissions to a minimum. The model can be used to simulate different future situations and show how alterations in physical characteristics of the population could affect emissions, such as LW increase as well as changes in feeding or manure management systems dependent on how the industry grows. An economic aspect could be considered as to what is the most cost effective way to increase production while keeping environmental impacts to a minimum.

Furthermore, studies specific to Scotland on emissions mitigation and achieving the lowest EI per kg protein from the population would be beneficial, while allowing for profit to be made by farmers and encouraging more into the industry. Given that enteric fermentation comprises the largest proportion of the overall EI, this represents an area of potential future focus as well as reducing emissions from feed production.

10 CONCLUSION

The farmed deer sector in Scotland, while small, represents a potential economic opportunity for the country. However, it is clear from this study that the environmental impact of venison production with regards to GHG emissions is high in comparison to other livestock. The EI of Scottish venison was found to be higher than other commodities despite having lower emissions per head. From the model, this was determined to be due to the high feed conversion ratio and high net energy requirements of deer in comparison to other livestock. Other general reasons for differences between ruminants are the kg of output achieved per tonne DM consumed as well as productivity, feed digestibility and herd dynamics.

From a GHG inventory perspective, this study found total emissions from the population to be 8.52ktCO_2eq/year. The EI was determined as 381kgCO2eq/kg protein. The IPCC default emissions factor for enteric fermentation is 20kgCH_4/head/year yet this study finds a value of 25.9kg CH_4/head/year. The default emissions factor for CH_4 from manure is 0.22kgCH_4/head/year yet this study finds a value of 0.6kgCH_4/head/year. This results in a total inventory underestimation of 1.72kgCO_2eq/year. This underestimation is small in comparison to the whole inventory. However there has been a considerable increase in market demand for venison as well as a planned rise in venison production. As such, the contribution of farmed venison may have a much more significant impact to Scotland's GHG inventory in the future. As it is an international requirement to meet emissions reductions under the Kyoto Protocol, it is important that all sectors are considered in meeting targets. Agriculture has been identified as lagging in comparison to other sectors in emissions reductions.

If the farmed deer sector is to increase at the required rate of demand, research will be necessary to determine the most efficient ways of farming. An environmental aspect will have to be considered while protecting the perspective of the meat to customers. Ways to decrease the EI of venison while ensuring animal welfare and profitability of farmers will be intrinsic to the sustainability of the industry and the ability of it to grow in Scotland.

Overall, venison as a product poses various positives including health and potential medicinal benefits and an opportunity to use lower quality land for a purpose. However, given the high EI associated with production, it will be essential to find a balance between different conflicts of interest. Taking advantage of the health benefits of consumption, and exploiting the potential economic contribution of the sector is paramount. However, it is more significant that Scotland's global obligations to meet emissions targets are met, in order to aid in securing global sustainability.

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11 Appendices

Appendix 1

Table 17: Herd Data Inputs

Factor	Value	Reference
Stag to Hind Ratio	40 hinds: 1 stag	(Venison Advisory Service Ltd., 2016)
Fertility Rate	92% calves produced, 85% reared to weaning	(SAC Consulting, 2017)
Replacement Rate (Adult Hind)	8-9%	(Fletcher and Sneddon, 2012)
Replacement Rate (Adult Stag)	1%	" "
Calf Mortality (per year)	5%	(CALU, 2005)
Hind Mortality (per year)	1.3%	(Moore et al., 1988)
Stag Mortality (per year)	1.9%	" "
Age at Replacement (first calving) (years)	2	(SAC Consulting, 2017)
Age at Slaughter (years)	1.5	" "

Appendix 2

Table 18: Weight And Age Range Of Subcategories

Factor	Age at Entry (years)	Age at Exit (years)	Weight at Entry (kg)	Weight at Exit (kg)	Average Weight (kg)	Growth Rate (kgLW/day)
Adult Hind	2	12	100	120	110	0.01
Replacement Hind	0	2	9	100	54.5	0.12
Adult Stag	2	6	133.3	180	156.7	0.03
Replacement Stag	0	2	9	133.3	71.2	0.17
Hinds Bred For Slaughter	0	1.5	9	90	49.5	0.15
Stags Bred For Slaughter	0	1.5	9	110	59.5	0.18

The age at entry was 0 for replacement and slaughter subcategories. The age at entry for adult subcategories upon their first calving or breeding cycle is age 2 (SAC Consulting, 2017). Age at exit for adult, replacement and slaughter subcategories was taken from the SAC Farm Handbook (SAC Consulting 2017).

The weight at entry (i.e. birth) for replacement and slaughter subcategories was taken from CALU technical notes (CALU, 2005). The weight at entry of adult hind and stags (same as weight at exit for replacements) was calculated by considering the weight at 3 years old and the weight at 1.5 years old.

Weight at exit of slaughter subcategories was taken from the SAC Farm Handbook (SAC Consulting, 2017).

Various key deer farmers in Scotland provided the maximum weight (weight at exit) of 120kg for adult hinds and 180kg for adult stags at age 3 (age when growth stops) during a research meeting at Glensaugh Research Station (Loder. A, Culquoich Farm, personal communication, March 20, 2018) (Sneddon. A, Venison Advisory Service, personal communication, March 20, 2018) (Prentice. B, Stagison, personal communication, March 20, 2018) (Barrie. D. James Hutton Institute, personal communication, March 20, 2018).

Appendix 3

Table 19: Pasture Characteristics

Factor	Value	Source
ME_{con}	10	Average of different grassland ME values collected Kirkton Farm (hill farm assumed to have similar grazing to deer farms) (Holland, J. Personal communication April 3rd, 2018)
DE%	65%	Digestible energy of rough grazing (Macleod, M. Personal communication 26th February, 2018)
DMD	0.65	DMD of rough grazing (Macleod, M. Personal communication 26th February, 2018)

Appendix 4

Table 20: Data Used In Nitrogen Calculations

Factor	Value	Source
Nitrogen Content of Feed (rough grazing)	2.56kg/100kg	(Macleod M, Personal communication 26th February, 2018)
Nitrogen Content (Body Tissue)	0.0371kgN/kg body tissue	(Ministry for Primary Industries, 2016)
Nitrogen Content (velvet)	0.009 kgN/kg velvet	(Ministry for Primary Industries, 2016)
Grassland N Content	2.56 kg/100kg	(Ministry for Primary Industries, 2016)

Appendix 5

Energy Requirements Estimation (ME_m) (Ministry for Primary Industries, 2016)

The calculation for energy requirements for maintenance, as described in section 1.4.1 (equation 4), was completed as follows:

$$ME_m = K \times S \times \frac{(0.28W^{0.75} \times \exp(-0.03A))}{k_m}$$

Where:

ME_m= the energy required by each subcategory for maintenance (MJ/animal/day)

K= A value of 1.4 is used for deer

S= A constant with the value 1.0 for hinds and castrated animals an 1.15 for stags

W= Live Weight (kg)

A= Age (years)

K_m= Net efficiency of ME utilisation for maintenance

= 0.02 x ME_{con} +0.5

Additional Energy Requirements for Activity (ME_{graze}) (Ministry for Primary Industries, 2016)

The calculation for the additional energy required for activity, as described in section 1.4.2 (equation 10), is as follows (Ministry for Primary Industries, 2016):

$$\mathrm{ME_{graze}}\left(\frac{\mathrm{MJ}}{\mathrm{day}}\right) = \frac{\left(\left(\mathrm{C} \times \mathrm{DMI}(0.9 - \mathrm{DMD})\right) + 0.05 \times \frac{\mathrm{T}}{\mathrm{GF} + 3}\right)\mathrm{W}}{\mathrm{k_m}}$$

Where:

ME_{graze}= the metabolisable energy required for additional activity of grazing animals

C= 0.05 (same value as used for sheep)

DMI= Dry matter intake per animal. This was originally assumed to be 10 kg/head/day. However more accurate DMI was calculated later in the model and iterations were performed with updated data.

DMD= Dry matter digestibility

GF= Availability of green forage. This was taken to be 3.5 tonnes per head.

T= Terrain factor taken to be 1.5 for deer (similar to sheep)

W= Live Weight (kg)

K_m= Net efficiency of ME utilisation for maintenance

=0.02 x Me_{con} + 0.5

Energy Requirements for Gestation (ME_c) (Ministry for Primary Industries, 2016):

The calculation for additional energy required for pregnancy, as described in section 1.4.6 (equation 22), is as follows:

$$ME_C(MJ\,ME/day) = 0.7 \times TF \times W^{0.75}$$

Where:

ME_C= The additional metabolisable energy required during pregnancy by breeding hinds

TF= Trimester Factor

W= Live weight (kg)

The trimester factor for each month is detailed in Table 20.

Table 21: Monthly Trimester Factor Of Breeding Hinds

Month	Trimester Factor (TF)
July	0.2
August	0.3
September	0.3
October	0.6
November	0.6
December	0.0
January	0.0
February	0.0
March	0.0
April	0.0
May	0.1
June	0.1

Energy Requirements for Lactation (ME_l) (Ministry for Primary Industries, 2016)

The calculation for additional energy required for lactation, as described in section 1.4.4 (equation 20), is as follows:

$$ME_l\ (MJ\ \ ME/day) = \frac{Y \times evl}{k_i}$$

Where:

ME_l= The metabolisable energy required for lactation

Y= the daily milk yield per hind

evl= 5.9MJ/kg

k_i= 0.64

Appendix 6

Gross Energy Need (GE) (IPCC, 2006)

The gross energy requirements of each subcategory were calculated using the IPCC Guidelines equation 10.16. The equation is detailed below:

$$GE = \frac{\left(\frac{NE_m + NE_a + NE_l + NE_{work} + NE_p}{REM}\right) + \left(\frac{NE_g + NE_{velvet}}{REG}\right)}{DE\%/100}$$

Where:

GE = gross energy, MJ day-1

NEm = net energy required by the animal for maintenance (Equation 10.3), MJ day-1

NEa = net energy for animal activity (Equations 10.4 and 10.5), MJ day-1

NEl = net energy for lactation (Equations 10.8, 10.9, and 10.10), MJ day-1

NEwork = net energy for work (Equation 10.11), MJ day-1

NEp = net energy required for pregnancy (Equation 10.13), MJ day-1

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation

10.14)

NEg = net energy needed for growth (Equations 10.6 and 10.7), MJ day-1

NEwool = net energy required to produce a year of wool (Equation 10.12), MJ day-1

REG = ratio of net energy available for growth in a diet to digestible energy consumed (Equation 10.15)

DE%= digestible energy expressed as a percentage of gross energy

REM (equation 10.14) (IPCC, 2006)**:**

$$REM = \left(1.123 - (4.092 \times 10^{-3} \times DE\%)\right) + \left(1.126 \times 10^{-5} \times (DE\%)^2) - \left(\frac{25.4}{DE\%}\right)\right)$$

Where:

REM= Ratio of net energy available in diet for maintenance to digestible energy consumed

DE%= digestible energy as a percentage of the gross energy

REG equation 10.15 (IPCC, 2006)**:**

$$REG = ((1.164 - (5.160 \times 10^{-3} \times DE\%) + (1.308 \times 10^{-5} \times (DE\%)^2) - \left(\frac{37.4}{DE\%}\right)$$

Where:

REG= Ratio of net energy available for growth in a diet to digestible energy consumed

DE%= digestible energy as a percentage of the gross energy

Appendix 7

Methane Emissions From Enteric Fermentation (IPCC, 2006)

The calculation for CH_4 emissions from enteric fermentation was followed as per IPCC equation 10.21:

$$EF = \left(\frac{GE \times \left(\frac{Y_m}{100}\right) * 365}{55.65}\right)$$

Where:

EF = emission factor, kg CH4 head-1 yr-1
GE = gross energy intake, MJ head-1 day-1
Ym = methane conversion factor, per cent of gross energy in feed converted to methane

The factor 55.65 (MJ/kg CH4) is the energy content of methane.

Methane Emissions From Manure Management (IPCC, 2006)

The calculation for CH_4 from manure management was followed as per IPCC equation 10.23:

$$EF = (VS \times 365) \times \left[B_o \times 0.67 kg/m^3 \times \sum \frac{MCF_{(S,k)}}{100} \times MS\right]$$

Where:

EF(T) = annual CH_4 emission factor for livestock category T, kg CH_4 animal-1 yr-1
VS(T) = daily volatile solid excreted for livestock category T, kg dry matter animal-1 day-1
365 = basis for calculating annual VS production, days yr-1
Bo(T) = maximum methane producing capacity for manure produced by livestock category T, m3 CH_4 kg-1 of VS excreted
0.67 = conversion factor of m3 CH_4 to kilograms CH_4
MCF(S,k) = methane conversion factors for each manure management system S by climate region k, %
MS(T,S,k) = fraction of livestock category T's manure handled using manure management system S in climate region k, dimensionless

Volatile Solid Excretion (IPCC, 2006)

The equation for estimating volatile solid excretion was followed as per IPCC equation 10.24:

$$VS = \left[GE \times \left(1 - \frac{DE\%}{100}\right) + (UE + GE)\right] \times \left[\frac{1 - ASH}{18.45}\right]$$

Where:

VS = volatile solid excretion per day on a dry-organic matter basis, kg VS day-1

GE = gross energy intake, MJ day-1

DE% = digestibility of the feed in percent (e.g. 60%)

(UE • GE) = urinary energy expressed as fraction of GE with a value of 0.04

ASH = the ash content of manure calculated as a fraction of the dry matter feed intake with a value of 0.08

18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg-1). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

Appendix 8

Nitrogen Intake (N_i) (Ministry for Primary Industries, 2016)

The calculation for nitrogen intake, as described in section 2.4.1 (equation 41), is as follows:

$$N_i(kg/head/day) = DMI \times N_d/100$$

Where:

N_i= nitrogen intake (kg/head/day)

DMI= dry matter intake (kg/head/day)

N_d= nitrogen content of the diet (kg/kg of feed)

Nitrogen Retention in Live Weight Gain (N_{lwg}) (Ministry for Primary Industries, 2016)

The calculation for nitrogen retained in body weight, as described in section 1.4.6 (equation 22), is as follows:

$$N_{lwg} = N_{bt} \times LWG$$

Where:

LWG= the daily live weight gain per category (kg)

N_{bt}= the nitrogen present in body tissue.