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Reducing the carbon footprint of red meat

Hyland, John

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Reducing the carbon footprint of red meat

Thesis submitted by John Hyland for the degree of Doctor of Philosophy

Supervised by:

Dr Prysor Williams

Prof Davey Jones

PRIFYSGOL BANGOR UNIVERSITY

School of the Environment, Natural Resources and Geography

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Abstract

The contribution of ruminant agriculture towards climate change is significant and responsible for approximately 14.5% of anthropogenic global greenhouse gas emissions. The reduction of sectorial emissions is dependent on farmer decision-making at a multitude of scales, which comprise of the field scale, the farm, farmer typologies (farm scale with focus on farmers), and the community-scale. This conceptual framework provides the basis for the research carried out in this PhD. The first research chapter builds upon previous work carried out by Bangor University where farmers deemed the most practical mitigation measure they could adopt on their farming enterprises was the planting of leguminous crops. The research in this thesis demonstrated that grass-clover systems offered the same yield as grass swards receiving conventional amounts of nitrogen fertiliser. However, nitrous oxide emissions from the grass-clover sward were significantly lower. My second research chapter moves onto the farm scale and investigates the carbon footprint (CF) from 15 farming enterprises over two timescales. Considerable reductions in the CF of beef and lamb were demonstrated if efficiencies were increased to match those of the least-emitting producers. On-farm decisions are motivated by personal interests and goals. Hence, the third research chapter identifies distinct types of farmers based on perceptions of climate change. Four farmer types were identified which can aid the dissemination of climate change information and consequently increase the adoption of climate change measures. The final chapter evaluates social capital and collaboration amongst farmers at the community scale; such interactions can serve to facilitate mitigation and adaptation. Although overall collaboration was low, there was considerable latent social capital which can be used to further encourage collective action. The work carried out in this thesis can help reduce the livestock sector's greenhouse gas emissions across numerous scales; thereby helping the industry meet its emission targets.

Table of contents

List of tables

List of figures

List of abbreviations

AA = acceptance and awareness

AN = ammonium nitrate

ANOVA = analysis of variance

BNF = biological nitrogen fixation

C = concentrate use

°C = celsius

CF = carbon footprint

CF- = carbon footprint of the 25% least emitting enterprises

CF+ = carbon footprint of the least 25% most emitting enterprises

CH_4 = methane

cm = centimetre

CO_2 = carbon dioxide

CO_2eq = carbon dioxide equivalent

conc = concentration

CV = coefficient of variation

d = day

DECC = Department for Energy and Climate Change

DEFRA = Department for Environment, Food and Rural Affairs

DMI = dry matter intake

DMY = dry matter yield

ECD = electron capture detector

ECW = edible carcass weight

E_R = output emissions

ER = environmental responsibility

F = fertiliser use

FAO = Food and Agriculture Organisation of the United Nations

g = gram

GC = gas chromatograph

GHG = greenhouse gas

GJ = gigajoule

GWh = gigawatt hour

GWP = global warming potential

H_2 = hydrogen

ha = hectare

HCC = Hybu Cig Cymru

High N = higher application of nitrogen fertiliser

IPCC = Intergovernmental Panel on Climate Change

ISO = International Organization for Standardization

KCL = potassium chloride

KESS = Knowledge Economy Skills Scholarship

kg = kilogram

K_R = inputs

kWhr = kilowatt hour

l = litre

LCA = life cycle analysis

Low N = lower application of nitrogen fertiliser

lw = liveweight

m = metre

min = minute

MM = manure management

Mt = megaton

N = nitrogen

N_2 = nitrogen gas

NH_3 = ammonia

NH_4 = ammonium

NH_4NO_3 = ammonium nitrate

N_2O = nitrous oxide

NO = nitric oxide

NO_2 = nitrite

NO_3 = nitrate

NO_X = nitrogen oxides

NUE = nitrogen use efficiency

N_R = animal numbers

OECD = Organisation for Economic Co-operation and Development

P = productivism

PAS = Publically Available Specification

PCA = principal component analysis

ppm = parts per million

PR = perceived risk

Prod efficiency = production efficiency

RWC-G = grass swards with red and white clover

SIP = Sustainable Intensification research Platform

SOC = soil organic carbon

t = tonne

Tg = teragram

t0 = time zero

UNFCCC = United Nations Framework Convention on Climate Change

VFA = volatile fatty acids

WC-G = grass swards with white clover

WFPS = water-filled-pore-space

yr = year

Y_R = output

α_R = effect on output from increasing inputs

β_R = effect on output from increasing livestock numbers

ρ_R = production effect

Chapter 1: Literature review

Literature review

1.1 Introduction

Spurred on by productivist ideals, past agricultural policies often focused primarily on output. However, a more sustainable approach to the manner in which food is produced has been increasingly advocated since the European 'butter and cheese' mountains of the 1980s (Almås and Campbell, 2012). Indeed, sustainability has become an important policy theme of UK agriculture (Foresight, 2011). There is a general consensus on three basic elements of sustainable agriculture in the literature: environmental, social, and economic (Carreón et al., 2011). Sustainability is therefore a combination of all of these constructs and the components are included in the term 'Triple-Bottom-Line' as the 3P's: people, planet, and profit (Elkington, 1994).

The multidimensional concept of the triple-bottom-line recognises the presence of an economic dimension which requires feasibility, a social dimension which requires acceptability, and an environmental dimension which requires carrying capacity (Conway, 1987; Gerdessen and Pascucci, 2013; Spangenberg, 2002). The approach sees sustainability as equally important as environmental and economic performance (Bowden et al., 2002; Elkington, 1994). Therefore, agricultural sustainability can be described as simultaneously achieving optimal economic, social, and environmental outcomes (Gerdessen and Pascucci, 2013). Indeed, The Sustainable Development Commission in the UK has developed principles which aim to improve the sustainability of the food system through integration (rather than trade-offs) between environmental, social, and economic outcomes. Through abiding by such principles it's anticipated that a strong, healthy, and just society, living within its environmental limits, can be realised (SDC, 2009).

It is widely acknowledged that food production, and consumption, particularly that of red meat, contributes significantly to anthropogenic greenhouse gas (GHG) emissions which drive climate change. The contribution of livestock towards such emissions is particularly important as the sector accounts for a significant percentage of global emissions. Following criticisms on the methodology used, the FAO has updated its analysis and data on emissions. This new study lowers the estimate of livestock's share of GHG emissions from all direct and indirect activities, from 18 to 14.5% of total global anthropogenic GHG emissions (Gerber et al., 2013). This updated figure of 14.5% has subsequently become the most widely accepted reference in the scientific literature for livestock's contribution towards climate change. The FAO's new study also differs in that livestock can be part of the solution for climate change; a notable change from previous reports. The primary GHGs associated with ruminant production systems are methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). The red meat sector is consequently under considerable pressure to reduce its GHG emissions (Ripple et al., 2013). Mitigation and adaptation measures adopted by farmers within the sector are dependent on decisions taken at an individual scale, a farm scale, by farmers who share the same ethos, and finally by decisions taken at a community scale (Lyle, 2015). The scope of the literature reviewed in this section is to provide scientific and theoretical background to the forthcoming research chapter. The initial part of the review concerns the GHGs associated with red meat production and how they are generated. The quantification of these GHGs for the purpose of carbon footprinting provides the next focus. The review subsequently moves onto actions which can help mitigate emissions and discusses the concept of sustainable intensification. In the final section the importance of perceptions is discussed and how they can used to foster pro-environmental behaviour.

1.2 GHGs associated with red meat production

1.2.1 Methane

Methane (CH_4) is a potent GHG with a global warming potential (GWP) 25 times greater than that of CO_2 (IPCC, 2007). The GWP of a gas depends on how effectively, and at what wavelength, it absorbs infrared radiation, and how long such a gas stays in the atmosphere (Lashof and Ahuja, 1990). The magnitude of each individual gases emissions is expressed in terms of their carbon dioxide equivalent (CO_2eq), usually over a 100 year horizon in order to compare and report emissions from different GHGs (IPCC, 2007). Agriculture contributes considerably to global CH_4 emissions through livestock and the management of their manures (McDowell, 2009). Weighed by its GWP, the Department of Energy and Climate Change estimated that UK CH_4 emissions in 2010 totalled 41.3 MtCO_2e. The sizable amount of such emissions (44%/18.1 MtCO_2e) are attributed to agriculture (DECC, 2012). As a result of future global increase in the demand for food, global CH_4 emissions from livestock production are expected to increase by 60% by 2030 (FAO, 2006). With this in mind, the challenge is to reduce livestock emissions without lowering production levels (Godfray et al., 2010).

1.2.1.1 Main sources of methane emissions

Enteric fermentation

Ruminant animals are prominent sources of CH_4 as they produce high quantities per unit of feed consumed (Liu, 2012). Enteric fermentation, attributed to the digestion process that characterises ruminant animals, is the most significant contributing factor to CH_4 emissions from beef and sheep farming systems (Olivier et al., 1999). Microbes called methanogens form a subgroup called *Archaea* in the fore-stomach of the ruminant; CH_4 is subsequently produced through the fermentation of feed (Buddle et al., 2011). The amount of CH_4

produced differs between ruminant species; sheep produce 25-55 l/day, whereas cattle produce 150-240 l/day (Czerkawski, 1986; Holter and Young, 1992; McAllister et al., 1996). Ruminants differ from non-ruminant animals in that their stomach comprises of four compartments - the rumen, reticulum, omasum, and abomasum (Liu, 2012).

Dry matter intake (DMI) is the main factor driving CH_4 emissions from ruminant species (Kirchgessner et al., 1991; Molano and Clark, 2008; Moss et al., 1995). The digestibility of the feed plays an integral role in the amount of CH_4 produced by the ruminant (Blaxter and Wainman, 1964). CH_4 yield per unit of intake decreases with increasing DMI of forage; this may be explained by a higher rumen turnover, leading to lower digestibility of the diet (Pinares-Patiño et al., 2003a, 2003b). Hence, as the daily feed intake increases, CH_4 emissions also generally increase (Kirchgessner et al., 1991). However, as a ruminant's feed intake increases above its maintenance requirements, CH_4 yield (g/kg DMI) decreases by 5-15% for each multiple of the amount of intake above maintenance requirements (Blaxter and Clapperton, 1965).

The fermentation process primarily occurs in the rumen, which is located at the beginning of the digestive tract (Patra, 2012). The small intestine is flanked by two microbial compartments at both ends which are more efficient for degrading of carbohydrates of the cell walls (Moss et al., 2000). Figure 1.1 represents the processes of the rumen. It highlights the microbial fermentation of the ingested feed to volatile fatty acids (VFA's): mainly acetic, propionic and butyric acids) to hydrogen (H_2) and CO_2.

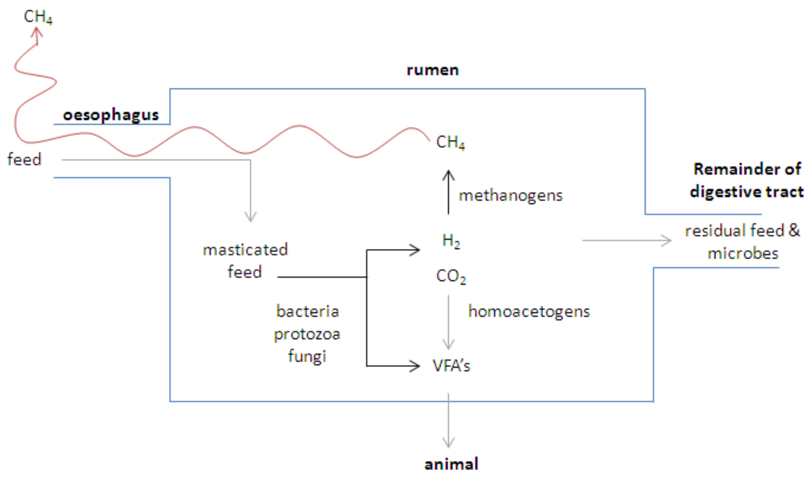

Figure 1.1. Diagram representing rumen processes. Adapted from Buddle et al. (2011). The black lines with arrows indicate the digestive tract of the ruminant, and the animal compartments are in bold text

VFA's are absorbed across the rumen wall, acting as a major source of carbon and energy for the animal. The H_2 is used by methanogens to generate CH_4 (equation 1), which is released by the animal, primarily through belching, into the atmosphere. Residual feed and rumen microbes enter the remainder of the digestive tract and are further broken down, forming a significant source of nitrogen for the animal.

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \qquad (1)$$

Figure 1.2 illustrates the numerous factors which influence CH_4 production in ruminants. The production of CH_4 represents a loss of energy from the animal itself, often up to 6-7% of feed grass energy intake from temperate pasture, or about 10% of absorbed energy (Waghorn and Woodward, 2006).

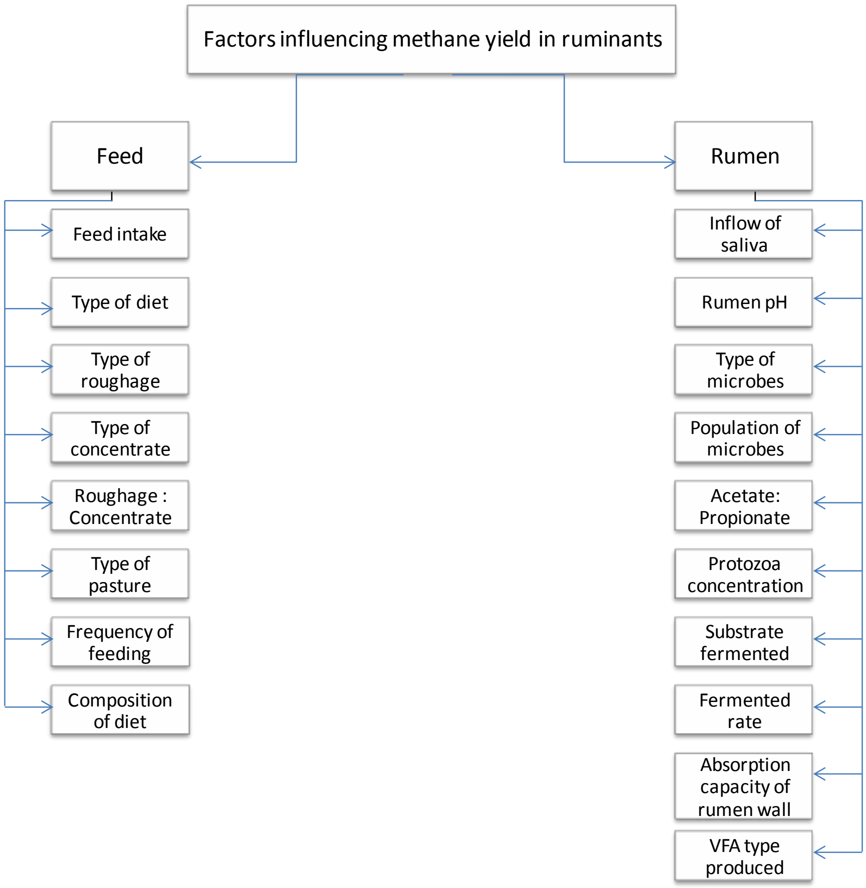

Figure 1.2. Factors influencing methane production in ruminants. Adapted from Sejian et al (2011)

Manure management

The production of CH_4 from livestock manure occurs due to the anaerobic decomposition of organic material contained in faecal matter and bedding material (Batstone and Keller, 2003; Batstone et al., 2002; Hellmann et al., 1997). These organic materials are subsequently degraded to other compounds such as volatile acids by acid-producing bacteria. Subsequently, CH_4-producing bacteria use these volatile acids to produce the aforementioned GHG. The absence of oxygen is essential in this process (Abbasi et al., 2012). The production of CH_4 from manure is also affected by other environmental factors such as temperature (Clemens et al., 2006; Sommer et al., 2007), biomass composition, and manure management (Hill et al., 2001; Ni et al., 2008). Estimations of CH_4 emissions from manure management are based on the assumption that manure has a specific maximum CH_4 producing capacity which is dependent on diet and animal species (Safley, 1992; Steed and Hashimoto, 1994). CH_4 producing capacity is also known as the ultimate methane productivity, or the biochemical methane potential, and is measured in m^3 CH_4 kg^{-1} of volatile solids in manure.

CH_4 emissions attributed to animal housing occur from slurry stored below livestock buildings as a result of favourable anaerobic conditions (Sommer et al., 2009). Temperature has been observed as being a critical factor in determining CH_4 production during slurry and manure storage, with emissions low at temperatures <15°C, increasing exponentially at temperatures >15°C (Clemens et al., 2006; Husted, 1994; Massé et al., 2008; Sommer et al., 2007). Collection yards, however, have been depicted as only a minor source of CH_4 emissions (Ellis et al., 2001; Misselbrook et al., 2001).

If manure is treated as a solid, or directly deposited on pasture, then decomposition occurs under more aerobic conditions, hence less CH_4 is produced. CH_4 losses attributed to cattle farm yard manure heaps can be contribute between 0.4% and 9.7% of the total carbon content of the heap (Chadwick, 2005). Furthermore, the compaction and covering of manure heaps can either increase or decrease CH_4 emissions as these can affect how anaerobic the manure pile is, and its temperature (Chadwick, 2005). The CH_4 emissions from manure spreading occur immediately after application and are short-lived, as methanogenesis is sensitive to oxygen (O_2), and diffusion of O_2 into the manure on the soil surface inhibits CH_4 formation (Chadwick and Pain, 1997; Chadwick et al., 2000). Indeed, within a few days of application, the amount of CH_4 emitted is negligible following the reduction of VFA's (Chadwick and Pain, 1997; Rodhe et al., 2006; Yamulki et al., 1999).

1.2.2 Nitrous Oxide

Nitrous oxide (N_2O) is one of the primary GHGs associated with climate change. Although the atmospheric concentration of N_2O is low, it is a potent GHG with a GWP 298 times that of CO_2 (IPCC, 2007). Agriculture contributes roughly 60% of global anthropogenic N_2O emissions (IPCC, 2007). Globally, beef cattle are the largest source of N_2O emissions from animal production systems (44%), followed by dairy cattle (16%), sheep (12%), pigs (9%), and poultry (6%) (Oenema et al., 2005). With increasing future demands for food, global N_2O emissions levels are expected to rise. Davidson (2012) suggests that global N_2O concentrations will continue to increase mostly unabated unless major improvements in agricultural efficiencies and/or significant changes in dietary habits of the developed world are achieved. N_2O makes the largest contribution to GHGs from European and UK agriculture (Rees et al., 2013). The Department of Energy and Climate Change (DECC) estimated UK N_2O emissions in 2010 totalled 35.6 $MtCO_2e$, with the majority of these emissions attributed to agriculture (80%/28.6 $MtCO_2e$) (DECC, 2012).

1.2.2.1 Nitrification and denitrification

Biological emissions of N_2O are mainly controlled by two microbial processes, nitrification and denitrification. Nitrification describes the oxidation of ammonia N to nitrate N (equation 2), and is controlled by ammonium supply (Hopkins and Lobley, 2009). Ammonia (NH_3) present in the soil is oxidised to ammonium (NH_4^+) and then into nitrite (NO_2^-) by Beta-Proteobacteria and Thaumarchaeota; and finally, NO_2^- is converted (predominantly by bacteria of the genus *Nitrobacter*) to NO_3^- (Kowalchuk and Stephen, 2001).

$$\begin{tikzcd} & & N_2O & \\ NH_3 \arrow[r] & NH_2OH \arrow[r] \arrow[ur] & NO_2^- \arrow[r] \arrow[u] & NO_3^- \end{tikzcd} \qquad (2)$$

Denitrification describes the microbial reduction of NO_3^- to nitrogen gas (N_2). It is an anaerobic stepwise reduction of soil NO_3 to gaseous N compounds, where N_2O is an intermediate product (equation 3). It can be described as a sequence of reactions converting NO_2^- to dinitrogen gas via intermediates including the gases nitric oxide (NO) and N_2O (Van Cleemput and Baert, 1984). Denitrification is the only process that returns reactive N (derived from animal manures, fertilisers, biological N fixation etc.) back to dinitrogen, therefore closing the N cycle (Galloway et al., 2003).

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2 \qquad (3)$$

In the 'hole-in-the-pipe' model by Firestone et al. (1989), soil water content is conceptualised by the relative size of the hole in the pipe through witch nitric oxide and nitrous oxide 'leak' (Fig. 1.3). The bigger the hole, the higher the water content, and the greater potential for emissions. The model has been used by a number of authors to explain spatial and temporal variability of N_2O emissions from soils (Davidson, 2012; Davidson et al., 2000; Oenema et al., 2009; Verchot et al., 2006). It is proposed that the total N oxide flux (NO + N_2O) is proportional to the rate of N cycling. N_2O emissions from pastoral soils are determined by three factors: (i) the rate of nitrification and denitrificacation; (ii) the ratio of the end products of denitrification; and (iii) the diffusion of N_2O through the soil profile (Firestone et al., 1989).

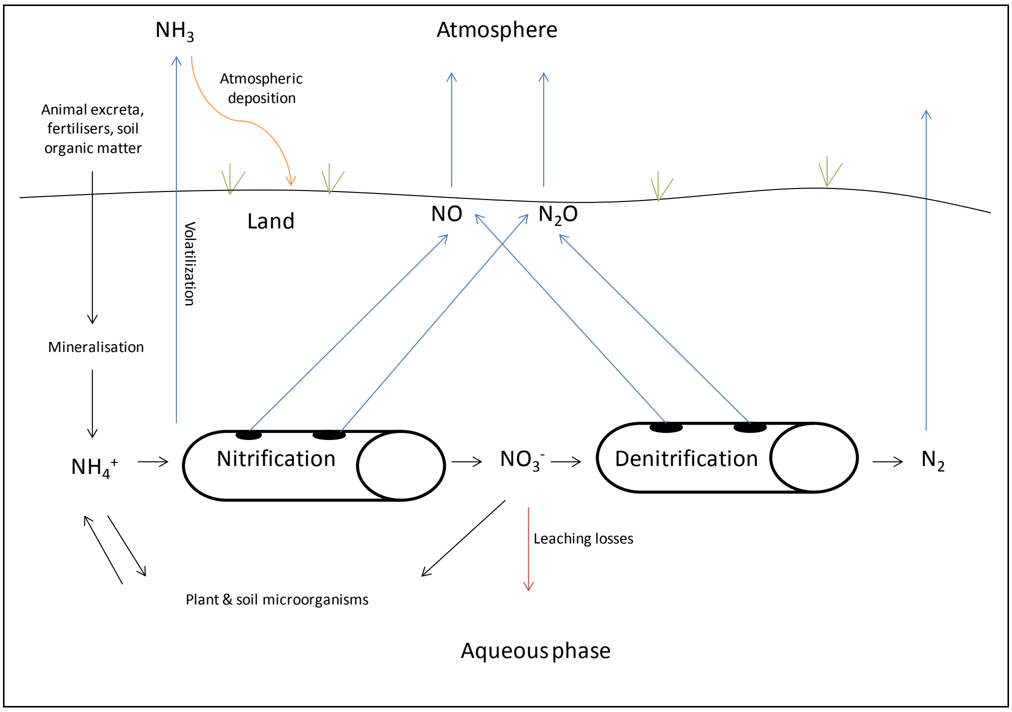

Figure 1.3. The 'hole-in-the-pipe' conceptual model of nitrification and denitrification. Adapted from Firestone, et al. (1989)

Although both nitrification and denitrification produce N_2O emissions, it is denitrification that contributes most towards N_2O emissions from soil (Firestone et al., 1989). Where soil has greater water content, and therefore less oxygen present, denitrification dominates, and more nitric oxide and nitrous oxide is produced. Hence, the relative proportion of each gas emitted from the soil is controlled by the water-filled-pore-space (WFPS). NO dominates emissions with WFPS <60%, N_2O becomes the prevalent gas at WFPS at intermediate WFPS, and at WFPS > 90% di-nitrogen (N_2) dominates the gas flux (Potter et al., 1996).

1.2.2.2 Main sources of nitrous oxide emissions

N-input and supply to grassland

N_2O emissions from soils occurs both directly and indirectly. Direct emissions are as a result of synthetic fertilisers, crop residues, N fixing crops and manure applications. N_2O emissions from direct sources such as mineral fertiliser and animal manure are estimated as 1% of the N applied, incorporated, fixed is emitted as N_2O (Houghton et al., 1996). Indirect soil emissions are a consequence of atmospheric deposition of nitrogen oxides (NO_X) and NH_3 (originating from fertiliser use and livestock excretion of N) and leaching and run-off from fertiliser applied from agricultural fields (Rees et al., 2013). Emissions of N_2O from agricultural systems are associated with the application of synthetic N fertiliser and manure to soils (23%) (Rees et al., 2013). N excretion onto pasture and paddocks accounted for 12%, crop residue, 8%, and manure storage systems 9% of the UK's N_2O emissions in 2009 (Thomas et al., 2011).

Research finds that N_2O emissions associated with applied animal wastes tend to be lower for cattle slurry when compared to that of other farm animals, such as pig slurry, while anaerobic digestion and increased storage time of the wastes prior to application decrease N_2O emissions after application to land (Amon et al., 2001; Clemens and Huschka, 2001; Velthof et al., 2003). Emissions also tend to be higher from wet soils compared to dry soils and from soils poor in organic carbon compared to soils rich in organic carbon (Velthof et al., 2003). Figure 1.4 depicts the key processes associated influencing N in soils from fertiliser application.

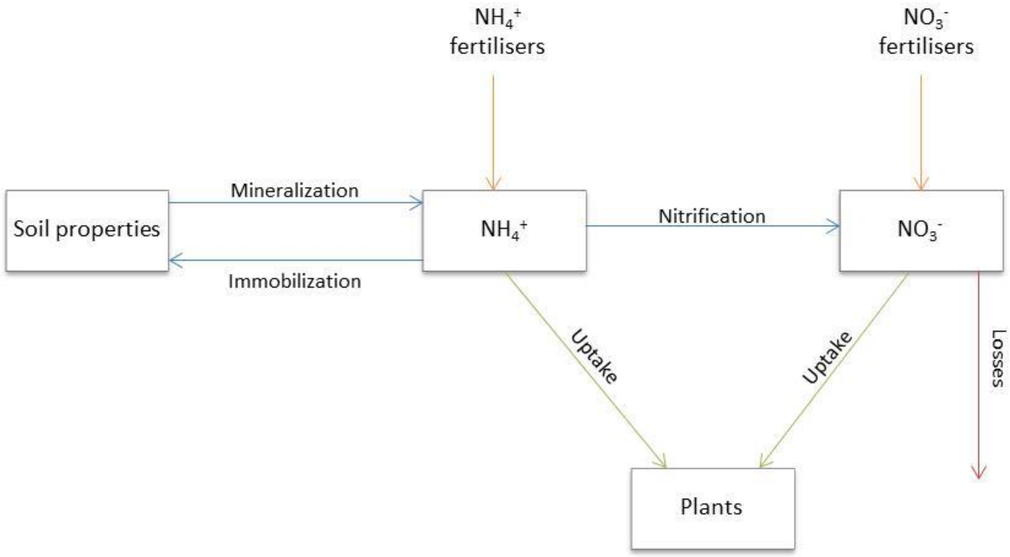

Figure 1.4. An overview of the key processes and transformations influencing N in soils. Adapted from Norton (2008)

Synthetic fertiliser is typically applied to grazed grassland at the beginning, or throughout, the growing season to increase grass yield (Dillon et al., 2009). The use of synthetic fertilisers in modern agriculture has greatly contributed to N_2O emissions associated with the sector (Skiba et al., 2012). However, the ability of soil to convert surplus N is limited and most of this surplus is lost as NO_3^-, N_2O, and N_2 (Ussiri and Lal, 2013). As mentioned previously, emission levels of N_2O can vary considerably depending on fertiliser type, application rate, climate, soil drainage and chemical soil characteristics (Bouwman et al., 2002). Fertiliser application stimulates N_2O emissions for up to three weeks after application, however there are marked difference in the level of emissions depending on the time of year applied (Clayton et al., 1997).

High inputs of N fertiliser (coupled with high protein feeds) allow for higher production levels, but most of the N ingested by the animal is not retained in the milk and meat produced, instead it is mostly excreted (Calsamiglia et al., 2010; Kebreab et al., 2006). This excreted N is conducive to N losses to the environment in the form of NH_3, NO_3^-, N_2O, NO, and N_2, in nitrification and denitrification processes during housing and grazing of the animals, and during manure storage (Oenema et al., 2007). In grazed grasslands, urine and dung patches can add up to 1,000 kg N ha^{-1} annually in a very random and localised fashion, assisting the production of N_2O emissions (van Groenigen et al., 2005). N_2O from excreta deposited to grassland is largely derived through N from urine, rather than dung; Oenema et al. (1997) found that 0.1-3.8% of urine N, and 0.1-0.7% of dung N is emitted to the atmosphere as N_2O. In the UK, cattle are often housed indoors for the wetter months of the year, typically 20-21 weeks annually (Defra, 2012). There are little N_2O emissions from slurry-based cattle buildings (Zhang et al., 2005), but there are some disagreements as to whether straw bedding actively promotes N_2O emissions from housing systems (Amon et al., 2001; Thorman et al., 2002).

1.2.3 Carbon Dioxide

Global livestock production accounts for 9% of CO_2 emissions (Steinfeld et al., 2006). The livestock sector with the largest energy use is the dairy sector, contributing to 42%, followed by the poultry sector with 32%; beef accounts for 11%, whereas the pork and sheep sectors make up the final 10% and 5%, respectively (Warwick and Park, 2007).

Soils are a significant stock of carbon, where the global stock of soil organic carbon (SOC) in the 0-30 cm layer is about twice that of carbon in atmospheric CO_2 (Batjes, 1996), and up to three times of that stored in vegetation (Watson, 2000). In fact, many temperate grasslands can be considered as being a carbon sink as they increase the SOC stock (Jones et al., 2006). The ability of grasslands to sequester carbon is however highly variable and dependent on climate, management, and site characteristics (Soussana et al., 2010). Indeed, carbon can only be accumulated over a finite period of time (Powlson et al., 2011), and is a function of the vegetation type, climate, hydrology, topography and nutrient environment that the soil is exposed to (Gupta and Rao, 1994). There is consequently some disagreement as to the capacity of grasslands to act as a perpetual carbon sink (Smith, 2014).

1.2.3.1 Main sources of carbon dioxide emissions

Land use change

Land use change is the primary source of CO_2 emissions in agriculture. Tillage and cultivation speed up the oxidation process, releasing carbon from soil into the atmosphere, and are two of the many contributors to CO_2 emissions from agricultural soils (Lal, 2004). Crop cultivation accelerates the process by which soil microbes convert carbon present in the soil to atmospheric CO_2 (Schlesinger and Andrews, 2000). SOC is lost when converting grasslands to croplands, and also tends to increase when restoring grasslands (Soussana et al., 2010). Furthermore, draining, cultivation, or liming highly organic soils result in SOC losses (Smith et al., 2008). In a review carried out by Soussana et al. (2010), it was acknowledged that improved management practices could increase carbon stock levels but also have the potential to decrease carbon stock levels (Soussana et al., 2010).

The above ground carbon cycle in grazed grasslands is determined by both the livestock stocking density and digestibility of the herbage. Under intensively grazed systems, up to 60% of the above ground dry matter is ingested by the animal; and subsequently digested and respired. The non-digested carbon, which ranges from 25-40% of intake according to the digestibility of herbage, is returned to pasture as excreta (Lemaire and Chapman, 1996). Only a small fraction of the ingested grassland carbon is accumulated by ruminants (0.6% of carbon intake) under extensive conditions (Allard et al., 2007), but this fraction rises significantly under intensive grazing systems such as dairy (Soussana et al., 2010). Moreover, carbon losses of 3-5% occur through emissions from enteric fermentation (Martin et al., 2010).

Energy use

CO_2 emissions at farm level are also attributed to machinery and electricity use. Monogastric animals tend to be housed throughout the year and tend to be more intensive in terms of their electricity use compared to ruminant systems, since beef and sheep spend most of the year grazing outside (Table 1.1). Although UK beef cattle spend on average between 20-21 weeks of the year housed indoors (Defra, 2012), their energy usage is minimal. The main contributor of direct energy inputs to the production of red-meat is feed, representing 88% of the energy required to produce 1t of beef or lamb meat. Primary energy inputs represent the next largest proportion of direct energy inputs for beef and lamb meat production, representing 30% and 22% respectively of energy used in production (Williams et al., 2006).

Table 1.1. Energy usage in animal production in England and Wales. Percentages of feed, manure and little, housing, and direct energy are expressed in terms of their contribution towards energy demand (Williams et al., 2006).

Commodity	**Poultry**	**Pig meat**	**Beef**	**Lamb meat**	**Milk**	**Eggs**
Unit	1t ECW*	1t ECW	1t ECW	1t ECW	m^3	1t
Primary energy, GJ	17	23	30	22	2.7	12
Feed (%)	71	69	88	88	71	89
Manure and litter (%)	2	1	1	1	0	-4
Housing (%)	1	4	0	0	3	3
Direct energy (%)	25	26	11	11	26	12

***'ECW' = edible carcass weight (killing out % * liveweight). Energy used in slaughter is not included. 1 m^3 milk ~ 1t, 15,900 eggs ~ 1t.**

Warwick and Park (2007) calculated that the annual energy use for beef and lamb production in the UK is 1,122 GWh (Table 1.2), where it was assumed that beef were produced on lowland sites, and sheep enterprises were characterised as being half lowland/upland. The primary energy inputs to both sectors are oil and diesel for field operations. The production of synthetic fertilisers has a high fossil fuel energy requirement due to the NH_3 production stage which commonly uses natural gas; in total the energy requirement equates to approximately 58 MJ/kg N (Ecoinvent, 2012). The amount of GHGs attributed to the production stage of synthetic fertilisers is particularly high, representing between 0.6-1.2% of the world's total GHG emissions (Wood and Cowie, 2004).

Table 1.2. Primary energy inputs to the UK beef and sheep sectors (Warwick and Park, 2007)

	Annual production (000's)	**Primary Energy Inputs (kWhr/unit)**			**Energy use (GWh)**
		Electricity	*Other static*	*Mobile machinery*	
Beef cows	1,768	trace	trace	453.1	801
Ewes/shearlings	16,990	trace	trace	18.9	320
Total					**1,122**

1.3 Quantifying GHG Emissions

1.3.1 Carbon footprint: an introduction

The contribution of the agricultural sector towards GHG emissions has been already specified in previous sections. To identify where emissions can be reduced in the production chain, it is important to quantify emissions to determine a systems impact on the global environment. The environmental impact of food consumption is usually quantified either by life-cycle-analysis (LCA) or carbon footprinting. In LCA, emissions and resource use that occur at all phases in a product's lifecycle are quantified and used to calculate its respective environmental impact (Baumann and Tillman, 2004). The concept of the carbon footprint can be traced back as being a subset of the 'ecological footprint' which was proposed by Wackernagel (1996) in the 1990s. It can be defined as a measure of the exclusive total amount of GHG emissions that are directly and indirectly caused by an activity, or that are accumulated over the life stages of a product (Nijdam et al., 2012). The methodology of carbon footprinting is continually evolving (Pandey et al., 2011), and is based on LCA guidelines (ISO, 2006) and PAS 2050 (2011), which are usually combined with GHG emissions algorithms recommended by IPCC. The carbon footprint of a product is often used as a guide to customers and policy-makers but only includes the environmental impact of GHGs, whereas the LCA aims at comprehensively assessing a broader range of environmental impacts (e.g. eutrophication potential, acidification potential). However, in comparison to indicators on eutrophication, acidification, and biodiversity, which are all site-specific, the global warming potential of GHGs is uniform regardless of where emissions originate (Röös et al., 2013). Indeed, the ability to communicate a value which is both globally applicable and accepted is one of the attractions of the carbon footprint.

1.3.2 Reporting protocols for agricultural GHGs

To quantify the overall impact of GHGs, it is important to take into consideration the respective GWPs of the distinct gases (Table 1.3). To meet reporting requirements established by the United Nations Framework Convention on Climate Change (UNFCCC) for Annex I countries, the IPCC first established guidelines for calculating national GHG inventories in 1996 (IPCC, 1997).

Table 1.3. CO_2 equivalents for the GWP of CH_4 and N_2O for different time perspectives (IPCC, 2007)

Gas	20 years	100 years	500 years
CH_4	72	25	7.6
N_2O	289	298	153

These guidelines required that emissions, from all sectors of the economy, were to be calculated in six categories, namely: energy; industrial processes; solvent and other product use; agriculture; land use change and forestry; and waste. These categories were subsequently reduced to four in 2006. In the case of reporting emissions that arise from agricultural systems, land use change and forestry were combined into a single category called 'agriculture, forestry and other land use' (IPCC, 2006). Most Annex I (developed) countries prepare national annual under the United Nations Farmework Convension on Climate Change (Webb et al., 2014).

The robustness of such inventories is dependent on developing country-specific emission factors and verifying emission inventories via modelling and/or direct measurement (Crosson et al., 2011). Consequently, a three-tiered methodology was developed for quantifying emissions which allowed for increased inventory refinement where possible, while recognizing that there were variations in the availability of data, technical expertise, and inventory capacity across nations (Crosson et al., 2011). The tiered system created was predicated on the availability of emission factors associated with activity data. Tier I is the simplest approach, and relies on default emission factors published by the IPCC (2006). Tier II is also empirical in nature, but emission factors are instead derived from experimental work that is country-specific (Rochette et al., 2008). The most complex method is Tier III, and relies on process-based models (Smith et al., 2004). Moving to a higher Tier is advisable where possible when conducting a product's carbon footprint. The IPCC classes non-CO_2 emissions from agriculture into the following categories: enteric fermentation; manure management; rice cultivation; agricultural soils; the burning of savannahs; and the burning of agricultural residues. Sources, or sinks, of CO_2 that result in changes in biomass carbon or SOC are classified in agriculture, forestry and other land use (IPCC, 2006). An overview of how emissions from agricultural livestock systems are calculated is shown in Table 1.4.

Table 1.4. Overview of the calculation of agricultural GHGs according to IPCC methodologies

Carbon dioxide:
Emissions of CO_2 are of a consequence of practices such as liming and land use change. In the case of liming, emissions are expressed as the amount of lime applied multiplied by the emission factor of limestone (IPCC, 2006a).

Methane:
Methodologies, whether they are Tier I or higher, are usually based on animal categories, daily feed intake, and the nutritional value of the diet (IPCC, 2006a).

Nitrous Oxide:
Tier I methodology estimates direct N_2O emissions as being 1% of N applied to soils as synthetic fertiliser, manure, and crop residues. Indirect N_2O emissions are estimated as 1% of N from volatilisation, and 0.75% of leached N (IPCC, 2006).

Enteric fermentation:
Estimates are based on animals' average daily feed intake as gross energy (GE) (MJ/day), and CH_4 conversion rates. Default gross energy values for Tier I methodology is assumed from animal body weight, average weight gain, diet digestibility, pregnancy, and their level of feed. For example, for beef cattle fed on a diet based on forage it is predicted that 6.5% +/- 1% of gross energy is converted to CH_4. This results in an estimated CH_4 of 109 kg/cow/year in Western Europe. IPCC estimates that sheep emit 8 kg CH_4/year through enteric fermentation.
More information is required for Tier II, and especially Tier III, methodologies in relation to the nutrient content and digestibility of the feed. Tier II approaches involve the quantification of GE values generated from a national, or regional, level. Furthermore, Tier III methodologies focus on farm level parameters such as genotype differences, seasonal effects, and variations in conversion rates (IPCC, 2006).

Manure management:
Tier I relies on quantifying the CH_4 emissions from manure management as the product of the livestock population multiplied by the respective animals emissions factor (Y_m). The emissions factor is based the climate of the region, and the prominent manure management system.
Tier II quantifies the quality of volatile solid produced by livestock and the maximum amount of CH_4 that can be produced from that manure type. This is measured using a specific CH_4 conversion factor, which varies with the manner in which manure is stored and the climate, both of which are country-specific (IPCC, 2006).

The UK currently adopts a Tier I approach for agricultural inventories for the majority of its emission factors. As this is a relatively simplistic approach, which may not be relevant for UK conditions, there has been a push towards a more sophisticated inventory based on Tier II methodology. However, Tier I methodology will continue to be used for inventory analysis until such time as a Tier II method has been adopted (expected post-2016) (Defra, 2011). Nevertheless, IPCC Tier II methodology has recently been adopted for emissions from enteric fermentation from beef cattle and the management of ruminant manure (Webb et al., 2014). Tier I assumptions continue to be used as the default emission factor for enteric fermentation for sheep; however, the UK uses a country-specific emission factor for enteric fermentation for lamb, set at 40% of that for an adult sheep (Webb et al., 2014).

1.3.4 Calculating a carbon footprint

The three sectors (agriculture, land use change, and forestry) in which agricultural systems' emissions are reported in accordance to IPCC guidelines do not cover emissions that arise from indirect sources such as industrial processes and waste categories (IPCC, 1997). As such, if data from these three sectors are combined to generate a whole farm balance, any emissions generated outside of national boundaries are not included. Furthermore, farmer activities that reduce GHG emissions may not be reflected in IPCC methodologies (Defra, 2011). Therefore, whole farm models are widely adopted because the structure of IPCC protocols for reporting GHG emissions are not conducive to integrating systems analysis as a result of the sector-based approach. Indeed, modelling at a farm level has been recommended by authors such as Weiske et al. (2006), since mitigation measures may have differing abatement potentials at the farm and at the farm component level. Whole-farm models may be classified as systems analysis models or LCA models.

There are three methods that can be used to calculate the carbon footprint of food items: modelling, aggregated, and empirical (Taylor et al., 2010). Modelling carbon footprints typically relies on theoretical considerations of agricultural systems rather than data collected from such systems, and therefore does not represent any variations between farms. Aggregated carbon footprints are based on real-farm data that after collection has been combined to form a national statistic, allowing for general observations on best practice management. Empirical carbon footprinting follows an applied approach based on inputs and process data collected directly from the farmer via a questionnaire and subsequently analysed using relevant emission factors. The approach towards carbon footpinting is both determined and constrained by the size of the study. Empirical data from reliable sources offers the optimal approach to gather emissions data as it represents the best opportunity to obtain accurate measurements. However, such an approach is very time consuming and often not feasible or practical for larger studies.

A typical beef and/or lamb ‘cradle to farm gate’ system would include GHG gases from: (i) the emissions associated with the individual ingredients of concentrate feed production, transport, and processing: (ii) the emissions associated with N fertiliser production, transport, and application; (iii) emissions associated with livestock and related manure management; and (iv) emissions associated electricity, and diesel for agricultural operations (Fig. 1.5).

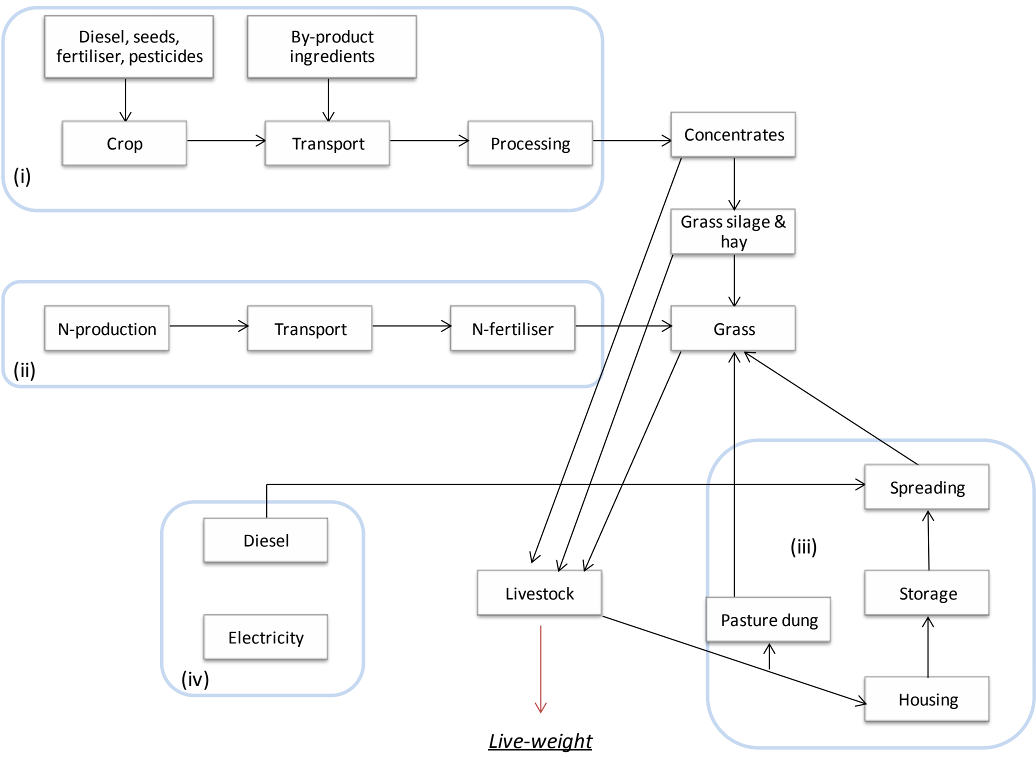

Figure 1.5. A flowchart of a typical 'cradle to farm gate' production system for beef and/or lamb. Adapted from Casey and Holden, (2006)

The magnitude of the carbon footprint of a product is determined by the system boundaries in which such a product is analysed. For the case of beef and lamb, most carbon footprints system boundaries are set from ‘cradle to farm gate’, where all direct and indirect emissions are incorporated into a footprint from the birth of an animal until it leaves the farm for slaughter, and expressed in a functional unit (usually expressed as CO_2eq/kg live-weight) (Edwards-Jones et al., 2009).

1.3.5 The carbon footprint of beef and lamb

Some farming systems will have higher footprints than others due to location and farm characteristics, i.e. farms that have a high percentage of organic soils will inevitably have a higher footprint because of the greater N_2O emissions associated with such soil types (Edwards-Jones et al., 2009; Taylor et al., 2010). For instance, Jones et al. (2013) elicited carbon footprints for Welsh lamb of 10.85, 12.85, and 17.89 kg CO_2e/kg live-weight for lowland, upland, and hill farms respectively.

The carbon footprint of beef has received considerably more attention than that of lamb. Much like lamb, direct pre- and on-farm emissions for beef production systems are primarily dominated by enteric fermentation; where 55–92% of emissions are directly attributed to the process (Ridoutt et al., 2011; Vergé et al., 2009). Fertiliser production and emissions from manure storage compile, in equal parts, towards the rest of the footprint (O’Brien et al., 2011). Extensively farmed beef can result in a carbon footprint which can be three to four times greater than intensively farmer beef. Casey and Holden (2006) estimated that a suckler-beef production system, typical of many Western-European countries, produces 11.26 kg CO_2e kg/year of live-weight. However, there have been a wide range of carbon footprint values reported from global beef production, and range from 9–129 CO_2e kg of live-weight (Table 1.5). Differences between extensively and intensively famer beef can be ascribed to the greater feed efficiency of intensively farmed cattle, such as those kept in feedlots, compared to those reared in extensive systems (Pelletier et al., 2010).

Table 1.5. Carbon Footprint of product per kilogram of product from several LCA and CF studies (cradle to retail, n = number of analysed products). Adapted from Nijdam et al. (2012)

Product	**Carbon footprint (kg CO_2e kg^{-1})**
Beef (15 studies, n = 26)	*9 -129*
Industrial system (n = 11)	9 - 42
Meadows, suckler herds (n = 8)	23 - 52
Extensive pastoral systems (n = 4)	11 - 129
Culled dairy cows (n = 3)	9 - 12
Mutton and lamb (4 studies, n = 5)	*10 - 150*

Differences can be attributed to a host of variables, such as the type of farming system, location, the type of management practices, the boundary of the study, and the resource use that has been considered (Desjardins et al., 2012). Nevertheless, red meat has an inherently higher carbon footprint than proteins produced from monogastric animals, such as pork (3.9 – 10 kg CO_2e/kg), chicken (3.7 – 6.9 kg CO_2e/kg), and eggs (2 – 6 kg CO_2e/kg) (De Vries and De Boer, 2010; Nijdam et al., 2012). However, in many countries such as the UK, land that is used in extensive systems is only suitable for the grazing of ruminant animals and not favourable towards arable or monogastric production; therefore converting grass into an edible and high protein food source for human consumption. Such extensive production systems, despite their higher GHG emissions, could thereby be described as a land-efficient method of food production; especially where measures to sequester carbon are implemented on farms.

Large sequestration rates can cancel out enteric emissions from enteric fermentation, manure, and feed production. Without any sequestration, Cederberg et al. (2009) assumed carbon footprint of extensively breed beef to be 36 kg/CO_2e per kg. When carbon sequestration was included in the analysis, the carbon footprint was substantially reduced. Schmidinger and Stehfest (2012) estimated that by not incorporating sequestration into analyses that the missed potential carbon sink, over a 100 year horizon, to be 166.4 kg/CO_2e for Brazilian beef, 22.1 kg/CO_2e for Irish beef, and 14.8 kg/CO_2e for Dutch lamb. Thus, the inclusion of carbon sequestration in footprinting models can cause potentially large differences within, and between, farming systems. However, the variability and uncertainty associated with soils potential to sequester carbon has led to few studies including carbon emissions from soil, or carbon uptake from changes in soil organic matter, in their models (Röös et al., 2013).

1.3.6 Allocation

If a system has more than one saleable output then allocation is required to assign the environmental impacts of the functional unit. Allocation concerns the issue of distributing inputs, to the outputs generated from a farming system. Different allocation methods include economic allocation, mass allocation, and allocation based on protein content, on potential environmental impacts of each co-product delivered from the system (Nguyen et al., 2012). Economic allocation can be used for feed ingredients derived from processes yielding several co-products, and the market value of the live-weight mass of each co-product. Mass allocation implies that there is no difference in quality between live-weight mass of different animal types. Protein-based allocation is based on the protein content in the live-weight mass of each co-product (Nguyen et al., 2012). The method of allocation can have a decisive effect on the carbon footprint of livestock products (Cederberg and Stadig, 2003). Desjardins et al. (2012) observed that by using mass allocation for Canadian conditions, that at the exit gate of slaughterhouse, the carbon footprint of cattle was 12.9 kg CO_2e/kg of produce. Based on an economic allocation, the carbon footprints was 19.6 kg CO_2e/kg.

1.3.7 Uncertainties associated with carbon footprinting

Measuring and modelling GHG emissions from agricultural production involves some uncertainty (Röös et al., 2013; van Middelaar et al., 2013). Although the IPCC (2007) method of calculating GWP is generally accepted as a legitimate mid-point indicator, its validity has been questioned (Tanaka et al., 2010). Variation surrounding farm-system input and output parameters, along with the inherent uncertainties associated with emissions factors, can have large implications for the reporting of emissions (Basset-Mens et al., 2009). Data uncertainty and model uncertainty aggregate, adding to the uncertainty associated with a carbon footprint model, which in itself inherits some uncertainty from functional unit, boundary, and allocation parameters (Fig. 1.6).

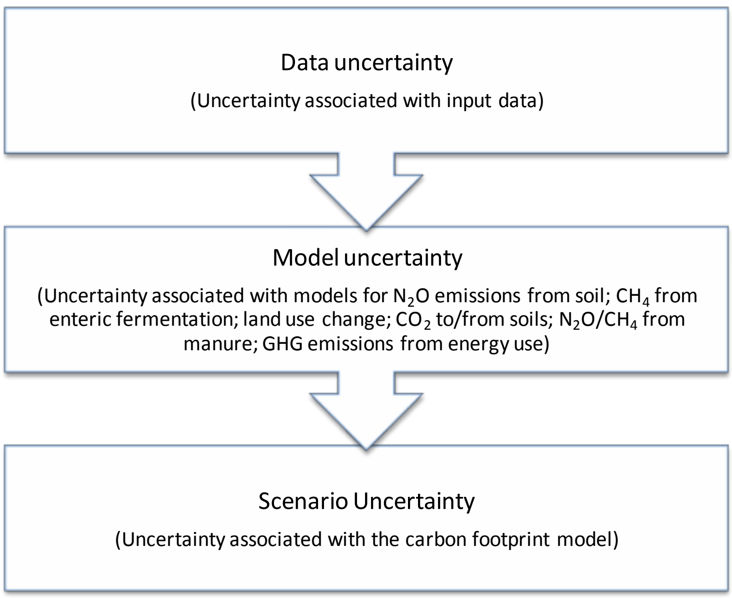

Figure 1.6. Uncertainties associated with the carbon footprint of livestock products. Adapted from Röös and Josefine (2013)

To overcome data uncertainty, ISO standards require the inclusion of sensitivity analysis (ISO, 2006). A sensitivity analysis evaluates the impacts of possible errors and also explores how altered management practices may affect the overall carbon footprint of the farm (Taylor et al., 2010).

1.4 Sustainable intensification: a possible solution to GHG reductions?

Although emissions associated with livestock products are substantial, the global demand for sustenance has risen substantially as the world population increases and gains wealth to purchase more varied and resource-intensive food. The global food price spike of 2007-08 brought further attention to the fact that global demand for food was starting to rise faster than supply (Mitchell, 2008). These challenges require action throughout the food system that can meet the multiple challenges of increasing the provision of food while lowering emissions associated with production. It is widely acknowledged that one of the best and most effective ways that the livestock industry can reduce emissions is by increasing efficiencies of production (Elliot et al., 2014; Pullar et al., 2011). In fact, the FAO predict that if the higher emitters adhere to the production practices of their least emitting peers that emissions associated with livestock could be reduced by 30% (Gerber et al., 2013). Some mitigation measures may require an alternative and less productive focused ethos which may not be favoured by the farmer (Garnett et al., 2013). However, many mitigation measures are a win-win in terms of production and the environment. Against this backdrop, The Royal Society championed the concept of sustainable intensification (SI) (The Royal Society, 2009).

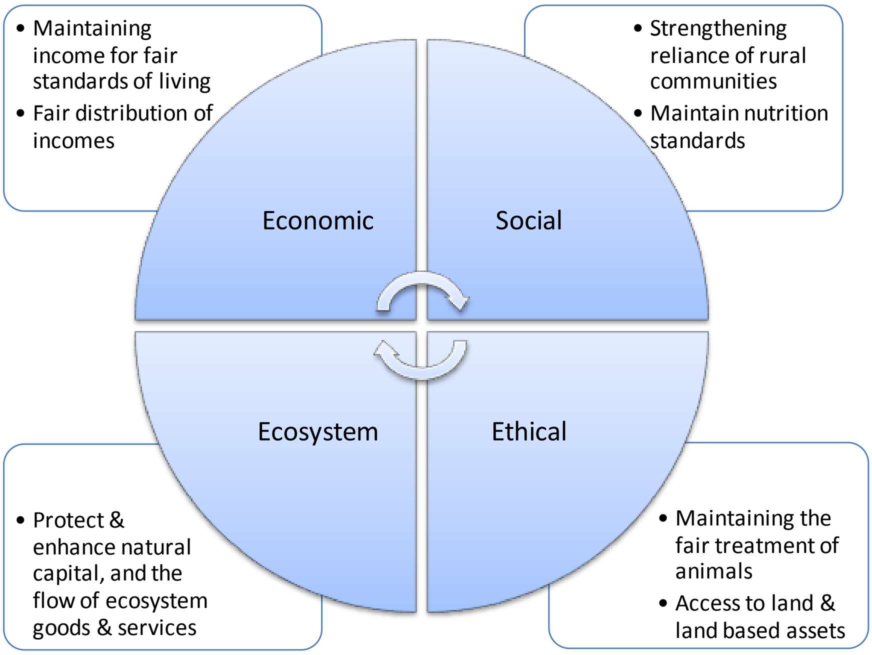

Figure 1.7. Dimensions of sustainable intensification (Barnes and Poole, 2012)

The principle of sustainable intensification is based on increasing output without adverse environmental impacts, and without the cultivation of more land (Garnett and Godfray, 2012; Smith, 2012). Some authors consider that the concept should go further than requiring no additional environmental harm; thereby involving increases both in food production and the flow of eco-system services (Firbank, 2009; Foresight Report 2011; Garnett et al., 2013) while not compromising animal welfare (Wathes et al., 2013). Other studies have called for it to include additional economic and social dimensions (Barnes and Thomson, 2014; Barnes et al., 2011; Garnett et al., 2013). As such, farming systems can be thought of being as meeting the principles sustainable intensification if they satisfy four dimensions: economic; social; ecosystem; and ethical (Fig. 1.7).

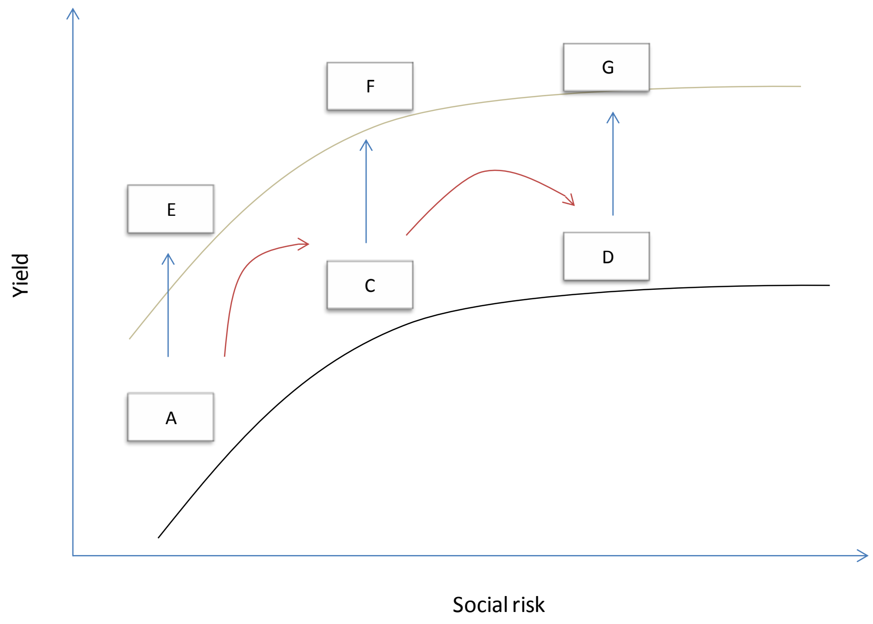

Figure 1.8. Risk return framework of sustainable intensification (Barnes and Thomson, 2014)

Much like sustainability, there is no agreed definition of sustainable intensification, the concept can be thought of as producing more output from the same area of land while reducing the negative environmental impacts while at the same time increasing contributions to natural capital and the flow of environmental services (Godfray et al., 2010; The Royal Society, 2009). Barnes and Thomson (2014) used a risk return framework (Fig. 1.8) to conceptualise sustainable intensification. Yield growth is measured against social risk (environmental, economic, and wider environmental dimensions). The points A, C, D, E, F, and G represent stages in the trajectory of a farm towards intensification. The black line in the graph is a technology frontier, where in a given system a farm is operating at its most efficient with the technology available for that industry. To increase yield, the only option is to intensify production, moving from A-C. However, this expands the amount of resources needed and hence increases social risk. Consequently, such a move along a technology frontier is not sustainable and cannot be depicted as being sustainably intensive. Therefore, Barnes and Thomson (2014) denote that the only way to view sustainable intensification is as a new technology which is represented as a grey line on the graph. Subsequently, a farm can increase its output by shifting to point E while not increasing its social risk as no extra resources are needed in the process. Per contra, it is not possible to move from E-F as increased yield increases social risk. Hence to meet the principle of the concept, a farm must rise upwards to a new frontier where the relationship between inputs and outputs are reconfigured to where there is no social risk attributed to such a modification.

Although sustainable intensification incorporates other objectives, it can be inferred that land that is best suited for the purpose of food production and other agricultural products should be used as such, in the most resource and GHG efficient manner possible (Gerber et al., 2013; Hester and Harrison, 2012). However, efficiency gains should be done with the concept of sustainable intensification in mind; thereby, not unduly harming the environment.

1.5 Influences of pro-environmental behaviour

Central to climate change responses is the role of the individual (the farmer) who exhibits beliefs and risk perceptions of climate change. Unless it is examined how individuals perceive climate change, along with the factors which influence mitigation and adaptation behaviours, it is unlikely that society will act effectively (Clayton and Myers, 2009). There are numerous options available to farmers to fulfil the concept of sustainable intensification; however, correct drivers are needed to influence the aspirations of individual farmers to meet the concept (Firbank et al., 2013). Although sustainable intensification may serve as a vessel to reduce emissions, farmers must be engaged with the issue of climate change to best achieve emission reductions (van Bueren et al., 2014). There is consequently a need to determine what influences farmers' behaviour in relation to climate change to instigate behaviour change. Otherwise, concepts such as mitigation, adaptation, and sustainable intensification may get misinterpreted and the industry my not fulfil its obligations to reduce emissions.

Psychological research postulates that for messages to be responded to, the source must be trusted, the message relevant, clear and coherent, and the audience motivated to act (Petty and Cacioppo, 1986). To invoke a particular response to address climate change, individuals need to believe that climate change is real. It has been suggested that the tendency of researchers to examine easily measurable individual and farm characteristics has overlooked the complexity of motivational factors which influence farmer participation in pro-environmental behaviour. A recent meta-analysis of 55 articles addressing the adoption of environmental best management practices revealed that there is no clear connection between adoption and commonly studied socio-demographic variables (Prokopy et al., 2008). However, a number of belief and attitude variables significantly influence the adoption of pro-environmental practices, including: awareness, positive attitudes towards the environment, and attitudes towards risk (McGuire et al., 2013).

1.5.1 Theoretical framework of behaviour

Schwartz's (1977) norm activation theory proposes that altruistic behaviour supersedes the activation of personal norms. Personal norms reflect commitment to internalise values that are expressed as feelings of personal obligation to engage in certain behaviour and can hold personal responsibility to take action. The value-belief-norm theory (VBN) of pro-environmental behaviour is an extension of the norm activation theory (Stern et al., 1999) (Fig. 1.9). The theory suggests that situational factors, such as problem awareness, depend on values (i.e. a goal that serves as guidance in an individual's life) and ecological worldviews (i.e. an individual's belief of the interactions between humans and nature). Egoistic values are negatively related to ecological worldviews, whereas altruistic and biospheric values are positively related (Steg et al., 2012).

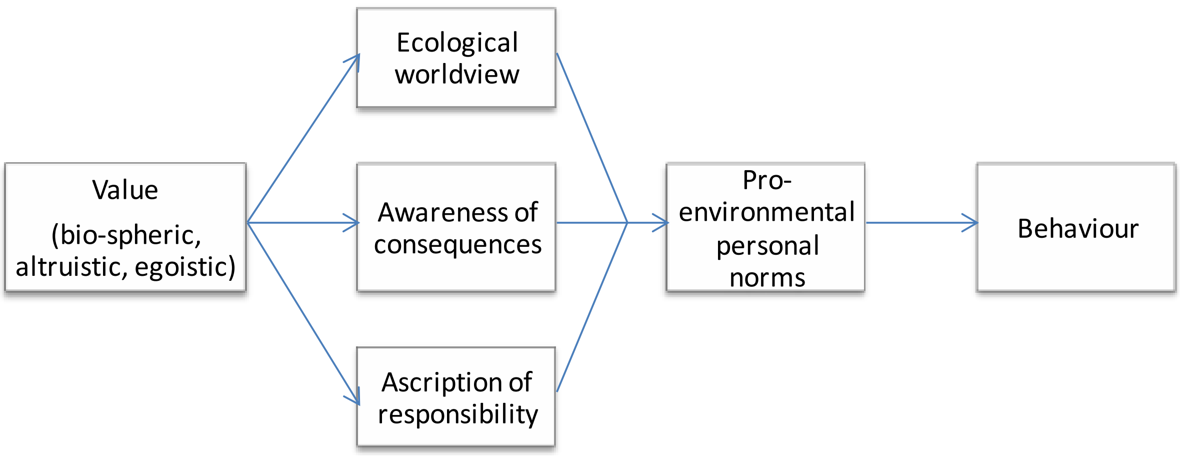

Figure 1.9. The Value-Belief-Norm Theory

Ecological worldviews predict problem awareness, influence awareness of the consequences, the responsibility one holds for their actions, one's belief on whether they can act to reduce the environmental threat, their personal norms, and subsequently their eventual behaviour. Individuals experience a feeling of moral obligation to act in an environmental manner when they: hold ecological worldviews; are aware of potentially adverse consequences of their behaviour; and ascribe responsibility for these consequences (Klöckner, 2013). Awareness of the environmental impact of ones' actions is a necessary, but not sufficient, condition for pro-environment action. To fully understand willingness to partake in pro-environmental behaviour, awareness and appraisal of the environmental problem must be evaluated. Story and Forsyth's (2008) awareness-appraisal-responsibility model asserts that as awareness and responsibility increase, and appraisal becomes more negative, individuals become more engaged with environmental problems.

There is distinct variability in the benefits of specific climate change policy initiatives; with emphasis often placed on either the production benefits or the environmental benefits of such schemes. Hence, when dissemination environmental information industry is often guilty of assuming that farmers are atypical; subsequently, long-term sustainability strategies are based on such preconceptions (Andersen et al., 2007). The uptake of initiatives can therefore be understood by determining which factor is considered as being most important by the individual farmer (Reimer et al., 2012). Climate change is not widely accepted across a wide range of countries and agricultural industries; therefore there is an urgent need to overcome communication barriers when disseminating climate change information to lay audiences (Moser and Ekstrom, 2010). An understanding of problem awareness, environmental motivations (i.e. self-identity), and risk perceptions are important to tailor public investment aimed at providing improvements in the environmental performance of agriculture (Greiner et al., 2009; Yazdanpanah et al., 2014).

1.6 Conclusions

To meet the challenge of sustainable production, the different livestock components of the UK Agriculture and Horticulture Development Board have produced roadmap documents (HCC, 2011). Industry roadmaps define where problems lie in their respective sector, set targets, and outline measures that are conducive to sustainable agriculture. These roadmaps advocate resource efficiency across the whole system through best-management techniques which include: reducing GHG emissions, fertiliser use efficiency, feed and fuel efficiency, pollution abatement, and addressing genetic improvement that can be made. Such recommendations will reduce the environmental impact of the agricultural sector and subsequently create a more sustainable food production system. Furthermore, the concept of sustainable intensification is being increasingly promoted as a means of increasing food production and lowering GHG emissions. Nevertheless, farmers must be engaged with the concept of climate change to fulfil industries' potential to address the issue. There is therefore not only a need to investigate measures which allow farmers to achieve sustainable intensification, but there is also a requirement to assess what influences their behaviour in adopting climate change measures and addressing misconceptions of the issue.

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Chapter 2: Incorporating clover into grass swards: a viable alternative to synthetic N

Incorporating clover into grass swards: a viable alternative to synthetic N

Hyland, J.J., Jones, D.L., Chadwick, D., Williams, A.P.

2.1 Abstract

Modern agriculture is very nitrogen (N) dependent; a growing global population who require sustenance is likely to further increase this dependence unless viable alternatives to synthetic are adopted. The production of N fertiliser is an energy-intensive process; furthermore its use represents a significant cost to the environment, notably through emissions of the greenhouse gas nitrous oxide (N_2O). Incorporating legumes such as red (*Trifolium pratense)* and white (*Trifolium repens)* clover varieties into grass swards offers an opportunity to reduce synthetic N demands from agriculture through biological N fixation. This study aims to determine changes in N_2O emissions when different proportions and varieties of clover are used to replace N-fertiliser. N_2O measurements were taken throughout a growing season. Low emissions were observed for all treatments throughout, with the highest flux occurring after a particularly high rainfall event. Thereafter, weather and dry soil conditions had a limiting effect on emissions. Grass swards which had red and white clover incorporated had similar yields to that of grass swards receiving typical N application rates (120 kg N ha^{-1}). Emissions per unit of yield for the clover treatment were significantly lower than those of fertilised swards and the control (no N input) treatment. Furthermore, grass swards with both red and white clover showed evidence of transgressive over-yielding and had a high crude protein content; thereby signalling the viability of intercropping to reduce reliance on synthetic N.

2.2 Introduction

Food production is required to double in its output by 2050 to meet increasing demands as the global population rises (Godfray et al., 2010). Modern agriculture is very nitrogen (N) dependant (FAO, 2015). Addressing the nutritional needs of an ever-increasing global population will likely create a greater demand for synthetic N-fertilisers (Reay et al., 2011). Indeed, the FAO predicts European N-fertiliser consumption to further increase by 1.1% per annum from 2014 through to 2018 (FAO, 2015). Sustainable measures which allow agriculture to increase output while lessening its dependency on synthetic fertilisers are imperative if food production is to expand to the levels required in the coming decades (Baulcombe et al., 2009). Legumes have been increasingly proposed as an effective measure for farmers to adopt which could allow the industry to reduce its demand for synthetic N (Lüscher et al., 2013). Leguminous crops such as clover have the potential to reduce the environmental externalities associated with the use of N fertilisers and could be used to mitigate against climate change (Phelan et al., 2015).

The Haber-Bosch process, in which fertilisers are produced, consumes 58 MJ of energy while also emitting 8.6 kg CO_2 equivalents per kg of N synthesised (Ecoinvent, 2010). Furthermore, N-fertiliser use represents a significant cost to the environment as it stimulates nitrous oxide (N_2O) emissions when applied to soils when inputs exceed plant requirements (Bolan et al., 2004; Soussana et al., 2010). N_2O is produced in soils through two important microbiological processes: nitrification and denitrification (Kool et al., 2011). Agricultural soils are a major source of anthropogenic N_2O emissions; providing 2.8 of a total 6.7 Tg N_2O-N yr^{-1} (Denman et al., 2007). Furthermore, N_2O contributes towards 6% of overall global radiative forcing, and has a global warming potential 298 times greater than that of carbon dioxide over a 100 year time period (WMO, 2012).

Jones et al. (2013) found that farmers viewed the adoption of legumes as being the most practical climate change mitigation measure they could incorporate. In clover-based pastures, N is derived from biological N fixation (BNF) of atmospheric N_2 by rhizobium bacteria in the legumes' root nodules. This fixed N becomes slowly available over time to accompanying grasses once it is released to the soil via exudates from the living legume root, by mineralization of senesced legume tissue, and through excreta once consumed by grazing livestock (Ussiri and Lal, 2013). Direct N-losses associated with N_2O are negligible and cannot be directly attributed to the fixation process itself (Rochette and Janzen, 2005). Conversely, N_2O-losses from N-fertiliser are estimated as 1% of N applied (IPCC, 2006). N_2O-losses from fixation are lower as N is fixed symbiotically within nodules and therefore not freely available in the soil in reactive form (Lüscher et al., 2013). Moreover, symbiotic N_2 fixation activity is down-regulated if the sink of N for plant growth is low. In optimised grass-legume mixtures, grass roots take up N derived from legume roots and from mineralization of soil organic matter (Lüscher et al., 2013).

N_2O emissions from legume-based pastures do not differ significantly from losses from grass pastures receiving no N inputs (Rochette et al., 2004). Li et al. (2011) found a 16-19% reduction in N_2O emissions from grass-white clover swards compared to grass only swards receiving different applications of synthetic N but receiving the same levels of N input when BNF was considered. In the grazing experiment carried out by Li et al. (2011), grass-clover wards received 58 kg N ha^{-1} yr^{-1} of synthetic N (with the rest derived from BNF); whereas the grass monocultures received 226 kg N ha^{-1} yr^{-1}. Research which focuses solely on cutting regimes when assessing N_2O emissions from legume-based swards is limited. In a field experiment, Schmeer et al., (2014) observed that a multi-species sward of grass, white clover, and lucerne, had comparable dry matter yields (DMYs) as fertiliser-based production, with 67% less emissions when direct and indirect emissions from N-fertiliser application were taken into consideration.

A major challenge for European livestock systems is to lessen their reliance on imported sources of crude protein while reducing inputs of mineral fertiliser and losses of N to the environment (Lüscher et al., 2013). Species richness within a sward may bolster production levels through transgressive over-yielding. It has been observed that plant productivity increases significantly with increasing plant diversity (Cardinale et al., 2011; Reich et al., 2012). Research indicates that plants complement each other in mixtures; transgressive over-yielding thereby leads to greater productivity than the most productive monoculture (Cardinale et al., 2011; Schmid et al., 2008). Greater species diversity can assist in the better utilisation of resources, such as soil available N or P, as a result of species-niche complementarity (Finn et al., 2013).

Other studies which investigate N_2O emissions associated with grass-clover swards do so where synthetic N is applied early in the growing season to assist sward development. This study differs in that that the grass-clover swards investigated receive no synthetic N throughout the experiment and N_2O emissions and yield are compared to pure grass swards receiving N fertiliser. Furthermore, many studies which focus on N_2O emissions from grass-clover systems are based on swards which include only one clover species. However, the inclusion of red clover in grass/white clover mixtures increases yield and clover content under cutting regimes (Eriksen et al., 2014). This study therefore aims to: (1) investigate changes in

N_2O emissions when BNF is used to replace a split N-fertiliser applications (i.e. application split over the growing season) for moderate and high-yielding leys; (2) investigate changes in N_2O emissions between grass-clover swards when more than one clover variety is used; (3) assess emissions per DMY from grass and grass-clover swards.

2.3 Methods

2.3.1 Experimental site and design

The experimental site was located at Bangor University's Henfaes Research Centre, Gwynedd, UK (53°13.9'N, 4°0.9'W). The predominant soil is a well-drained sandy clay loam, comprising of sand (51-61%), silt (15-19%) and clay (24-30%). Mean organic matter, bulk density, and pH at 10cm were 5.8%, 1046.5 g l^{-1}, and 5.85 respectively. Each treatment consisted of ryegrass; with one of the grass-clover treatments also including white clover (*Trifolium repens*), while the other grass-clover treatment included both white and red (*Trifolium pratense*) clover varieties. Popular commercial medium-term forage mixtures that were deemed optimal for cutting, but also for grazing once harvested, were chosen for treatments (ryegrass mix: Broadsword; white clover and ryegrass mix (Oliver Seeds, Lincoln, UK): ABER HSG-4 (Germinal Seeds, Lincoln, UK); red clover, white clover, and ryegrass mix: Broadsword Hi-Pro (Oliver Seeds).

The five treatments were replicated four times on plots of area 1.44 m^2 and included: (1) ryegrass receiving 300 kg N ha^{-1} yr^{-1} (High N); (2) ryegrass receiving a more conventional N application rate of 180 kg N ha^{-1} yr^{-1} (Low N); (3) ryegrass with both red and white clover receiving no synthetic N inputs (RWC-G); (4) ryegrass with white clover receiving no synthetic N inputs (WC-G); (5) a grass control receiving no inputs (Control). Edge effects were not an issue as experimental plots were separated by a 1.22 m buffer. Both the high and conventional N application rates were chosen based on the RB209 Fertiliser Manual recommendations for average grass growth conditions for beef and sheep cutting systems (Defra, 2010). RB209 offers best practice guidance for UK farmers on application of mineral fertilisers to grassland. The chosen levels of N application were further deemed appropriate considering the amount of N that could be potentially fixed in the grass-clover treatments. On average, a good grass-clover sward will give annual dry matter yields equivalent to that produced from about 180 kg N/ha applied to a pure grass sward and can even provide up to 300 kg N/ha (Defra, 2010). Timing of N application considered the growing season experienced by farmers in the region and their approach on when best to apply fertiliser to grass swards for a cutting regime.

Grass plots were based on a randomized block design; clover plots were assigned to a position within a leys to give the best representation of the clover cover, as clover density can vary considerably. The experiment ran for the duration of the growing season and ran from May to October 2014. Ammonium nitrate fertiliser (NH_4NO_3; AN) consisting of 34.5% N was applied to the appropriate treatments on the 23rd of May, 13th of August and 29th of Sept. The treatment receiving higher levels of N fertiliser had 140 kg N ha^{-1} applied in the first fertiliser event, 100 kg ha^{-1} on the second, and 60 kg N ha^{-1} on the final application. The treatment receiving a lower, but more conventional level of N fertiliser, had 84 kg N ha^{-1} applied in the first fertiliser event, 60 kg ha^{-1} on the second, and 36 kg N ha^{-1} on the final application. There was no tractor traffic on experimental plots and animals were excluded throughout.

2.3.2 N_2O flux measurements and sampling

The method used in this experiment for gas sampling, ancillary soil measurements and their frequency, and the provision of weather data, followed the protocols set by Chadwick et al. (2014) and the Global Research Alliance (2013). N_2O fluxes were measured by a closed static chamber technique. The chambers (diameter top 225 mm, diameter base 265 mm, height 264 mm, volume 11.5 l) were made of polypropylene and fitted into polyethylene collars, which were inserted 5 cm into the soil at least 24 hours before gas samples were taken. A removable sampling port was used as a vent to relieve pressure gradients when chambers were initially positioned into the collar. Sampling was conducted weekly (22 May 2014 to 22 October 2014) with an increase in frequency for two weeks following N applications. Flux measurements were conducted between the times 09:00 and 12:00 and at sampling time the chamber lids were placed on their respective collars for the appropriate time.

On each sampling occasion, five ambient air samples were collected both before and after flux measurements to determine the concentration in the chambers at t0. N_2O concentrations at t0 and t40 min were used to estimate N_2O flux (g kg N ha^{-1} d^{-1}) for each chamber (Chadwick et al., 2014). Moreover, a linearity check (i.e. that the t40 measurement is within the linear part of the accumulation of gas inside the chamber) was carried out on two chambers at each sampling occasion at t0, t20, t40, and t60 minutes. A 12 ml sample of gas was extracted from each chamber using a syringe, and samples analysed using a gas chromatograph (GC) (5890 series II; Hewlett Packard) fitted with an electron capture detector (ECD). Measurements were made for five months in an effort to capture the growing season, with one set of background measurements prior to fertiliser application.

2.3.3 N_2O flux calculation

The N_2O flux was calculated using the N_2O concentrations from the samples obtained from field measurements and used chamber height, the ideal gas law, air temperature, and chamber closure time. For each plot of each treatment, the mean flux was calculated and used to derive the mean flux of each sampling occasion using the following equation:

$$N_2O\ flux\ (g\ N_2O\ ha^{-1}day^{-1}) = \frac{\left(\frac{\Delta g}{\Delta t}\right)(ppm)\ \times\ chamber\ height\ (cm)\ \times\ conversionfactor}{Chamber\ enclosure\ time\ (\mathrm{min})}$$

Where (Δg/Δt) is the average rate of change of gas concentration inside the chamber. The conversion factor refers to converting the increase in N_2O concentration (ppm) inside a chamber to a N_2O flux rate using the ideal gas law. The trapezoidal method was used to calculate cumulative emissions for each treatment during the experimental period (Cardenas et al., 2010). The method was used to interpolate fluxes between sampling dates. For each treatment, cumulative emissions were calculated using the mean of four chambers per treatment and associated standard errors.

2.3.4 Weather and soil measurements and calculations

Daily weather, including air temperature (°C) and rainfall (mm), was recorded at a weather station at the research centre situated adjacent from the experimental plots. Soil temperature (°C) was also recorded from sensors (LogTag TRIX-8 temperatue data loggers) at 10 cm below the soil surface. Furthermore, air temperature was monitored every minute (LogTag TRIX-8 temperature data loggers) both inside and outside the chamber to determine if any significant differences were observed. At each sampling date, soil samples were taken from each treatment plot and over dried at 105 °C to calculate their percentage water content per g of soil. This subsequently determined volumetric water content (Haney and Haney, 2010):

$$\text{Volumetric water content}\left(\frac{\text{g}}{cm^3}\right) = Soil\ water\ content\ \times\ Bulk\ density$$

Using the soil moisture content, soil porosity, and volumetric water content, the water-filled-pore-space (WFPS) of each plot could be determined:

$$WFPS\ (\%) = Volumetric\ water\ content\ \times \frac{100}{Soil\ porosity}$$

At regular intervals throughout the experiment, soil samples (0-10 cm) from each plot were used for soil ammonium ($N\text{-}NH_4^+$) and nitrate ($N\text{-}NO_3^-$) analysis. Soil $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ contents were measured from a 5 g subsample of soil and KCL extraction (1 M KCL, 1:10 dilution).

2.3.5 Cutting and forage analysis

Above ground biomass was manually harvested on the 7th of August and the 29th of September from the 1.44 m^2 experimental plots. Sub-samples of the cut biomass from each plot were dried at 60 °C for 48 hours, and subsequently weighed. The N content in grass samples was determined from the dried subsamples using a Leco C:N Analyser (Leco Corporation, St. Joseph, MI, US). The N uptake of the herbage was determined as follows (Burchill et al., 2014):

$$N\ uptake\ (\frac{kg}{ha}) = N_{conc} \times DMY$$

Where N_{conc} refers to the N concentration of the herbage harvested. The crude protein content of the harvested forage was determined by multiplying the N content of the herbage by 6.25 (AOAC International, 2005).

2.3.6 Statistical analyses

Statistical analyses were carried out using IBM SPSS Statistics 22. Cumulative emissions, flux emissions, and data which were not normally distributed were $\log_{10}$ transformed before ANOVA was carried out to satisfy the assumption that random effects are normally distributed. It is common practice to transform emission data using the natural logarithms before analysis to more closely satisfy the assumption that residuals and random effects are normally distributed (Burchill et al., 2014; Dijkstra et al., 2013; Global Research Alliance, 2013; Hansen et al., 2014; Klumpp et al., 2011; Ussiri and Lal, 2013). For all analysis the data was transformed if necessary to reduce heteroscedasticity and improve assumptions of normality. The value of one was added before log transforming the N_2O data, which was sufficient to prevent the generation of negative transformed values [y = log (x + 1)].

After log-transformation, measured N_2O emissions were analysed by a repeated-measures one-way ANOVA to test for differences between treatments. One-way ANOVAs were also used to determine differences in harvest yield, crude protein content, DMY, and N_2O emissions per DMY differences between treatments. Furthermore, a two-way ANOVA was used to assess the effect of the harvesting period on grass yields (N uptake, DMY) between treatments. Simple and multiple linear regressions were used to estimate the effects of WFPS and soil temperature on N_2O emissions.

2.4 Results

2.4.1 Weather and soil data

The highest rainfall event was observed following the first application of fertiliser, with 50.5 mm of rain falling on the 25th of May; two days after application (Fig. 2.1a). The rest of the experimental period was markedly dry; total precipitation for June, July, August, September, and October were 3.5, 55.3, 70.4, 5.2, and 47.6 mm, respectively. Total rainfall in the summer months was especially low with 129.3 mm of precipitation observed at the experimental site; only 45.1% of the mean Wales 1981-2010 summer rainfall (Met Office, 2015). The average WFPS for the experimental period was 43%. Exceptionally low rainfall in June caused the WFPS to drop from a 72.2% on the 27th of May to a low of 17.6% on the 26th of June (Fig. 2.1b).

The average air temperature for June, July, August, September, and October was 14.4, 17.0, 15.1, 15.1, and 12.9 °C, respectively (Fig. 2.1a). The mean summer temperature was 15.5 °C; 1 °C higher than the 1981–2010 Wales average (Met Office, 2015). Furthermore, the average monthly soil temperature was 16.6, 19.0, 17.4, 16.0, and 12.7 °C for June, July, August, September and October, respectively.

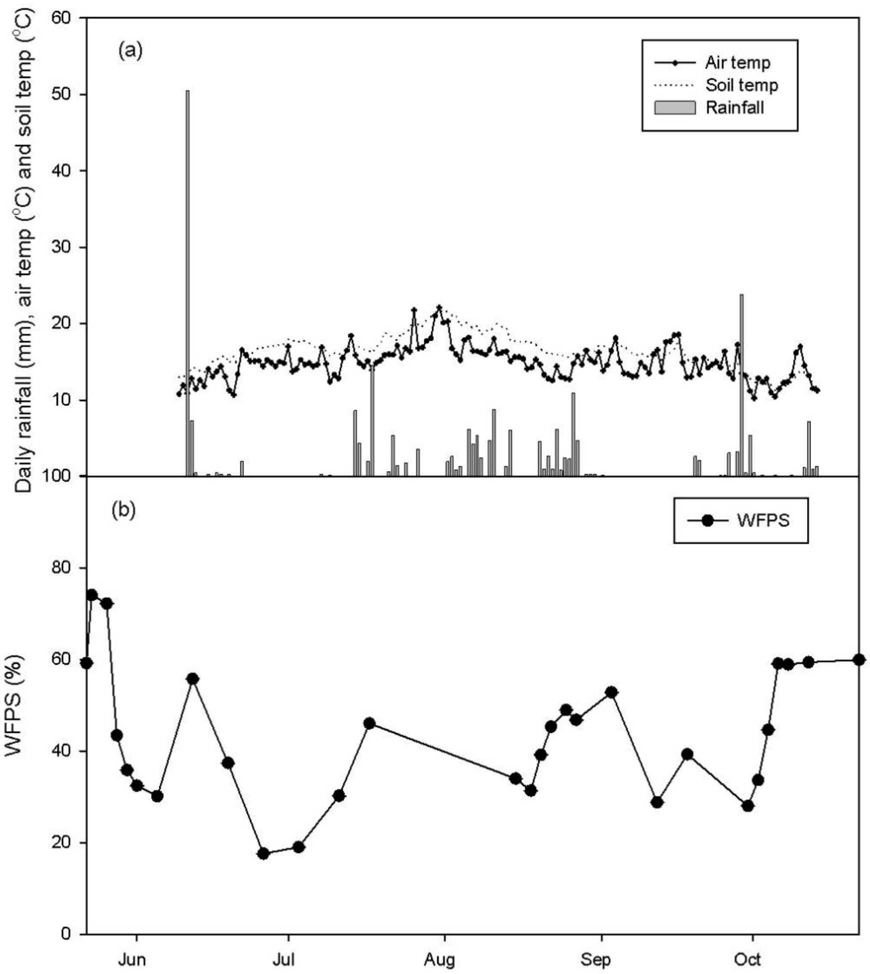

Figure 2.1. Temporal dynamics of soil temperature, air temperature, and rainfall (a) and WFPS (b)

2.4.2 Nitrous oxide emissions

The highest N_2O flux observed over the experimental period was after the exceptionally high rainfall event on the 25th of May (Fig. 2.2), two days after the first addition of inorganic N. This consequently generated an N_2O emission peak for most treatments, especially those which received AN fertiliser; with High N generating a flux of 357.6 g N ha^{-1} d^{-1} and Low N generating 96.4 g N ha^{-1} d^{-1} (Fig. 2.2). N_2O fluxes of lesser magnitude were observed across all treatments for the remainder of the experiment. Nevertheless, there were some increases in emissions following fertiliser application in late August and October.

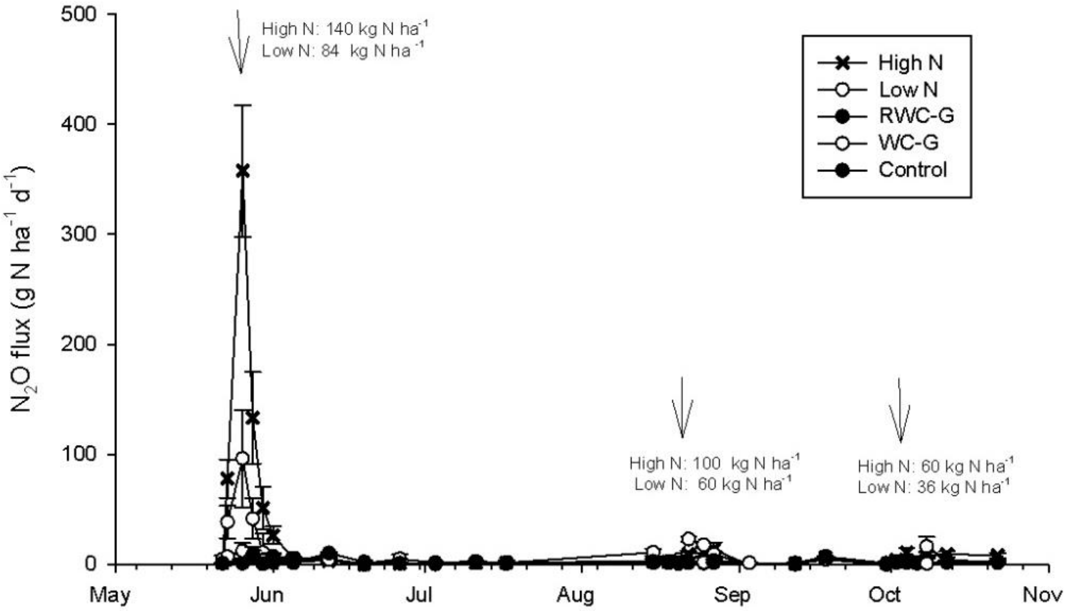

Figure 2.2. Temporal dynamics of nitrous oxide fluxes. Arrows indicate fertiliser application events

There was a large variation in cumulative N_2O emissions between fertilised and unfertilised treatments (Fig. 2.3). Unsurprisingly, the High N treatment had the highest cumulative emissions (emissions for the duration of the sampling period) (1908.7 g N ha^{-1}); followed by Low N (1105.7 g N ha^{-1}), WC-G (363.8 g N ha^{-1}), control (298.3 g N ha^{-1}), and RWC-G (263.4 g N ha^{-1}) (Fig 2.3). Most notably, there was no significant difference in the cumulative N_2O emissions between the RWC-G and the control.

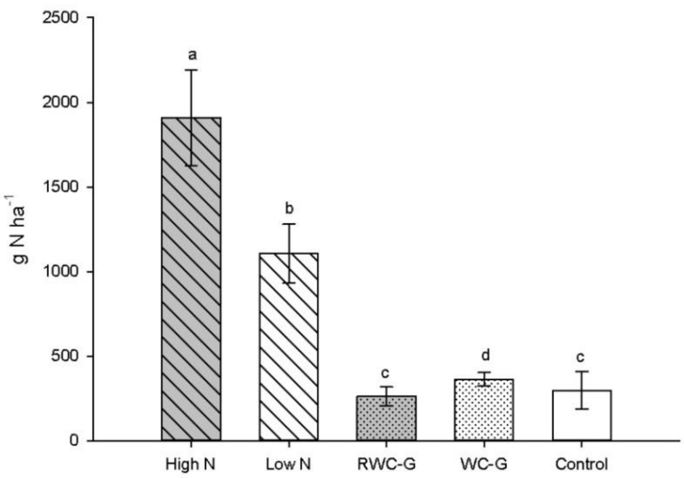

Figure 2.3. The mean cumulative emissions per treatment. Error bars illustrate the standard error of the mean (n = 4), while different letters above the bars represent a significant difference between treatments

2.4.3 Environmental factors affecting N_2O fluxes

Regression models were utilised to estimate a regression equation based on the experimental data that relates N_2O emission rates to soil moisture and temperature; the two primary variables associated with the generation of N_2O fluxes. It was found that while WFPS accounted for a significant amount of variation in the mean daily flux for all treatments, this was not the case for soil temperature. However, the inclusion of soil temperature in the regression model along with WFPS provided model with a higher R^2 than with WFPS alone (higher R^2 value) (Table 2.1).

Typically N_2O emissions increase with temperature (Ussiri and Lal, 2013). However, it is likely that N_2O fluxes in this study were driven more by soil moisture rather than temperature, as WFPS was significantly negatively correlated with soil temperature ($P = 0.002$, $R^2 = 0.30$). It is possible that the effect of increased soil temperature on the N_2O flux was offset by the inhibitory effect of reduced soil moisture (Dijkstra et al., 2013).

Table 2.1. Results of single and multiple regression analyses with the mean N_2O flux from all samples as a dependent variable and environmental factors as an independent variable. SE = standard error.

Dependent variable	Environmental factor	Relationship	R^2	P value	SE
N_2O flux (z)	WFPS (x)	Log (z+1) = 0.014x + 0.07	0.196	0.016	0.419
	Soil temp (y)	Log (z+1) = -0.077y + 1.85	0.116	0.071	0.440
	WFPS (x),soil temp (y)	Log (z+1) = 0.012x – 0.031y + 0.657	0.209	0.047	0.424

The weather during the sampling period was for the most part consistently dry, with little variation in WFPS throughout. This may also explain the negative relationship between soil temperature and N_2O emission fluxes and the low R^2 observed in the regression analyses (Table 2.1). The large rainfall event immediately after AN application in late May increased WFPS to 72.2%, the highest it had been throughout the experiment. Conversely, the mean

WFPS immediately after the 2nd and 3rd application was 32.67%, and 35.40% respectively. The soil temperature was lower for the 1st application of AN (12.97 ˚C) than for the 2nd (17.19 ˚C) and 3rd (14.99 ˚C) applications of fertiliser. The high flux observed after the high rainfall event in May, particularly from treatments receiving AN, further implies that WFPS has a greater control over emissions than soil temperature.

2.4.4 Soil ammonium and nitrate concentration

The soil inorganic N content remained low throughout the study across all treatments (Table 2.2). The highest observed measurement of N-NH_4^+ (11.1 4 mg N kg^{-1} dry soil) was recorded for the WC-G treatment on the 3rd of September. The N-NO_3^- content was lower than that of N-NH_4^+ on all the sampling dates where mineralized N was measured; peaking at 4 mg N kg^{-1} for the RWC-G treatment on the 13th of August.

Table 2.2. Soil contents of ammonium and nitrate (mg N kg^{-1} dry soil). Number in brackets illustrate the standard error of the mean (n = 4)

	N-NH_4^+	**N-NO_3^-**
29^{th} Jun		
Control	5.9 (± 0.19)	1.2 (± 0.07)
Low N	7.4 (± 0.53)	1.5 (± 0.03)
High N	6.6 (± 0.38)	2.0 (± 0.05)
RWC-G	7.0 (± 0.27)	2.9 (± 0.06)
WC-G	7.2 (± 0.20)	1.7 (± 0.13)
13^{th} Aug		
Control	3.8 (± 0.44)	2.5 (± 0.03)
Low N	3.7 (± 0.14)	2.1 (± 0.08)
High N	5.6 (± 0.37)	2.1 (± 0.03)
RWC-G	4.0 (± 0.22)	4.0 (± 0.14)
WC-G	6.7 (± 0.36)	2.6 (± 0.20)
3^{rd} Sept		
Control	4.8 (± 0.03)	0.6 (± 0.03)
Low N	5.9 (± 0.36)	1.1 (± 0.03)
High N	4.6 (± 0.08)	2.3 (± 0.11)
RWC-G	10.4 (± 0.39)	2.2 (± 0.15)
WC-G	11.1 (± 0.18)	0.5 (± 0.06)
29^{th} Sept		
Control	1.7 (± 0.14)	1.3 (± 0.07)
Low N	1.3 (± 0.11)	2.0 (± 0.13)
High N	1.5 (± 0.04)	1.9 (± 0.10)
RWC-G	2.2 (± 0.58)	1.5 (± 0.15)
WC-G	1.9 (± 0.19)	1.1 (± 0.15)

2.4.5 N uptake and crude protein content of the herbage harvest

Clover's ability to cohabit with ryegrass can vary throughout the growing season (Hodgson, 1990). Therefore, a two-way repeated measures ANOVA was carried out to compare the effect of treatment and harvest time on grass yields and N uptake across all treatments (DMY, and N-uptake). Uptake of N in the herbage was significantly affected by treatment ($p < 0.05$) but not harvest period (Fig 2.4a). Conversely, both treatment and harvest time had a significant effect on DMY. However, there was no interactional effect between harvest time and treatment as all treatments were affected differently (Fig 2.4b).

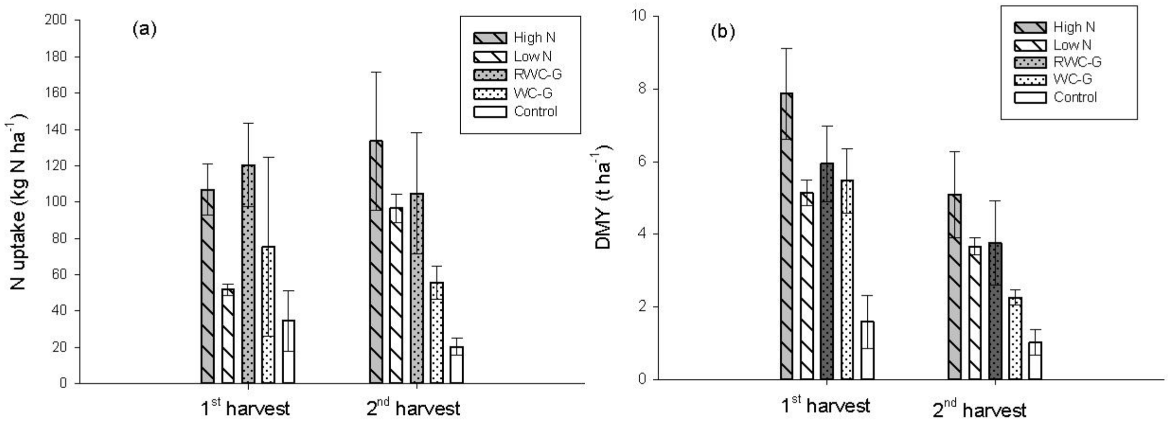

Figure 2.4. N-uptake (a) and DMY (b) per harvest event. Error bars illustrate the standard error of the mean (n = 4)

The N content was significantly higher ($p < 0.05$) for RWC-G compared to that of the other treatments (Table 2.3). Hence, RWC-G had a significantly higher ($p<0.05$) crude protein content (15%) compared to the other treatments.

Table 2.3. The mean crude protein content of the harvested herbage. NS = not significant

	Crude protein content (%)	Standard error	Significant difference
High N	12.3	± 0.251	NS
Low N	11.5	± 0.338	NS
RWC-G	15.0	± 0.153	<0.05
WC-G	12.3	± 0.298	NS
Control	10.3	± 0.262	NS

Nitrogen use efficiency (NUE) is an important indicator of the effectiveness of fertiliser application. NUE was calculated as the ratio between the amount of fertilizer N removed with the crop and the amount of fertilizer N applied and is expressed as a percentage (Brentrup and Palliere, 2010); it reflects the efficiency that crops utilise N fertiliser. In this study, the measure was calculated based on differences between N-uptake in fertilised AN plots and that of the control over one cropping season. Through such assessments, it was observed that the NUE was higher for the High N treatment that of Low N (Table 2.4). As no fertiliser was applied to any of the other treatments, an NUE measure was unwarranted. The amount of N applied for High N for the cropping season was 240 kg N ha^{-1}, and 144 kg N ha^{-1} for Low N.

Table 2.4. The mean NUE of treatments receiving AN fertiliser (n=4)

	N uptake (kg N ha^{-1})	N uptake – N uptake of control (kg N ha^{-1})	NUE (%)
Control	57.16	-	-
Low N	150.10	92.94	64.54
High N	233.13	175.96	73.31

2.4.6 Crop yield and yield-scaled emissions

Average dry matter yield (DMY) ranged from 2.17 t ha^{-1} for the control treatment to 6.48 t ha^{-1} for the High N treatment (Fig. 2.5a). Significantly greater DMY ($p < 0.05$) was obtained for the High N treatment; however, there was no significant difference between the DMY obtained from the treatment receiving a more conventional N application rate (Low N) and both RWC-G and WC-G. Interestingly, RWC-G outperformed Low N by 9.25% in terms of its DYM; whereas, the DMY of WC-G was 12% lower.

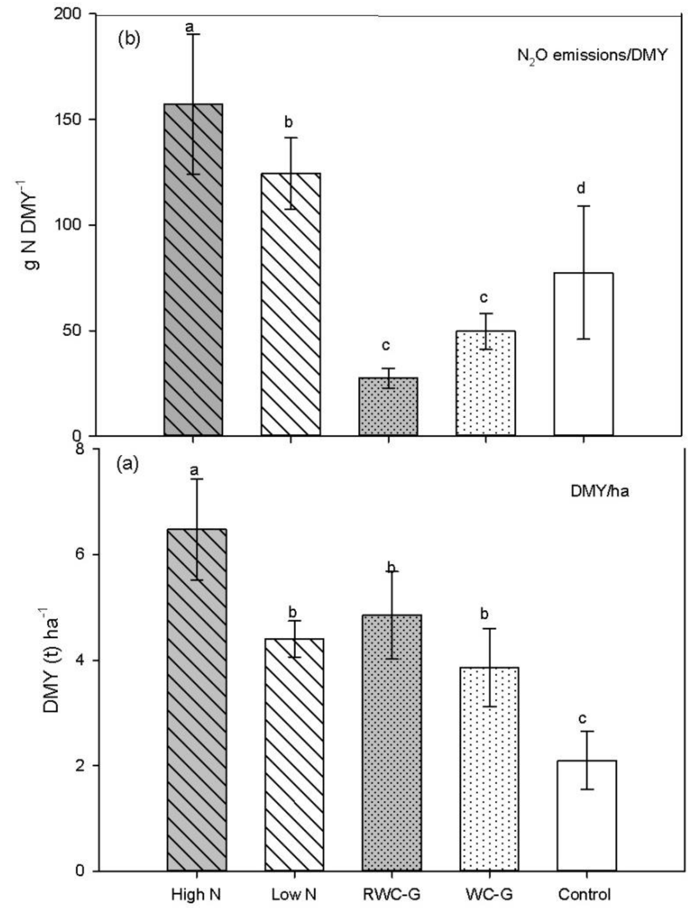

Figure 2.5. The mean DMY per harvest (t ha^{-1}) (a) and average N_2O emissions per harvested DMY (t) (b). Error bars illustrate the standard error of the mean (n = 4), while different letters above the bars represent a significant difference between treatments

Yield-scale emissions were therefore significantly lower ($p < 0.05$) for both the clover treatments compared to those which received AN (Fig. 2.5b). RWC-G had the lowest yield-scale emissions of 24.78 g N t^{-1} DMY, followed by WC-G (49.63 g N t^{-1} DMY), control (77.44 g N t^{-1} DMY), Low N (124.39 g N t^{-1} DMY), and High N (157.12 g N t^{-1} DMY). As expected, there was a significant difference in the yield-scale emissions between clover and treatments receiving AN. However, there was also a significant difference ($p<0.05$) in yield-scale emissions between clover treatments and the control.

2.5 Discussion

Nitrification and denitrification are controlled by many factors, particularly WFPS. In general, poorly-drained soils emit more N_2O compared to moderately well drained soils due to higher soil moisture (Tesfai et al., 2015). In well-drained soils, nitrification is the most important source of N_2O emissions and is favoured by supply of ammonium-N (Lüscher et al., 2013). Therefore large fluxes in emissions are often recorded immediately after fertiliser application (Klumpp et al., 2011). The rate of N_2O produced during nitrification peaks at 55-65% WFPS, and is low below WFPS of 40%. Soil aeration is reduced above WFPS 60-70%; thereby slowing down nitrification as the diffusion of oxygen becomes limited. For soils with WFPS between 70-90%, denitrification becomes the dominant source of N_2O emissions (Davidson et al., 2000; Ussiri and Lal, 2013).

N_2O emissions were generally low throughout the majority of the experiment and were likely to have been caused by a low WFPS, high soil and air temperatures, and low soil available N. The summer rainfall was considerably lower than the 1981-2010 average for Wales, while air temperature was considerably greater. In contrast, the May application of N was made at a much higher WFPS than that observed for the remainder of the study. Consequently, the highest recorded N_2O flux followed the heavy rainfall event after the 1st application of fertiliser. Thereafter, WFPS generally decreased in continuing dry weather, especially for June, with relatively low emissions recorded. Indeed, both simple regression and multiple regressions elicited the importance of WFPS on N_2O emissions fluxes during the course of the experiment; more-so than that of soil temperature. Unsurprisingly (considering the weather conditions), although significant, the variation in N_2O fluxes explained by the single and multiple regressions were quite low. Nevertheless, correlations between environmental factors and N_2O flux emissions are typically low in experimental studies and may be explained by threshold levels for abiotic factors for nitrification and denitrification, along with interactions with biotic processes (Flechard et al., 2007; Klumpp et al., 2011).

Soil N-NH_4^+ and N-NO_3^- remained low throughout the study; peaking at 11.14 mg N kg^{-1} and 4 mg N kg^{-1} respectively. The warm and dry climatic conditions stimulated good growth across all treatments; demonstrated by the high %NUE of grass swards receiving AN fertiliser. Losses of N from grassland occur mainly after N is converted to N-NO_3^- prior to plant uptake; N in the form of N-NH_4^+ is therefore less susceptible to denitrification (Ussiri and Lal, 2013). Possible losses of N-NH_4^+ through plant uptake may therefore have contributed towards low soil N-NH_4^+, and consequently low levels of soil N-NO_3^- (Louro et al., 2013; Smith et al., 2012). Indeed, low levels of soil N-NH_4^+ suggest rapid nitrification and efficient plant uptake of N-NO_3^-. NUE increased with increasing N application which suggests that the treatment receiving the more conventional N application was affected to a greater extent by the low WFPS throughout the experiment (Abassi et al., 2005).

Soil WFPS is the most important regulator of soil denitrification, followed by other factors such as N-NO_3^- (Dobbie and Smith, 2003; Ussiri and Lal, 2013). Conversely, when soil N-NO_3^- is less than 5 mg N kg^{-1}, there is a limiting effect on N_2O emissions (Dobbie and Smith, 2003). Therefore, a combination of low WFPS and low soil N-NO_3^- may have led to the cessation of denitrification in this experiment across all treatments. Moreover, the soil's nitrification potential may have been limited as the mean WFPS for the duration of the study was 43%. This may further explain the persistence of low fluxes throughout the growing season.

This study has reiterated that the inclusion of legumes within grass swards has the potential to reduce N_2O emissions per hectare. It has been shown that biological N fixation by legume crops is a minor source of N_2O emissions (Carter and Ambus, 2006). Indeed, Li et al. (2011) found 16-19% lower N_2O emissions per hectare from grass and white clover swards receiving 58 kg N ha^{-1} in comparison to grass swards receiving 226 kg N ha^{-1} from an experiment which assessed emissions from a grazing-based dairy system; although both treatments received similar levels of total N (grass-clover sward N input = synthetic N + BNF). Furthermore, Jensen et al. (2011) found annual N_2O emissions from fertiliser grass swards (300-18,160 g N-N_2O ha^{-1}) are larger than that of grass-clover swards receiving little or no fertiliser application (100-1,300 g N-N_2O ha^{-1}). The results elicited from the research carried out in this study experiment further reaffirm the potential of legumes to reduce N_2O emissions from grassland-based agricultural systems. Cumulative fluxes over a growing season were significantly lower ($p<0.05$) for both WC-G and RWC-G in comparison to treatments receiving AN fertiliser (High N: 1908.7 g kg N ha^{-1}; Low N: 1105.7 g kg N ha^{-1}). RWC-G swards were particularly advantageous in terms of lowering cumulative emissions; displaying significantly lower ($p<0.05$) N_2O emissions (263.4 g kg N ha^{-1}) than the experimental control (298.3 g kg N ha^{-1}). Differences in emissions in the clover treatments and the control suggest more efficient use of available soil N in the clover swards (Nyfeler et al., 2011). Higher N utilisation in grass-clover mixtures would imply less available N which could be lost to the environment in the form of N_2O emissions. As in this study, previous work on clover systems discuss results on a 'per hectare' basis; further work could be done to ascertain the spatial variation of N fixation by clover, given that there can often be considerable within-field variation in clover density.

Legumes have been proposed as a viable alternative to synthetic N for grassland-based agricultural systems (Lüscher et al., 2013). Grass-clover systems can displace N use and contribute towards climate change mitigation over a wide range of production levels (Nyfeler et al., 2009; Suter et al., 2015). Such systems can display transgressive over-yielding and outperform both grass and clover monocultures; a phenomenon that cannot be explained by symbiotic N_2 fixation alone but through the combination of fast-establishing species with slower-developing species which are temporally persistent (Finn et al., 2013).

The richness of species numbers in swards could thus bolster sustainable intensification as greater species diversity can assist in the better utilisation of resources through species-niche complementarity (Lüscher et al., 2013). Species-niche complementarity allows swards to outperform both grass and legume monocultures (Finn et al., 2013). Harvest average DMY of RWC-G and WC-G were comparable to the treatment which received the more conventional fertiliser rate (Low N), but DMY differed significantly from that of High N (6.48 t DMY ha^{-1}). Relatively high average DMYs per harvest, and low cumulative N_2O emissions, meant that the grass-clover treatments had significantly lower yield-scale emissions that the grass swards receiving AN fertiliser. Similarly, Ruz-Jerez et al. (1994) measured higher yield-scale emissions from grass swards receiving 400 kg N ha^{-1} yr^{-1} when compared to grass-white clover based swards receiving no fertiliser. Furthermore, average yield-scale emissions of N_2O were also significantly lower for RWC-G and WC-G in comparison to the control treatment.

RWC-G also offered significantly higher crude protein content (15%) relative to the other treatments. Although the crude protein content does not accurately reflect absorbable protein in the digestive tract of the ruminant, ruminants require forage with crude protein contents of 10-17% (Phelan et al., 2015). It is unclear whether animals grazing the higher protein swards would subsequently deposit greater levels of N within their faeces and urine, which in turn may generate greater soil emissions of N_2O (de Klein et al., 2014). However, livestock performance has been shown to be improved when grazing swards that include clover to those with grass monocultures (Phelan et al., 2015); this may in turn reduce the time spent on farm (i.e. time to slaughter), which is one of the biggest drivers of the carbon footprint of meat, due to methane emissions (Gerber et al., 2013; Pullar et al., 2011). If suitably managed to maintain persistence, the inclusion of clover within grass swards may therefore make important contributions to reducing the environmental impact of meat through both reducing dependency on inorganic fertiliser (whilst not compromising yield), and improving the efficiency of ruminant production. Comparison of the results with other studies is impended as no comparable published studies on grass-clover swards receiving no application of N for cutting regimes have been carried out. The results of this experiment should be nevertheless be interpreted considering the prevailing weather conditions throughout the study. Therefore, it would be advantageous to carry out similar experiments over numerous years to determine if grass-clover systems are comparable to grass monocultures receiving N fertiliser over longer timeframes.

Over many years, the Common Agricultural Policy encouraged large increases in agricultural production. Low energy prices during the latter part of the 20th century resulted in an abundant supply of cheap synthetic N fertilizer and consequently lowered the prevalence of legumes (Peyraud et al., 2009). Past varieties of clover species were also known to cause bloat and fertility issues which also led to lower uptake. However, easily implemented management practices and newer plant varieties mean animals are less susceptible to such problems but misconceptions still prevail within the farming community (Phelan et al., 2015). There are hence important issues which need to be addressed to improve uptake of clover. The uptake of any technology is strongly influenced by the perceived net rewards associated with adaptation. The price of fertiliser is expected to rise in the future which may cause farmers to look towards alternative N sources and offers an opportunity to increase adoption of clovers. The importance of DMY is particularly pertinent to farmers with industry constantly promoting its economic advantage to farming enterprises (EBLEX, 2011; HCC, 2012). The favourable DMY of grass-clover swards could therefore also be highlighted to farmers in an effort to promote uptake of such systems. It is important that farmers are made aware of the environmental and economic benefits of grass-clover systems if the sector is to reduce its dependence on synthetic N.

2.6 Conclusions

Low rainfall totals meant that N_2O fluxes were found to be quite low across all treatments; however, cumulative emissions were statistically higher for the High N application (1908.7 g N ha^{-1}); followed by Low N (1105.7 g N ha^{-1}), WC-G (363.8 g N ha^{-1}), control (298.3 g N ha^{-1}), and RWC-G (263.4 g N ha^{-1}). Of particular relevance was that there was a significant difference in the cumulative N_2O emissions between the clover and grass treatments. Yield-scale emissions of the clover treatments were significantly lower than those of the grass swards receiving fertiliser and that of the no N-input control. Both DMY and protein content were greater in RWC-G treatments; indicating that incorporation of such legumes could improve livestock production efficiencies (e.g. rate of liveweight gain). The study demonstrates the potential of including clover in grass swards as a viable alternative to synthetic N at conventional application rates, while also offering significant environmental benefits.

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Chapter 3: Improving livestock production efficiencies presents a major opportunity to reduce sectorial greenhouse gas emissions

Improving livestock production efficiencies presents a major opportunity to reduce sectorial greenhouse gas emissions

Hyland, J.J., Styles, D., Jones, D.L., Williams, A.P.

3.1 Abstract

The livestock sector is under considerable pressure to reduce greenhouse gas (GHG) emissions. Repeated measurements of emissions over multiple years will indicate whether the industry is on course to successfully meet GHG emission reduction targets. Furthermore, repeated analyses of individual farm emissions over different timeframes allows for a more representative measure of the carbon footprint (CF) of an agricultural product, as one sampling period can vary substantially from another due to multiple stochastic variables. To explore this, a CF was measured for 15 enterprises that had been assessed three years previously. The aim of the research was to: (1) objectively compare CFs between sampling periods; (2) assess the relationship between enterprise CF and input efficiency; (3) use scenario analyses to determine potential mitigation measures. Overall, no significant difference was detected in beef and lamb enterprise CFs between the two sampling periods. However, when all observations were pooled together lower footprints were found on more efficient systems with higher productivity with lower maintenance “overheads”. Of relevance, scenario analyses revealed that the CF of beef and lamb could be reduced by 15% and 30.5%, respectively, if all enterprises replicated the efficiency levels depicted as necessary for low CFs. Encouraging and implementing efficiency gains therefore offer the livestock industry an achievable method of considerably reducing its contribution to GHG emissions.

3.2 Introduction

Despite its many positive contributions to society, agriculture is responsible for some negative externalities; one of which is greenhouse gas (GHG) emissions. The contribution of livestock towards such emissions is particularly important as the sector accounts for 14.5% of total global anthropogenic GHG emissions (Gerber et al., 2013). The primary GHGs associated with ruminant production systems are methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). CH_4 emissions are primarily induced through enteric fermentation, excreta, and manure management (McDowell, 2009). N_2O emissions are associated with nitrification and denitrification of soils following nitrogen inputs such as excreta, urine, or inorganic fertiliser (Galloway et al., 2003). Depending on management regimes, CO_2 may be emitted or sequestered from agricultural soils, representing either a source or a sink of emissions (Soussana, et al., 2010). However, there is some disagreement as to the capacity of grasslands to act as a perpetual carbon sink (Smith, 2014).

Considerable attention has therefore been bestowed on the red meat sector's contribution towards climate change. However, the carbon footprint (CF) of both beef and lamb varies substantially; ranging from 9-129 kg CO_2eq per kg meat for beef, and 10-150 kg CO_2eq per kg meat for sheep meat (Nijdam et al., 2012). Differences can be attributed to a host of variables such as the type of farming system, location, management practices, the study's system boundary, and the resource use that has been considered (Desjardins et al., 2012; Ripoll-Bosch et al., 2013; Ruviaro et al., 2015). There are numerous sources of variation in estimating farm-level CFs, namely: variation arising from uncertainties in the primary activity data, including farm management practices, and variation arising from emission factor model uncertainties, as well as inter-farm variations (Basset-Mens, et al. 2009). Therefore, comparisons of CFs are difficult as models and farm characteristics vary both between and within studies.

Analysis over different timeframes can serve to elicit where, and how, emissions have changed and are useful in estimating whether industry is meeting environmental targets. Nevertheless, despite their potential value, there has been a distinct lack of studies that temporally assess the CF of individual beef and lamb farm enterprises. Veysset et al. (2014a and 2014b) found no significant differences in the CF of two consecutive sampling years when investigating breed-specific, extensive beef suckler systems in France.

The agricultural sector in Wales is dominated by pasture-based livestock systems. Government targets aspire to reduce overall national emissions by 3% per annum from 2011 onwards (Welsh Government, 2009). Subsequently, the livestock sector has initiated a strategic plan outlining strategies to meet such targets (HCC, 2011). There is a need to capture the CF of beef and lamb over multiple years to determine if the industry is to successfully meet these emission reduction targets. By using the same model, repeated C-footprinting of an enterprise enables comparisons of its environmental performance over time. Such analyses also allow for a more representative measure of the CF of an agricultural product; such is the nature of the sector that one sampling period can vary substantially from another due to multiple stochastic variables (e.g. disease, policy reform, weather).

Empirical data was collected for the years 2009/10 and 2012/13 from a set of 15 Welsh beef and/or sheep farmers. Both sampling periods experienced unusual weather events that may affect the CF in alternative ways; 2009/10 had a particularly cold winter (Defra, 2011), whereas 2012/13 experienced an especially wet summer and autumn (Slingo, 2013). The aims of the research were (1) to objectively compare CFs between sampling periods; (2) to assess the relationship between enterprise CF and input efficiency; (3) to use scenario analyses to determine potential mitigation measures that may lower emissions. It is anticipated that the findings will help determine how the industry can reduce emissions and subsequently guide future policy recommendations.

3.3 Method

3.3.1 The carbon footprint model

To quantify the overall impact of GHGs, it is important to take into consideration the respective global warming potential (GWP) of the distinct gases involved in production. GWP is a relative measure of how much heat, relative to CO_2, a GHG traps in the atmosphere. The magnitude of individual gases' emissions are subsequently categorised in terms of their carbon dioxide equivalent (CO_2eq) over a 100-year horizon to compare and report emissions. The GWP's for CH_4 and N_2O are 25 CO_2eq and 298 CO_2eq, respectively (IPCC, 2007).

The CF model used in this study has been designed to assess the CF of beef and lamb from input data that was collected from farm records and published relevant GHG emission values; no input values were assumed or estimated. Empirical farm data were used to estimate the CF of beef and lamb production using an updated model to the ones employed by Edwards-Jones et al. (2009) and Taylor (2010); a model which has been recently used to assess the CF of sheep systems in England and Wales and can be viewed in Appendix A and B (Jones et al., 2014). The model calculates the emissions associated with bringing 1kg of beef or lamb to slaughter and includes emissions from direct and indirect inputs associated with production. It also encapsulates emissions from other animals in the herd. For instance, if one enterprise can produce the same volume of liveweight to slaughter with fewer breeding stock than another enterprise then it will consequently have a lower carbon footprint. This is a consequence of having fewer animals to contribute towards GHG emissions to produce the same volume of slaughter liveweight. Animal movements are also monitored on a monthly basis so that accurate assessments can be made on the quantity of animals within a certain cohort. Liveweight gain per month is also considered for growing stock.

3.3.2 The functional unit and system boundary

The magnitude of a CF of a product is determined by the system boundaries in which it is analysed. For beef and lamb enterprises, most system boundaries are set from 'cradle to farm gate', where all direct and indirect emissions are incorporated into a footprint, from the birth of an animal until such time it leaves the farm for slaughter. Upstream emissions were also considered for the manufacture of fertiliser, concentrate feed production, bedding etc. Many CFs of consumer products are calculated from 'cradle to grave' and incorporate all emissions from all stages of their life cycle. The 'cradle to farm gate' system boundary is typically used to assess emissions from agricultural products such as beef, lamb, and milk as it is more beneficial for comparing different agricultural practices and efficacies of different management systems on GHG performances. The final CF is subsequently expressed as a functional unit, which is typically expressed as kg CO_2eq per kg liveweight (kg CO_2eq/kg lw) (Edwards-Jones et al., 2009).

The 'cradle to farm gate' system which the model accounts for emissions from direct and indirect inputs, emissions from on-farm production, emissions attributed towards the movement of stock in and out of the system, and sequestration from on-farm carbon sinks and stores such as trees, grassland, and hedgerows (Fig. 3.1). However, PAS 2050, the carbon accounting methodology standard developed by The Carbon Trust, does not include sequestration in its methodology (PAS, 2011). Hence, the CF in this study is reported without the inclusion of sequestration.

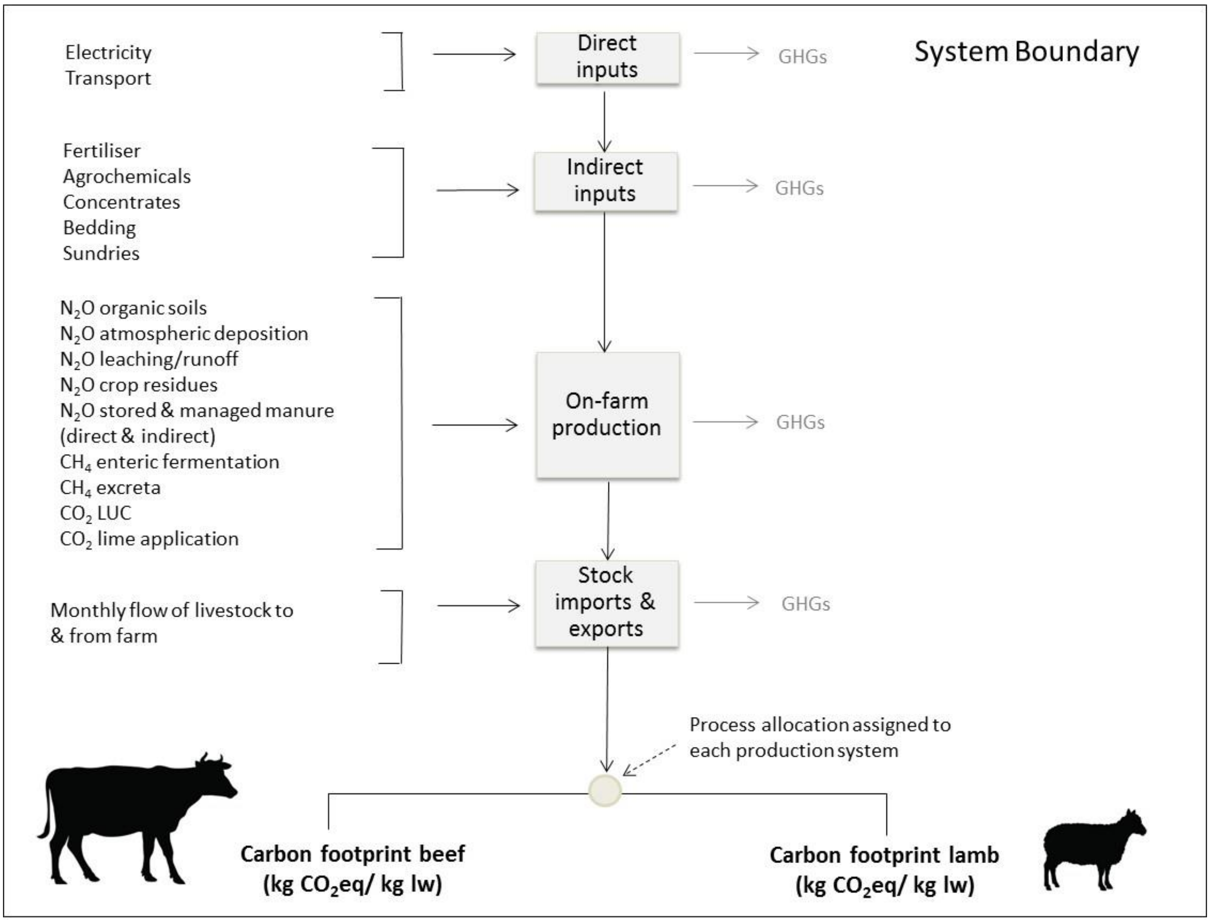

Figure 3.1. Schematic representation of the system boundary within which the carbon footprint was assessed

3.3.3 Allocation method

Allocation is required to assign the environmental impacts to the functional unit when a system has more than one saleable product. Different allocation methods include economic allocation, mass allocation, energy allocation, and allocation based on protein content (Nguyen et al., 2012). However, it is recommended that allocation is avoided where possible by dividing the unit process to be allocated into two or more sub-systems and collecting the input and output data associated with each sub-system (Flysjö et al., 2011; Pirlo et al., 2013). The aforementioned method was employed whenever possible to differentiate emissions associated with beef and lamb produced on the same enterprise; thereby empirically assigning emissions to distinct saleable outputs. Six mixed enterprises reared both cattle and sheep; thus certain aspects of production were subjected to economic allocation as emissions could not be assumed explicitly to one production system over another.

3.3.4 Data collection

Of the 15 farms sampled, five specialised in lamb, four specialised in beef, and six were mixed enterprises (both beef and sheep). During face-to-face interviews, demographic data were collected, as well as a brief assessment of participant's perceptions of GHG emissions from their farms. Farmers provided information on important aspects of their production system, such as direct and indirect inputs (e.g. feed, fertiliser, bedding), stock movements (e.g. purchases, births and housing), outputs (number and weight of animals sold), and farm characteristics. Data was provided for 12 months of production; stock movement records and other forms of inventory records were used where possible to verify and supplement data collection. Furthermore, farmers' perceptions of climate change were briefly assessed to determine perceptions of the issue.

3.4.5 Emission factors

IPCC Tier II methodology was adopted for emissions from enteric fermentation from beef cattle and the management of ruminant manure (Webb et al., 2014). All other calculations are based on standard Tier I approaches. Tier I assumptions continue to be used as the default emission factor for enteric fermentation for sheep; however, the UK uses a country-specific emission factor for enteric fermentation for lamb, set at 40% of that for an adult sheep (Webb et al., 2014).

Fertiliser, diesel, agrochemicals, bedding, and compound feeds emission factors were mid-range values from Edwards-Jones et al. (2009) and Jones et al. (2014). Emission factors for non-blended feed crops (straights) were taken from the Scottish Executive Environment (2007). A mean emission factor of 13.87 kg CO_2 eq/kg lw and 7.62 kg CO_2 eq/kg lw was used for the purchase of live beef stores and lamb bought for finishing, respectively (Edwards-Jones et al., 2009; Taylor et al., 2010; Jones et al., 2014). Mean emissions from UK peat soil were estimated to be 0.25 kg N_2O-N per hectare annually; a deviation from IPCC default emission factors (Scottish Executive Environment, 2007). Other studies have also adopted such an estimate in place of the IPCC default of 8 kg N_2O-N per hectare annually as it is arguably more representative of UK conditions (Taylor et al., 2010; Jones et al., 2014). It should be reiterated that sequestration is not included in the CFs reported in this study. A full breakdown of the emission factors used in the model can be viewed in Appendix B.

3.4 Results

3.4.1 Farmers' perceptions of on-farm emissions

The CF results calculated for 2009/10 had been previously sent to farmer's ca. 6 months after being first collected. From this farmers could ascertain how they compared to other farmers in the sample in terms of their CF. Considering their past experiences with carbon footprinting, farmers were asked to depict their perceptions of their on-farm emissions when data was collected again in 2012/13. Farmers who took part in the case study suspected their respective footprint to be low in comparison to similar farming operations. However, the farmers were somewhat unsure as to livestock's contribution towards climate change (Table 3.1); a discourse that could potentially influence the adoption of adaptation and mitigation measures that address climate change (Hyland et al., 2015). Nevertheless, most deemed themselves capable and willing to lower their respective footprints; but was dependent on financial viability (Table 3.1).

Table 3.1. Participants' perception of greenhouse gas emissions associated with production

	Strongly disagree	**Disagree**	**Unsure**	**Agree**	**Strongly agree**
I take the environment into consideration even if it lowers profit	1	8	0	6	0
It is possible to reduce my farm's footprint without affecting productivity	0	4	3	8	0
Livestock farmers should bear responsibility for their emissions	1	3	2	8	1
Livestock farming contributes towards climate change	0	4	7	3	1
Mitigation strategies should make economic sense	0	0	1	4	10
The best mitigation strategies are too costly to adopt	0	2	5	5	3
Climate change is a global issue; whatever changes I carry out on my farm are of little value	0	2	2	5	6
I am interested in trying different mitigation methods to reduce the farm's footprint	0	1	2	9	3
Switching to more climate friendly farming method's would not involve much change from my current operation	0	1	0	6	8
I plan to reduce my farm's footprint over the next 10 years	0	1	3	7	4
My farm's footprint is low in comparison to similar farming operations	0	0	3	7	5

3.4.2 Temporal comparison of carbon footprints

Mean GHG emissions from beef and lamb enterprises from both sampling years are summarised in Table 3.2; as is the contribution of each parameter to the CF. As one farm experienced a significant merger in 2012/13, it was subsequently omitted from the temporal analysis carried out in this section. A state of equilibrium was observed in the other farms during respective sampling periods. Equilibrium was determined by comparing the number of animals in certain categories (e.g. number of breeding animals and young stock intended for slaughter or replacement) at the beginning and end of the 12-month sampling period. Statistical analyses were restricted to non-parametric tests to determine significant differences between both years. The mean CF for lamb increased in 2012/13; whereas the mean footprint of beef decreased (Table 3.2); however, Wilcoxon rank test revealed that these changes were not statistically significant. Furthermore, Mann-Whitney tests revealed that there was no significant difference between the CF of beef-only and sheep-only systems and that produced in a mixed system. Therefore, the allocation method did not significantly affect the results.

Table 3.2. Mean GHG emission sources for beef and lamb in the years 2009/10 and 2012/13. Emissions are expressed as kg CO_2eq/kg liveweight

	Lamb				Beef			
	2009/10	CV (%)	2012/13	CV (%)	2009/10	CV (%)	2012/13	CV (%)
GHGs from inputs								
Diesel	0.63	65.45	0.51	35.11	0.75	80.08	0.48	35.54
Transport	0.08	16.27	0.07	15.58	0.49	91.67	0.37	66.34
Other fuels	0.03	2.56	0.02	2.33	0.04	3.71	0.01	1.66
Electricity	0.13	31.45	0.24	38.83	0.06	7.94	0.07	7.54
Fertilisers (inc. lime)	0.61	8.20	0.65	11.95	0.72	9.78	1.14	17.39
Agrochemicals	0.00	0.29	0.00	0.44	0.01	1.19	0.00	0.62
Bedding	0.03	6.61	0.02	1.74	0.10	8.42	0.05	4.18
Silage wrap & sheet	0.04	3.088	0.03	3.45	0.04	4.70	0.03	1.67
Bought-in stock	0.84	179.53	0.43	99.97	0.55	102.35	0.54	123.35
Concentrate Feeds	1.15	74.26	1.56	55.53	1.36	132.25	0.98	90.66
N_2O emissions								
N application	0.39	25.33	0.42	39.60	0.48	31.60	0.75	26.22
Manure/excreta	2.59	135.50	2.98	89.76	2.24	88.02	1.56	32.88
Organic soils	0.22	26.40	0.36	46.77	0.155	18.922	0.16	20.32
Atmospheric deposition	0.52	27.01	0.60	17.95	0.30	9.63	0.22	4.75
Leaching/runoff	0.58	30.49	0.67	20.20	0.31	10.84	0.25	5.34
Crop residues	0.00	0.50	0.00	0.03	0.00	0.65	0.00	0.12
Stored & managed manure - direct	0.14	10.39	0.13	12.62	0.57	20.36	0.48	13.31
Volatilisation - stored & managed manure	0.04	3.12	0.04	3.79	0.28	12.06	0.26	12.81
CH_4 emissions								
Enteric fermentation	6.21	237.317	6.88	188.40	8.11	266.60	6.81	157.58
Excreta	0.37	14.18	0.39	14.18	1.93	61.27	1.62	47.28
Land use change								
Lime application	0.04	13.93	0.00	188.40	0.00	266.30	0.00	157.58
Land-use change	0.37	5.51	0.00	14.18	0.00	61.27	0.00	47.28
Carbon footprint	**14.68**	8.20	**16.00**	11.95	**18.48**	9.78	**15.78**	17.39

The type of enterprises assessed in the study, their respective farm labels, and the total slaughter weight produced for the two sampling years are illustrated in Table 3.3. Figure 3.2 depicts the differences in CFs of beef and lamb of individual farms between the two sampled years. The slaughter rate for lamb, which is referred to in subsequent sections, was calculated by assessing the proportion of lambs potentially available for slaughter (lambs intended for slaughter carried over from previous year + bought store lambs + total lambs born – lambs born kept for replacement) sold for slaughter in the 12 month period. For beef production, the slaughter rate was calculated by assessing what proportion of cattle intended for slaughter were sold for slaughter during both 12 month sampling period.

Table 3.3. Farm characteristics and total liveweight produced for slaughter/ha for both sampling years. For mixed farming systems, liveweight produced for slaughter/ha represents the total volume of beef and lamb sold for slaughter

Farm Label	Farm specialisation	Farm size (ha)	Elevation (m)	Slaughter weight (kg)/ha 2009/10	Slaughter weight (kg) /ha 2012/13
L1	Lamb	117.35	310	27.43	41.75
L2	Lamb	110.00	220	291.55	223.09
L3	Lamb	30.45	70	82.76	67.00
L4	Lamb	69.00	120	77.59	58.06
L5	Lamb	460.00	350	156.96	27.01
B1	Beef	95.91	290	107.39	268.48
B2	Beef	64.75	70	66.72	83.40
B3	Beef	93.58	150	0.26	324.44
B4	Beef	49.37	110	317.84	243.30
M1	Mixed	106.00	340	180.67	165.09
M2	Mixed	203.00	210	205.56	365.57
M3	Mixed	71.68	200	290.90	254.74
M4	Mixed	673.00	100	198.66	119.05
M5	Mixed	370.00	240	146.86	129.03

Although not statistically significant, the mean percentage change in total emissions for lamb was +12% from 2012/13 in comparison to 2009/10. Enterprises L2 and L5 showed the highest increase in emissions between the two sampling years, 52% and 37% respectively; whereas M3 reduced its emissions by the largest proportion, of 39% (Fig. 3.2). L2 differed little between the two years in terms of total slaughter rate, lambing proficiency, or stocking rates, although 7.5% fewer lambs were brought to slaughter in 2012/13. On this enterprise, the main disparity was the average weight that lambs were brought to slaughter; being 38 kg in 2009/10, and 30 kg in 2012/13. Consequently, the total weight brought to slaughter in 2009/10 was 73% higher than in 2012/13; thereby resulting in a lower total footprint per kg of liveweight produced. The CF of lamb produced on L5 had also increased as emissions associated with bought in feed were 95% higher in 2012/13 compared 2009/10. In addition, a large proportion of its stock due for slaughter in 2012/13 were still on-farm at the end of the period (18%); conversely, the enterprise had sold all but 2% of its lambs assigned for slaughter by the end of 2009/10. However, this may have been brought about due to the extreme weather of spring 2012/13, the results of which are likely to be augmented on this enterprise due to its high elevation (350 m).

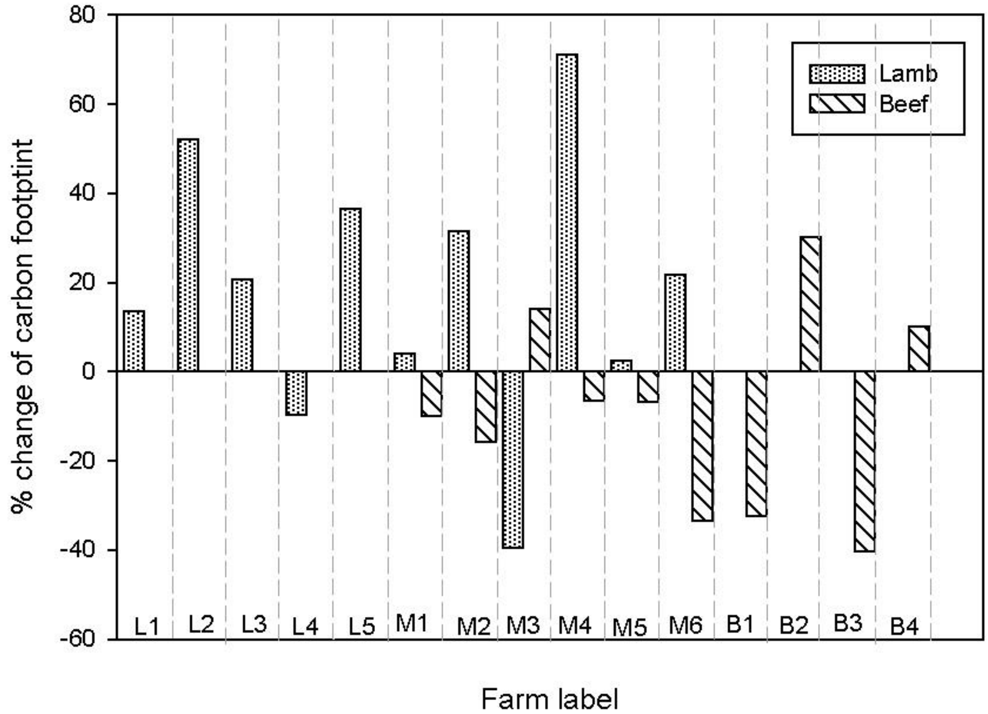

Figure 3.2. The percentage change of an enterprises 2009/10 CF to that of 2012/13. L = lamb only enterprises, M = mixed enterprises, B = beef only enterprises

The enterprise which showed the greatest reduction in their lamb CF between the two years was M3 (Fig. 3.2). Average liveweight of lamb brought to slaughter in 2009/10 was 36 kg, whereas it was 40 kg in 2012/13. It also simultaneously increased its total slaughter rate from 88% to 98%. Both measures resulted in an overall reduction of 39% in GHG emissions per kg of liveweight slaughtered.

As a whole, there was a mean -13% divergence in the mean CF for beef between the two periods, although this was not statistically significant. Enterprise B2 experienced the greatest inflation in emissions, its footprint rising by 30%; whereas B3 and M6 substantially reduced theirs (Fig. 3.2).

B2 did not vary to any great degree in terms of total slaughter rate, or the weight of animals brought to slaughter, while the stocking rate only expanded marginally. Direct N_2O emissions associated with manure management and storage increased by 38% as cattle were housed for two months longer in 2012/13 because of the poor spring weather. CH_4 emissions from manure also grew by 20%; a result of the longer housing period and a slight augmentation in herd size. B2 brought 2.82 tonnes of additional concentrate feed on-farm in 2012/13 due to the extended housing period brought about by the poor spring weather; thereby raising emissions from bought concentrates by 93% per kg of liveweight. Furthermore, a 21% increase in the amount of N applied between both years led to a rise in emissions associated with inorganic fertiliser. Consequently, emissions related to indirect and direct fertiliser use were raised by 75% and 46%, respectively.

Conversely, enterprises B3 and M6 both reduced their footprint by 40% and 30%, respectively. Diesel use decreased substantially on both farms. More importantly, both reduced livestock time to slaughter thereby increasing their total slaughter rate in 2012/13. As a result of a higher total slaughter rate, CH_4 emissions and N_2O emissions diminished accordingly.

3.4.3 Emission sources

As no significant difference were observed between both sampled years, both datasets were aggregated together. Aggregate data series refers to a set of values, each of which is averaged or otherwise aggregated across respondents. The CF was averaged over the two years and each model variable was assessed to determine its overall contribution towards the overall footprint (Fig 3.3). For both beef and lamb the dominant source of emissions was CH_4 from enteric fermentation which constituted 46% and 43% of their respective CF. N_2O from manure and excreta followed as the next most prevalent contributor of emissions for lamb production with 18% of its CF generated from such sources. Its higher value for lamb can be ascribed to the longer time period in which lambs are out to pasture. Beef had similar contributions from N_2O from manure and excreta (10%) and CH_4 from excreta (11%). Higher CH_4 emissions from beef excreta compared to that of lamb is a result of the longer housing period of cattle. Other emissions sources were considerably smaller for both.

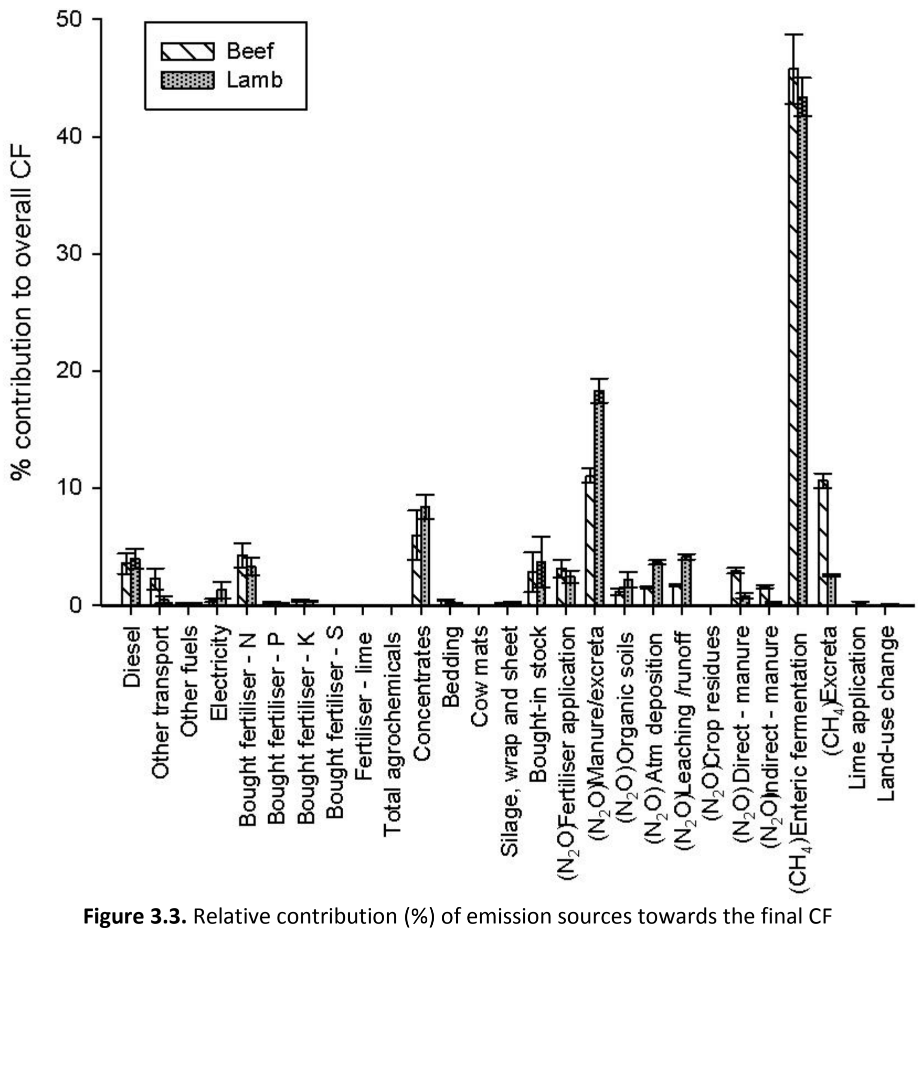

Figure 3.3. Relative contribution (%) of emission sources towards the final CF

The contribution of CH_4 and N_2O emissions towards the total footprint of beef and lamb is depicted in Figure 3.4. Enteric fermentation was by far responsible for the greatest proportion of emissions, followed by CH_4 arising from excreta. The greatest proportion of N_2O was from run-off/leaching (Fig. 3.4).

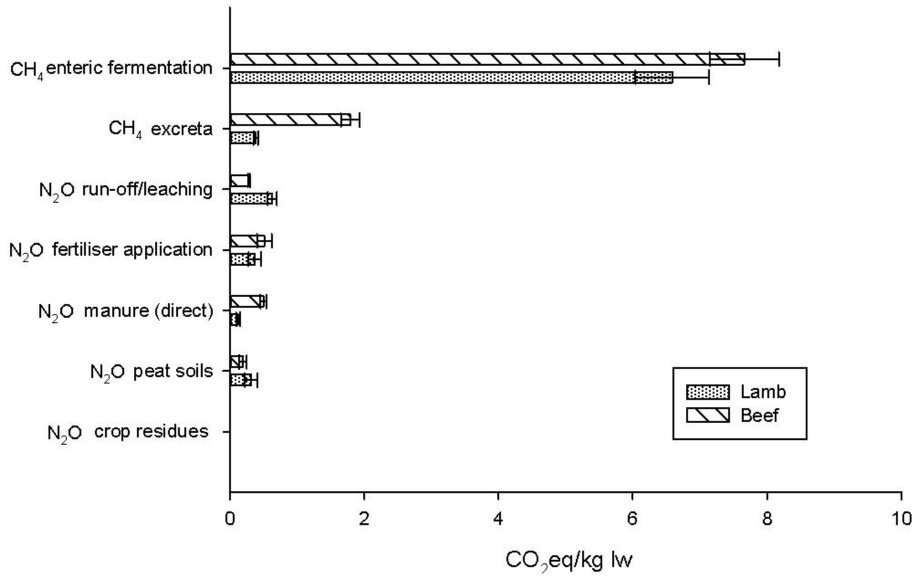

Figure 3.4. Mean emission sources of methane and nitrous oxide for beef and lamb carbon footprint

3.4.4 Variability

The aggregated datasets for paired years revealed a wide range of variation in emissions for both beef and lamb (Fig. 3.5). The mean CF of lamb was 15.13 kg CO_2eq/ kg lw, and 16.33 kg CO_2eq/ kg lw for beef. Total emissions ranged between 12.89–19.69 kg CO_2eq/kg lw for beef and between 9.89–21.14 kg CO_2eq/kg lw for lamb; a 34.52% and 53.33% variance between the highest and lowest CF for beef and lamb, respectively.

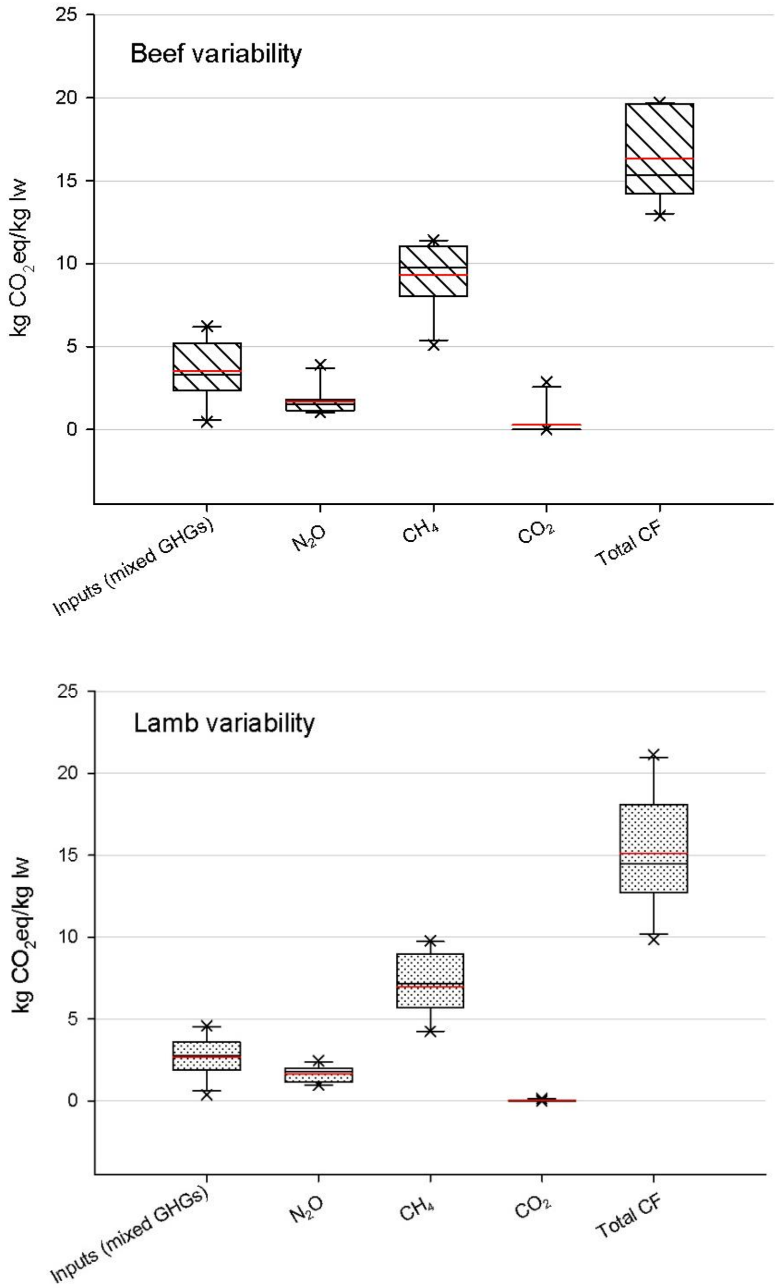

Figure 3.5. Variability, median, mean, 25th and 75th percentile (boxes), 10th and 90th percentiles (whiskers) and extreme values (crosses) of gross GHG emissions for beef and lamb

3.4.5 Comparison of highest and lowest CFs

It is useful to compare emissions between high and low footprints to highlight where differences lie (Veysset et al., 2014ab). For this purpose, data was pooled and direct comparisons between the lowest 25% (CF-) and highest 25% (CF+) of footprints (Table 3.4). Considering lambs firstly, the numbers of breeding stock, lambing percentage, and the number of animals slaughtered were similar for high and low CFs. Nevertheless, higher footprints were associated with farms taking longer to get lambs to slaughter; thereby, increasing CH_4 emissions associated with enteric fermentation and N_2O emissions from to urine deposition. Higher CFs also entailed higher concentrate use to fatten lambs when grass becomes less plentiful later in the growing season; though this was not associated with higher levels of liveweight of kg of lambs produced (Table 3.4).

Table 3.4. GHG emissions and farm characteristics of the 25% of enterprises with the lowest carbon footprint (CF-), and the 25% of enterprises with the greatest carbon footprint (CF+).

	Beef (CF-)	**Beef (CF+)**	**Lamb (CF-)**	**Lamb (CF+)**
Carbon footprint (kg CO_2eq/kg lw)	13.46	22.34	9.83	20.36
GHGs concentrates (kg CO_2eq/kg lw)	1.16	1.32	0.62	1.65
GHGs bought fertiliser (kg CO_2eq/kg lw)	0.57	0.68	0.27	0.64
GHG total inputs (kg CO_2eq/kg lw)	2.48	4.56	2.82	4.04
N_2O fertiliser application (kg CO_2eq/kg lw)	0.39	0.45	0.16	0.44
N_2O organic soils(kg CO_2eq/kg lw)	0.24	0.19	0.04	0.15
N_2O deposition and run-off (kg CO_2eq/kg lw)	0.43	0.71	0.71	1.80
N_2O stored and managed manure (direct) (kg CO_2eq/kg lw)	0.43	0.68	0.10	0.14
N_2O stored and managed manure (indirect) (kg CO_2eq/kg lw)	0.22	0.35	0.10	0.08
N_2O crop residues (kg CO_2eq/kg lw)	0.00	0.00	0.00	0.00
Total N_2O (kg CO_2eq/kg lw)	1.71	2.38	1.12	2.62
CH_4 enteric fermentation (kg CO_2eq/kg lw)	6.15	10.14	3.92	8.96
CH_4 excreta (kg CO_2eq/kg lw)	1.58	2.33	0.23	0.53
CH_4 total (kg CO_2eq/kg lw)	7.73	12.47	5.78	9.49
CO_2 total (kg CO_2eq/kg lw)	0.00	0.00	0.61	0.00
Farm size (ha)	378.02	173.69	140.09	163.4
Elevation (m)	107	246	172	206
Breeding stock (animals/ha)	0.24	0.35	4.02	5.00
Growing stock (animals/ha)	0.29	0.62	4.96	4.82
Total slaughter rate (%)	70.92	31.40	62.82	95.93

Likewise, the highest beef CFs had almost twice the stocking rate of growing stock (0.82 vs 0.49 heads of growing stock per hectare). This may have had a negative impact on animal growth rates. Consequently, a high beef CF was influenced by enterprises slower in getting stock to slaughter (56% of animals to slaughter, compared to 96% for a low CF); resulting in higher N_2O and CH_4 emissions per kg of liveweight produced. Higher beef CFs were observed at higher elevations while utilising the same levels of inputs as enterprises operating at lower elevations. The study found that enterprises who had higher beef footprints had similar production levels as enterprises who had lower emissions. However, these farms required a larger number of growing animals to reach parity in liveweight brought to slaughter which raised emissions per liveweight produced.

3.4.6 Scenario analyses

Scenario analyses were carried out to explore how changes in management practices may alter the CF of beef and lamb per kg of liveweight produced for each of the 42 observations. Mitigation measures should aim to reduce emissions without simultaneously increasing any other externalities (Picasso et al., 2014). Farmers consider the effects of multiple pressures when making decisions (Hyland et al. 2015). A recent study found that farmers consider the adoption of legumes as being the most practical measure they could adopt to lower their CF (Jones et al., 2013). Concentrate feed use and fertiliser demands could be reduced without compromising the farms carrying capacity of stock by incorporating legumes such as red and white clover into grass leys (Phelan et al., 2015). Another mitigation measure deemed practical by farmers was increasing young stock growth rates for early finishing (Jones et al., 2013); this would allow for improved slaughter rates. The management alterations that were examined therefore include: reduce concentrate feed by 50% and 80% (C < 25%; C < 80%), reduce fertiliser applied by 50% and 80% (F < 50%; F < 80%), and for the quicker finishing times for young stock, i.e. for all enterprises to match the slaughter rates of the least emitting enterprises observed in the previous section (> Prod efficiency). Manure management systems which could lower emissions are of particular relevance to beef enterprises. Consequently, the adoption of low-emission manure management systems (e.g. covering of farmyard manure stores) was also considered (MM) (Fig. 3.6).

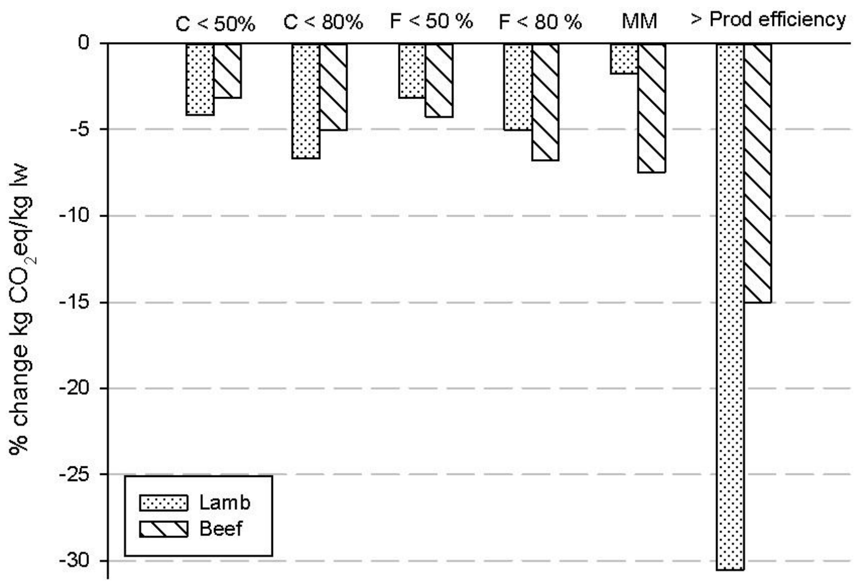

Figure 3.6. Scenario analyses of potential footprint reduction strategies. The graph represents how changes in management activities alter the footprint when all other variables are held constant. C = concentrate use reduction, F = fertiliser reduction, MM = efficient manure management, and Prod efficiency = matching the efficiencies observed for the lowest CFs.

The most effective method for enterprises to decrease their CF was through increasing production efficiency (Fig. 3.6). In such a scenario, emissions diminished by 15% and 30.5% for beef and lamb respectively. For beef production, this was followed by changing manure handing systems to lower emitting techniques (↓7.5%), reducing fertiliser by 80% (↓6.8%), feed concentrates use by 80% (↓5.0%), fertilisers by 50% (↓4.3%), and feed concentrates use by 50% (↓3.1%). Subsequent to adopting the practices of the least emitting producers, the most effective scenarios of lowering emissions for lamb was reducing feed concentrate use by 80% (↓6.7%), fertiliser use by 80% (↓5%), feed concentrate by 50% (↓4.1%), fertiliser use by 50% (↓3.1%), and changing manure management practices to lower emitting systems (↓1.8%).

3.5 Discussion

Wales is a country that presents characteristics that are applicable to various nations that aim to alleviate emissions from pastoral-based systems. The topography of the country varies considerably, encapsulating an array of challenges and environments faced globally by farmers in the sector. Whilst only fifteen farms were part of this study, they nevertheless capture the breadth of farming systems and challenges; while baseline and continued measures of CFs are useful to inform future studies (Ruviaro et al., 2015). The results of this study are therefore of relevance to other livestock systems. Furthermore, this study is one of few that have revisited livestock enterprises to determine whether their CF has changed with time, and the underlying drivers of any change.

While most of the farmers deemed themselves capable and willing to lower their respective footprints, none had purposefully adopted any mitigation measures since 2009/10 (Table 3.1). However, it is clear that those farmers that took part in the study did consider the GHG emissions associated with their production systems (Table 3.1).

Both sampling periods experienced abnormal weather patterns, and temporal analyses revealed that there were no significant differences in the mean CF for beef and lamb when comparing the two sampling years. The winter of 2009/10 was the coldest since 1978/1979, with significant snowfall between December and February (Defra, 2011). In 2012, the summer and autumn were much wetter than normal; receiving 131% of the average rainfall (Defra, 2014a). The above average rainfall continued into the latter months of the year, with December being its wettest since 1999. This may explain the 12% rise in the mean lamb CF in 2012/13. Smaller liveweights cause greater emissions associated with producing 1 kg of liveweight for slaughter as total emissions are spread over a lighter animal when all other aspects of production stay the same. The difficult weather conditions of 2012/13 also affected the number of cattle brought to slaughter. UK producers were faced with rationing their herd in the face of high input costs and concerns over forage availability and quality. Furthermore, the horse-meat scandal of 2013 assured demand for UK beef was high, with many UK farmers taking advantage of the strong market conditions (Defra, 2014b). This may explain the increase in total slaughtered beef liveweight sold in 2012/13; a factor which contributed to lowering the mean beef CF by 13%.

Famers' perceptions of the necessity to implement measures which address climate change differ (Hyland et al., 2015). Nonetheless, whether motivation to adopt is dictated by environmental or productivist tendencies, there are many measures which farmers could adopt to lower their CF which would appeal to both discourses. Some enterprises greatly reduced their respective footprints by increasing production efficiencies compared to 2009/10. As production systems become more efficient, emissions are spread over increased units of production. When both sample periods were pooled together it was observed that both high- and low-emitting enterprises produced the same volume of liveweight with no major differences in input levels. Furthermore, there were no defining differences in the breeds of sheep and cattle in which they managed. However, lower CFs were associated with better animal performance and productivity by requiring a lower carrying population to produce 1 kg of liveweight for slaughter; thus, pointing to an efficiency factor. At zero inputs, the highest CFs were burdened with an additional 7.66 and 9.48 kg CO_2eq/kg lw for beef and lamb respectively; this deviation in emissions persisted per unit increase in input.

In this study, higher productivity effectively 'diluted' emissions from stock maintenance on footprints with the lowest emission. Scenario analysis found that if all enterprises adopted the production practices of the enterprises with the lowest CFs, emissions for beef and lamb would be reduced by 15% and 30.5%, respectively. Such reductions far surpassed the other scenarios investigated, i.e. reduction in fertiliser use, reduction in concentrate feed, and the adoption of lower emitting manure management systems. The results therefore imply that there is substantial potential to reduce GHG emissions from the livestock sector if widespread uptake of efficiency measures were adopted. Such measures include improving the genetic potential (e.g. use of Estimated and Genomic Breeding Values) and optimising nutritional needs of the animals, better utilisation of pasture, improving soil and nutrient management, and reducing losses due to disease. For instance, inclusion of clover in grassland systems improve animal performance and concurrently 'fix' atmospheric N, thereby offers an opportunity to displace reliance on synthetic fertilisers (Phelan et al., 2015). Implementing such measures would bring about economic benefits to the sector and therefore represent 'win–win' options, which should appeal to producers and policy-makers alike (Hyland et al. 2015). The empirical data collected for this study showed no significant changes in the CF between the two sampling years and therefore highlights the need for longer term assessments. Nevertheless, footprinting farms at multiple time points in terms of kg CO_2eq per kg of liveweight brought to slaughter offers an appropriate metric to determine efficiency changes within, and among, producers.

The farmers who took part in this study believed that reducing emissions from their respective farms to be of little value. However, most expressed an interest in reducing their farm CF. Respondents may have answered in a manner that was deemed favourable considering the study focus when asked about an interest in reducing their own emissions. Conversely, farmers may indeed be aware of the economic advantages that can be forthcoming with many mitigation strategies and were interested in reducing emissions in such a scenario, even if it was of little value in reducing global GHG emissions. Farm resource endowments, capital structure, and financial leverage are critical factors which determine the potential of farms to adopt new practices. Farmers' interests in particular mitigation strategies, and their potential to adopt them, may depend on their existing endowments of resources as well as other attributes (FAO, 2013). The specific characteristics of individual farmers (e.g. wealth levels, age, farm endowment, land type, management system, and genetic profile) may limit their ability to adopt measures which address climate change. It is therefore important that policies and incentives consider the inequality of opportunity and outcomes among farmers. Nevertheless, it is likely that the results from the scenario analyses not merely casual. Indeed, it is widely reported that if farming enterprises adopted the efficiencies of the least emitting producers that a large reduction in sectoral emissions could be achieved (Audsley and Wilkinson, 2014; Gerber et al., 2013).

3.6 Conclusions

The red meat sector is a significant contributor to anthropogenic GHG emissions. To lower emissions, it is recommended that a broad array of mitigation measures are adopted. However, the results elicited from the two sampling periods reiterates that there is considerable potential to reduce sectorial emissions (15% and 30.5% for beef and lamb, respectively) if producers were to adhere to the practices and approaches adopted by their least-emitting peers.

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Chapter 4: Farmers' perception of climate change: identifying types

Farmers’ perception of climate change: identifying types

Hyland, J.J., Jones, D.L., Parkhill, K.A., Barnes, A.P., Williams, A.P.

4.1 Abstract

Ambitious targets to reduce greenhouse gas (GHG) emissions from agriculture have been set by both national governments and their respective livestock sectors. We hypothesize that motivation based on self-identity influences assessments of climate change. Disparity in such assessments may affect the behavioral capacity of farmers to implement measures which address the issue. Perceptions of climate change were elicited from 286 beef/sheep farmers and evaluated using Principal Component Analysis (PCA). The analysis elicits two components which evaluate identity (productivism and environmental responsibility), and two components which evaluate behavioural capacity to adopt mitigation and adaptation measures (awareness and risk perception). Subsequent Cluster Analyses reveal four farmer types based on the PCA scores. ‘The Productivist’ and ‘The Countryside Steward’ portrays low levels of awareness of climate change, but differ in their motivation to adopt pro-environmental behaviour. Conversely, both ‘The Environmentalist’ and ‘The Dejected’ score higher in their awareness of the issue. In addition, ‘The Dejected’ holds a high sense of perceived risk; however, their awareness is not conflated with an explicit understanding of agricultural GHG sources. With the exception of ‘The Environmentalist’, there is an evident disconnect between perceptions of agricultural emission sources and their contribution towards GHG emissions amongst all types. If such linkages are not conceptualised, it is unlikely that behavioural capacities will be realised. Effective communication channels which encourage action should target farmers based on the groupings depicted. Therefore,

understanding farmer types through the constructs used in this study can facilitate effective and tailored policy development and implementation.

4.2 Introduction

Approximately 14.5% of anthropogenic global greenhouse gas (GHG) emissions can be attributed to livestock production (Gerber et al., 2013). Per kg of produce, red meat, such as beef and lamb, has a higher carbon footprint in comparison than cultivated crops and alternative protein foodstuffs (Lesschen et al., 2011). For industry to reduce emissions, it is important to understand how farmers perceive climate change and their willingness to alter current management regimes. The aim of this study is to establish different types of beef/sheep farmers, based on their sense of self-identity and their perceptions of climate change. Such information can serve to improve future policy by enabling the targeted transfer of climate change information.

In a pioneering study, Gasson (1973) suggested that farmer behaviour is driven by profit maximisation. Subsequent research proposes that basing farmer behavioural types on the assumption of a simple profit-maximising behaviour is inappropriate (Vanclay, 2004; Pannell et al, 2006). Other assertions of behaviour have unveiled that farmers do not act in ways that are strictly governed by economic principles. Therefore, participation in environmental initiatives is determined by more than just financial incentives (Vanclay and Lawrence, 1994; Lockie et al., 1995; Edwards-Jones, 2006). It is therefore necessary to better understand what underpins farmer's participation in environmental initiatives when developing effective policies and extension programs (Vanclay et al., 2006; Pannell et al., 2006).

Farmers often ascribe different levels of importance to environmental and production aspects of farm management (Vanclay and Lawrence, 1994; Vanclay et al., 1998). However, extension strategies and practices have traditionally ignored farmer diversity, presuming that adoption programs are universally applicable, and thus universally adopted (Vanclay and Lawrence, 1994). Different epistemologies influence the mobilization and transformation of knowledge. The limitations of the traditional paradigm of knowledge transfer led to the formation of non-didactic 'human development' approaches, which are based on social learning, participation, and empowerment (Black, 2000; Fleming and Vanclay, 2010). Categorising farmers into groups has been proposed as a means of effectively capturing this diversity (Valbuena et al., 2008). Whilst perception-based farmer types are regarded by some to have limited salience – a criticism being farmers do not identify themselves within pre-defined groups (Vanclay et al., 2006) – they have gained prominence as a basis to effectively capture heterogeneity, and to effectively target farmers for the voluntary uptake of environmental initiatives (Bidogeza et al., 2009; Voss et al. 2009; Barnes and Toma, 2012; Morgan-Davies et al., 2011; Nainggolan et al., 2012).

Few studies have used typologies to characterise the perceptions of climate change from livestock farmers of temperate regions. Eggers et al. (2014) found that North German grassland farmers could be grouped into four types based on their perceptions of the issue. The research, which focuses on adaptation measures on ley and permanent grassland, postulates that farmers consider adaptation on economic factors or emotional reasoning. Elsewhere, Barnes and Toma (2012) depict six distinct types of Scottish dairy farmers from perceptions of climate change and planning goals. Half of the farmer types in the study believed that climate change would impact them negatively in the future; signalling the likely adoption of adaptive technologies to combat such scenarios. Conversely, other groupings did not perceive climate change as a significant enough threat to change their future management planning. Whereas these studies have focused on farmer types in other sectors, or on one aspect of adaptation or mitigation (Eggers et al., 2014; Bruce, 2013), there is a specific need to investigate beef and sheep farmers' perceptions of climate change in temperate regions. Such analyses are important in light of the considerable attention bestowed on the red meat sectors' contribution towards climate change; therein, assisting the industry's aspirations in reducing emissions.

Farmers' perceptions of climate change differ – conceptual, practical, and information barriers all act as limitations to pro-environmental behaviour (Fleming and Vanclay, 2010). As such, understanding farmers' self-identify, their awareness of an environmental issue and perceptions of its risk, are essential in tailoring initiatives aimed at providing improvements in the environmental performance of agriculture (Greiner et al., 2009; Yazdanpanah et al., 2014). These constructs may influence the likelihood of farmers' voluntary uptake of climate change measures, and their participation in programs that focus on reducing the sector's GHG emissions. Research proposes a gap between awareness and pro-environmental behaviour. Reasons for such disconnect can vary when considering climate change, and may be caused by the complexity of a problem that is global in character (Kollmuss and Agyeman, 2002). However, the level and type of knowledge can lessen the gap between awareness and mitigation behaviour (O'Connor et al., 2002). Moreover, the appraisal of risks climate change may bring is a significant factor in influencing adaptive responses (Arbuckle et al., 2015; O'Connor et al., 1999). Story and Forsyth's (2008) awareness-appraisal-responsibility model asserts that individuals become increasingly likely to protect and sustain the environment as awareness and responsibility of an environmental issue heighten, and appraisal of its risk become elevated.

We therefore use constructs that assess farmers' self-identity and their behavioural capacity to implement measures that address climate change. Two constructs determine self-identity, and are based on productivism and environmental responsibility. Motivation to adopt environmental behaviour is based on internal perceptions of how farming should be practiced (farmer-identity). The Dual Interest Theory acknowledges that both economic and environmental motivations are represented in varying strengths when individuals make environmental decisions (Sheeder and Lynne, 2011). Furthermore, two additional constructs assess awareness and risk perception, and hence the behavioural capacity to implement adaptation and mitigation measures. Behavioural capacity can be defined as the latent potential of behavioural change to affect improvements in the environment (Beretti et al., 2013).

Considering the limited focus on beef/sheep farmers perceptions of climate change in temperate regions, the aims of this study are to: (1) determine such farmers' perceptions of the issue; (2) create a typology of beef/sheep farmers based on these perceptions; (3) assess if self-identity influences the behavioural capacity of farmers to implement measures which address climate change. We hypothesise that farmers who align themselves with an environmental self-identity are conscious of the intricacies of climate change and the risks that it may bring. The opposite is foreseen for farmers who displayed productivist tendencies. In the following section, we critically engage with the conceptual literature associated with the aforementioned motivational and behavioural capacity constructs which are used to assess the hypotheses outlined above.

4.3 Awareness, self-identity, and perceptions of risk

4.3.1 Self-identity

Self-identity refers to the extent to which certain behaviour is considered part of one's self (Terry et al., 1999). Ascription of one's beliefs may be filtered through an individual's value system (Sulemana and James Jr., 2014). The more salient an identity, the greater the probability of it being activated; hence it is possible to predict desired action using self-identity (Burke and Stets 2009).

Pro-environmental and productivist identities are two of the most commonly examined in an agricultural context (Sulemana and James Jr., 2014). Although modern-day agriculture has adapted to serve multiple purposes, i.e. the provision of food and ecosystem services, research postulates that a productivist identity dominates the decision-making process of farmers (Burton, 2004; Burton and Wilson, 2006). Productivitism is often legitimised by government policies advocating that increasing output serves the national interest (Burton and Wilson, 2006). Indeed, Rosin (2013) demonstrated that despite increasing environmental concerns over intensification, the 2008 global food price spike has further reinforced productivist idealisms within New Zealand farmers.

Environmental programs may be resisted in cases where this productivist self-identity is threatened by the induction of pro-environmental legislation (van der Werff et al. 2013). Therefore, understanding farmers' sense of identity is important in assessing their motivation in adopting environmental measures and participation in environmental programs (Sulemana and James Jr., 2014). Indeed, Indiana farmers who were motivated by environmental responsibility (rather than profitability) were most likely to adopt conservation practices (Reimer et al., 2012). Moreover, Lokhorst et al., (2011) observed that self-identity is significantly related to farmers' intention to perform non-subsidised environmental practices.

Hence, self-identity can significantly affect an individuals' motivation to undertake voluntary measures where financial reimbursements, or awards, are not forthcoming.

4.3.2 Awareness

Awareness of environmental problems is a perceived estimate of reality that individuals formulate from accumulated knowledge (Dietz et al., 2007); this construct can subsequently influence behavioural decisions (McCown, 2005), and willingness to adopt solutions (Prokopy et al., 2008). Awareness in the context of this study refers to the degree to which individuals are aware that climate change is happening, and that agriculture is a contributing factor to anthropogenically-induced GHG emissions.

Past research has found positive correlations between awareness of the anthropogenic influences causes of climate change and the likelihood of implementing mitigation measures (Lorenzoni et al., 2007). Mitigation can be defined as an anthropogenic intervention to reduce sources or enhance the sinks of GHGs (IPCC, 2001). Climate change awareness is therefore a relevant facet in predicting pro-environmental behaviour (Bord et al., 2000; O'Connor et al., 2002; Prokopy et al., 2008; Semenza et al., 2008). Arbuckle et al. (2013) postulate that mitigation action requires farmer awareness of climate change, at least tacitly, and that human activity is an underlying cause of the issue.

4.3.3 Perceived risk

While awareness of climate change is a powerful predictor of behavioural intentions, it is independent from the belief that climate change will have negative impacts. Risk perception corresponds to the belief about adverse consequences for valued objects (Leiserowitz, 2006; Dietz et al., 2007; Brody et al., 2012; Arbuckle et al., 2015); it is dependent on values and ecological worldviews (Stern et al., 1999). Perceptions of the risks that climate change may bring can therefore influence engagement and the support of policies that address the issue (O'Connor et al., 1999).

In the context of this study, perceived risk is farmers' appraisal of the negative effects of climate change on agriculture. Individuals are more likely to adopt pro-environmental behaviour when they understand the adverse personal impacts of no action (Masud et al., 2013; O'Connor et al., 1999). Participation in adaptation and mitigation initiatives becomes less appealing when climate change is weighed up against risks such as economic instability (Stuart et al., 2014). Consequently, farmers who perceive climate change in terms of local consequences which may negatively impact their enterprise are more likely to support and participate in initiatives that aim to address the issue (Haden et al., 2012; Arbuckle et al., 2015).

The extent to which farmers succeed in living in accordance to their identity tends to be moderated by constraints such as risk (Pannell et al., 2006). Indeed, a dystopian perception of the adverse effects of climate change has been found to be among the strongest predictors of support for climate change policies (McCown, 2005; Dietz et al., 2007). For instance, it has been observed that climate change risk perceptions influence support of adaptive actions amongst US farmers (Arbuckle et al., 2015; Niles et al., 2013). Adaptation can be defined as adjustments in human or natural systems in response to actual or expected climatic stimuli and their effects or impacts (IPCC, 2001). Therefore, perceptions of the risks associated with climate change are a necessary precursor for the adoption of adaptation measures (Arbuckle et al., 2013).

4.4 Method

4.4.1 Wales: a case study

Little attention has focused specifically on beef/sheep farmers' perceptions of climate change in developed temperate regions. Moreover, factors which influence farmers' willingness to adopt initiatives aimed at reducing the sector's GHG emissions have been largely unexplored. This is in spite of livestock production accounting for a particularly high proportion of global GHG emissions (Gerber et al., 2013). To reduce livestock emissions, countries have adopted numerous approaches at the farm level, many of which are voluntary (Cooper et al., 2013).

Wales presents characteristics that are applicable to various nations that aim to alleviate emissions from pastoral-based systems; indeed, beef and sheep enterprises represent the overwhelming majority of farm holdings in Wales. The topography of the country varies considerably, encapsulating an array of challenges and environments faced globally by temperate farmers in the sector. Wales aspires to reduce its total emissions by annual increments of 3% from 2011 onwards (Welsh Government, 2009); the livestock industry has also initiated a strategic plan outlining how the sector plans to meet such targets (HCC, 2011). A better understanding of farmer perceptions of climate change will help identify whether these targets are achievable, and the barriers to change. Like many countries, Wales largely relies on farmers' voluntary uptake of adaptation and mitigation measures. Uptake has been incentivised through initiatives such as efficiency grants offered by government (Welsh Government, 2014).

4.4.2 Questionnaire design and distribution

The development of a pilot questionnaire resulted from a review of relevant literature on farmers' perceptions of climate change (Widcorp, 2009; Farming Futures, 2011; Barnes and Toma, 2012; Hall and Wreford, 2012). This was then trialled with 30 livestock farmers, and minor amendments (e.g. to the wording of some questions) were implemented thereafter. The final administered (*n* = 286) bilingual survey (English/Welsh) consisted of three sections (Appendix C). Section one elicited socio-demographic information, section two consisted of 29 statements where respondents were asked to express their opinion on a 5-point Likert scale, and the final section captured farmers' general views on climate change sources. Farmers were recruited by convenience sampling throughout Wales during 2012 at union meetings, livestock markets, agricultural extension open days, as well as agricultural shows and events.

4.4.3 Analyses

Survey results were analysed statistically in a variety of ways including Principal Component Analysis (PCA) and Cluster Analysis. The first part of the results section presents an overview of all respondents' perceptions of climate change along with issues related to the concept; therein setting the scene for subsequent analyses and discussion. Details of procedures used for PCA and cluster analysis used to assess famers' motivation and behavioural capacity are outlined in the sections that follow.

4.4.4 Principal component analysis

Participants' responses to statements in section two of the questionnaire were analysed using PCA to give a more detailed representation of perceptions of climate change. PCA identifies common factors to account for most of the variation in data and is performed by examining the pattern of correlations among independent variables (i.e. questionnaire statements). When these variables are highly correlated, they are effectively 'saying the same thing' and described as components (Field, 2009). The subsequently acquired factor loadings are merely the correlations among all individuals' answers to each of the questionnaire statements with the derived component score. The components extracted from the PCA are subsequently used as classification criteria to cluster respondents into types (Bidogeza et al., 2009; Voss et al., 2009; Barnes and Toma, 2012; Morgan-Davies et al., 2011; Nainggolan et al., 2012). These groupings are internally homogenous, while being externally heterogeneous from one another (Janssens et al., 2008).

The Kaiser-Meyer-Olkin measure of sampling adequacy was found to be greater than 0.6 (0.808), thereby verifying that the dataset was appropriate for PCA. Subsequently, the Bartlett's test of sphericity was seen to be significant ($p < 0.05$), thus indicating that PCA could proceed (Pallant, 2010). The factors selected (based on the Kaiser criterion with eigen-values ≥ 1) explained 55.7% of the variance.

A Varimax rotation was implemented to increase the interpretability of the results (Field, 2009). Considering the sample size, a statement was only retained if the loading factor was at least 0.35 (Janssens et al., 2008) and the difference between the loading, and two other cross-loadings, greater than 0.3 (Wang and Ahmed, 2009). Interpretation of the scree plot revealed inflexions that justified retaining four components; this was supported by parallel analysis (Pallant, 2010). The content of a component was best interpreted by examining items with factor loadings of 0.4 or above, such factors are considered to be 'fair' (Costello and Osborne, 2011). Subsequently, the four components were named: awareness (A), environmental responsibility (ER), productivism (P), and perceived risk (PR). Components were named according to the factors which loaded highly. Both environmental responsibility and productivism components can be described as identity standards; whereas awareness and risk perception components specifically reflect an individual's behavioural capacity to implement mitigation and adaptation measures (Table 4.1).

Table 4.1. Factor loadings of attitudinal statement (prior to varimax rotation). Factor loadings are derived from principal component analysis. The content of a component is best interpreted by examining items with factor loadings of .4 or above

	A	ER	P	PR
Livestock farming contributes to climate change	**.701**			
Climate change will affect Welsh farming in the next 10 years	**.669**			
I accept that man-made climate change is happening	**.633**			
Livestock farmers should share responsibility towards the industry's impact on climate change	**.612**			
Climate change is an important global issue	**.612**			
It is possible to reduce GHG emissions from my farm without lowering production levels	**.461**			
Environmental regulations are important for the future of farming	**.451**			
Others in my family think that I should farm as environmentally friendly as possible		**.686**		
I want to farm as environmentally friendly as possible		**.665**		
Switching to a more environmentally friendly farming methods would not require much change from my current operation		**.592**		
As a farmer I have an obligation to maintain or improve the environment for future generations		**.553**		
I am interested in trying different technologies and/or systems to reduce my farms' GHG emissions		**.534**		
The way farming colleagues think about my farm is important to me		**.449**		
The government should encourage food production in the UK to reduce reliance on imports			**.722**	
The government should financially support farmers in adapting to climate change			**.640**	
Other industries pollute more than livestock farmers and should therefore be penalised more			**.510**	
Any climate change reduction strategies must make economic sense to the individual farmer			**.475**	
Being seem as primarily as a food producer is important to me			**.426**	
The best climate change mitigation strategies are too costly to adopt				**.639**
Climate change poses more of a threat to farming in the next 10 years than that of a general recession				**.607**
Climate change will lead to lower productivity on my farm due to disease and pests				**.579**
Uncertainty due to variable weather patterns caused by climate change will negatively influence my ability to farm in the future				**.381**
Beef or lamb produced with low emissions should be sold at a higher price				**.351**
Cronbach's alpha	*.774*	*.700*	*.533*	*.512*

*** Factor codes: A = Awareness, ER = Environmental Responsibility, P = Productivism, PR = Perceived risk**

Cronbach's alpha was applied to test the reliability and internal consistency of the derived factor loadings (Pallant, 2010). Cronbach alpha's > 0.5 are considered acceptable as evidence of a common factor underlying the responses (Nunnally, 1967). The reliability of each factor's Cronbach's alpha was examined through the impact on alpha by the removal of each statement. An alpha value higher than the final value suggested the removed statement was unnecessary (Field, 2009). Consequently, question 28 ('I find information on climate change easy to understand') was removed from the analysis.

4.4.5 Cluster analysis

The factor scores from PCA were subjected to both Ward's hierarchical and K-means clustering methods (Burns and Burns, 2008). The PCA scores were used for the Ward's hierarchical clustering technique as the algorithms require continuous, rather than the categorical Likert scale data collected in the survey. Hair et al. (1998) point out that the selection of the final cluster solution requires substantial researcher judgement. The application of the hierarchical cluster analysis suggested the presence of four clusters from interpretation of the dendrogram (Köbrich et al., 2003). An elbow test verified the ideal number of clusters for the successive k-means clustering method to be $n = 4$, which was consistent with the interpretation of the dendrogram (Burns and Burns, 2008).

The K-means method minimises the distances within each cluster to the centre of that cluster, and was carried out following hierarchical cluster analysis. K-means methods are superior to the hierarchical methods when the choice is made for an initial configuration based on the results of hierarchical clustering (Janssens et al., 2008). Subsequently, respondents were grouped into their respective clusters. The types were labelled according to evident differences in perceptions of climate change based on the cluster centres for each grouping. Cluster comparison and validation was carried out by a one-way-analysis-of-variance and Bonferroni multiple comparison tests; the tests verified significant differences present between groups with regard to their perception of the four PCA components. Furthermore, Pearson's Chi-Squared test (X^2) was used to determine whether groupings differed significantly in their responses to questions not included in PCA analysis ($p < 0.05$).

4.5 Results

4.5.1 Characteristics and perceptions of respondents

In total, 286 completed surveys were obtained, representing ca. 2.2% of livestock farmers in Wales (Welsh Government 2012). Table 4.2 summarises the general characteristics of the respondents, while Figure 4.1 illustrates where farmers obtained information on climate change.

Table 4.2. Profile of survey participants

		%
Farmer type	Full-time farmer	68.5
	Part-time farmer	31.1
Gender	Male	90.6
	Female	9.4
Age	18-25	18.1
	26-35	12.2
	36-45	13.3
	46-55	19.9
	56-65	19.2
	>66	17.1
Highest level of education	Primary school	8.7
	GCSE/O-Levels	26.2
	A-Levels/NVQ	18.5
	HNC/HND	19.2
	University undergraduate degree or higher	27.3
Farm size (acres)	<100 (<40.47 ha)	35.3
	101-300 (40.5-121.41 ha)	33.9
	301-500 (121.81-202.3 ha)	14.3
	>501 (>202.75 ha)	16.1
Livestock sector?	Beef only	16.8
	Sheep only	18.5
	Mixed (sheep and cattle)	64.7
Farming experience (years)	0-10	15.7
	11-20	16.1
	21-30	23.8
	>31	44.1

*** In cases where percentages do not add up to 100, the respective question was not answered on all questionnaires or due to rounding**

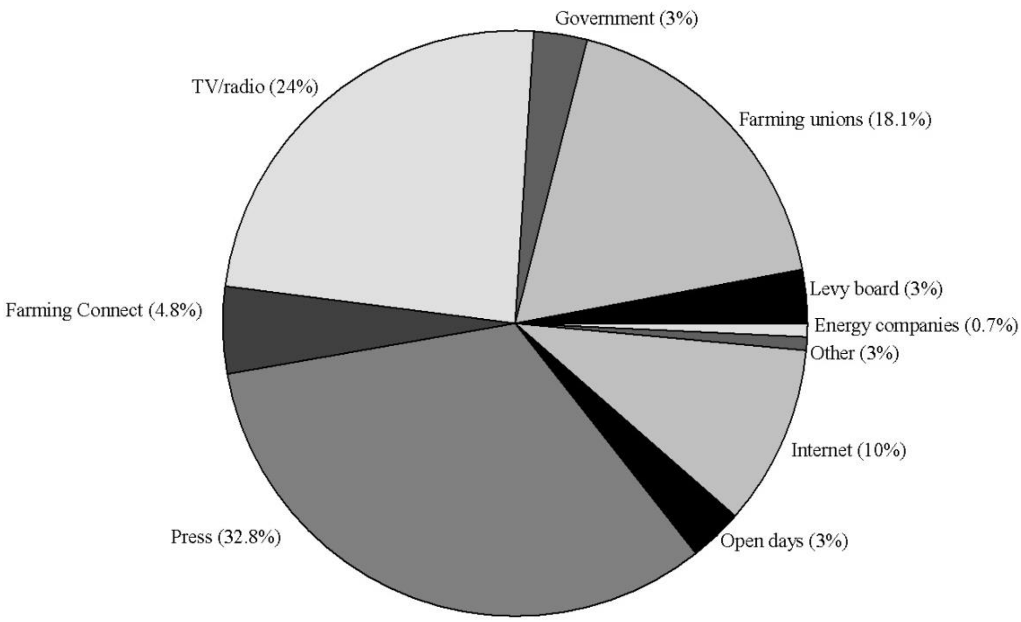

Figure 4.1. Respondents' main source of information on climate change
Farming Connect is a service financed by the European Agricultural Fund and Welsh Government, offering one-to-one support, knowledge, expertise, training, and advisory services, tailored to farmers' needs

Farmers were uncertain as to what opportunities, if any, that climate change may bring. The main opportunity that climate change may bring was thought to be that of a longer growing season. Unpredictable and extreme weather was ascribed as the greatest risk from climate change on their farms (42.3%) (Table 4.3). Whilst there was awareness that anthropogenic climate change is a reality, there was some uncertainty of the contribution of livestock to the problem (Fig. 4.2). It was interesting to observe how respondents were less hesitant in chastising other industries and activities as being contributors to climate change (Fig. 4.3).

Table 4.3. The main opportunities and risks respondents anticipate climate change may bring. Respondents were free to choose from a presented list.

Main opportunity that climate change may bring (%)		Main risk that climate change may bring (%)	
Don't know	25.6	Unpredictable/extreme weather	42.3
Longer growing season	24.9	Don't know	13.2
No opportunities	10.3	Increased taxes/regulations	9.6
Generating energy	8.9	Increased costs	8.9
Better prices for produce	8.9	Crop failure/reduced yields	6.8
Diversification	6.4	Animal husbandry issues (e.g. heat stress, disease)	5.3
Reduced costs	5.7	No risks	4.6
New markets	4.6	Price/Profit volatility	2.8
Increased biodiversity	1.4	Lower price for products	2.5
Other	1.4	Other	1.4
Carbon capture and storage	1.1	Soil erosion	1.4
Better conditions for livestock	0.7	Nutrient loss through run-off	1.1

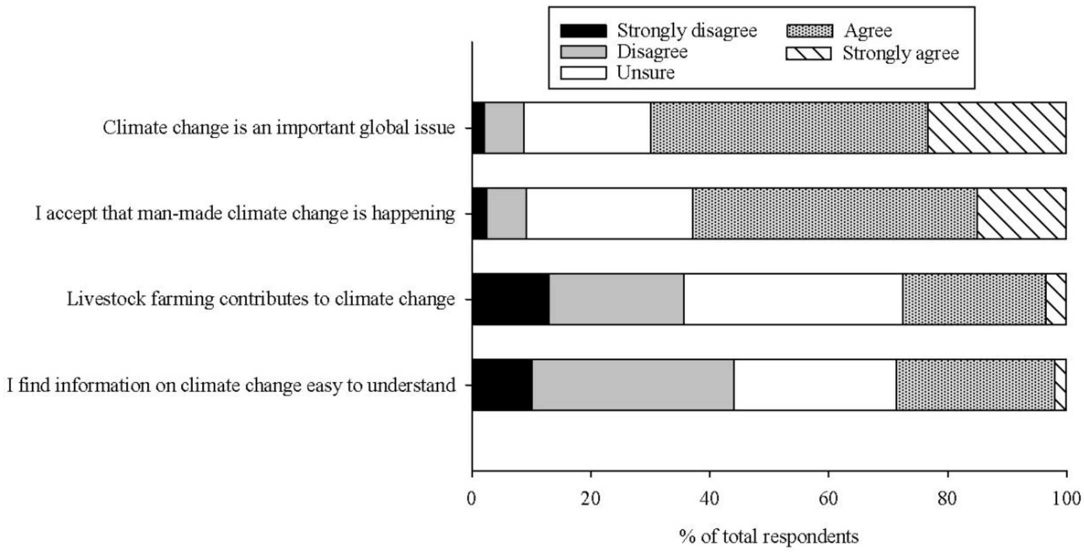

Figure 4.2. Respondents' attitude towards climate change statements (%)

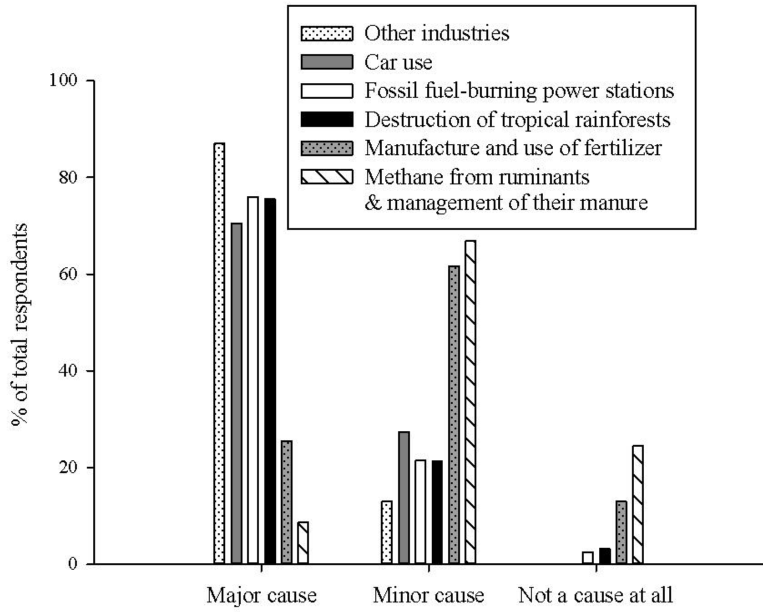

Figure 4.3. Respondents' perceived anthropogenic causes of climate change.

Farmers were also asked to rank the threat to society from climate change, relative to various other pertinent environmental issues. Food security was forecast as being the greatest future threat to society, followed by energy security, water quality, climate change, waste management, and air pollution (Fig. 4.4).

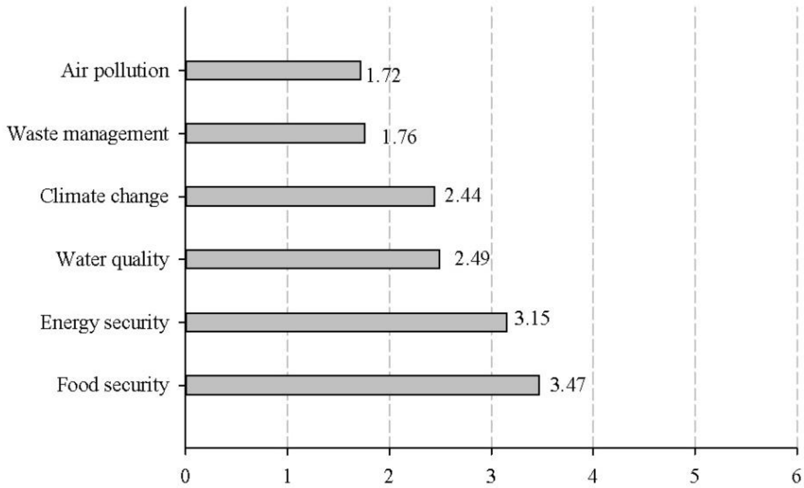

Figure 4.4. Respondents' median scores of the risk posed to society by environmental issues
*** Options ranked 1 – 6 (1 being the least risk, 6 being the greatest)**

The responses from all participants suggest an awareness that climate change is happening. We now create a typology of farmers to assess if the awareness and disconnection outlined above is influenced by farmer self-identity. We also investigate if self-identity impends on famers' behavioural capacity to implement issues that address climate change.

4.5.2 A typology of farmers

Through PCA and Cluster Analyses, four types of individual farmers were identified (Table 4.4). Using the cluster centres from the most appropriate solution from Ward's method (based on the four PCA components), K-means clustering was applied (Table 4.4).

Table 4.4. Scores of the final centres of farmer clusters, derived from K-means method. Types are labelled according to differences between groupings

Type (% of respondents)	Awareness	Environmental responsibility	Productivism	Perceived risk
The Environmentalist (28)	0.742	0.500	0.063	-0.789
The Dejected (26)	0.317	0.143	0.333	1.111
The Countryside Steward (23)	-0.888	0.284	-0.973	-0.100
The Productivist (23)	-0.342	-1.048	0.538	-0.199

A radar diagram is constructed from these cluster centres to give a visual representation of the differences between each of the types created with respect to the components elicited from PCA (Fig. 4.5). Two self-identity components evaluate motivation to act in a pro-environmental manner (environmental responsibility and productivism) while two evaluate behavioural capacity to implement mitigation and adaptation measures (awareness and risk perception). Furthermore, responses to non-statement questions in Section 3 of the questionnaire, which are not included in PCA analysis, are assessed based on farmer type and used to further define the four groupings (Table 4.5). These relate to what/where respondents perceived to be GHG sources. Such analysis deciphers farmer explicit knowledge of agricultural emissions. Where different farmer types obtained information on climate change was also determined (Table 4.5).

Table 4.5. Perceptions of emission sources, climate change contributors, and sources of climate change information based on farmer type

	The Productivist	The Countryside Steward	The Environmentalist	The Dejected
Perceptions of emissions associated with the management of livestock and their waste on their respective farms (%)				
Emits	42.1	33.3	56.0	47.1
Neutral	56.3	63.5	42.7	52.9
Stores	1.6	3.2	1.3	0
Perceptions of emissions associated with fertilizer use on their respective farms (%)				
Emits	34.4	22.6	45.3	33.8
Neutral	62.5	66.1	48.0	58.8
Stores	3.1	11.3	6.7	27.9
Perceived contribution of methane from livestock towards climate change (%)				
Major cause	3.1	9.0	13.3	8.5
Minor cause	70.8	49.3	80	66.2
Not a cause	26.2	41.8	6.7	25.4
Perceived contribution of the manufacture and use of fertilizers towards climate change (%)				
Major cause	13.9	23.9	39.5	22.5
Minor cause	67.7	59.7	56.9	63.4
Not a cause	18.5	16.4	6.7	14.1
Perceived contribution of 'other industries' towards climate change (%)				
Major cause	90.8	72.7	92.1	91.6
Minor cause	9.2	27.3	7.9	8.5
Not a cause	0	0	0	0
Information sources on climate change (%)				
Primary source	Press (42.3)	Press (27.0)	Press (30.7)	Press (31.9)
Secondary source	TV/Radio (20.3)	TV/Radio (25.4)	TV/Radio (24)	TV/Radio (26.2)

4.5.2.1 The Environmentalist

The defining features of The Environmentalist was their high awareness of climate change coupled with a low sense of the perceived risks that it may deliver. They also encapsulated a comparable sense of environmental responsibility to The Countryside Steward and The Pessimist. Hence, both motivation to act pro-environmentally and behavioural capacity to implement mitigation measures were high. The Environmentalist however had a low perceived sense of the risks which climate change may bring, suggesting a lower likelihood of adopting adaptation measures (Fig. 4.5). There was a general consensus from farmers in this group that the manufacturing and use of fertilizer, along with methane from ruminants and the management of their manure, contribute towards climate change (Table 4.5). Compared to the other groupings, a higher percentage of Environmentalists believed methane associated with livestock to be a cause of climate change. Indeed, only 6.7% ascribed it as not being a contributing factor.

The Environmentalist was the highest educated of the four clusters and 50% of those sampled had a university degree or higher. A significant characteristic ($p < 0.01$) in defining The Environmentalist from the other groups was the time period they had been involved in farming. Farmers sampled within this type had been farming for between 21 – 30 years, whereas the majority of farmers in the other groups had been farming for over 31 years. Evans et al. (2011) observed that the longer individuals had been farming, the more inclined they were to disagree that science had considered all factors in its estimates of climate change. Essentially, such farmers did not value the findings of scientists and researchers.

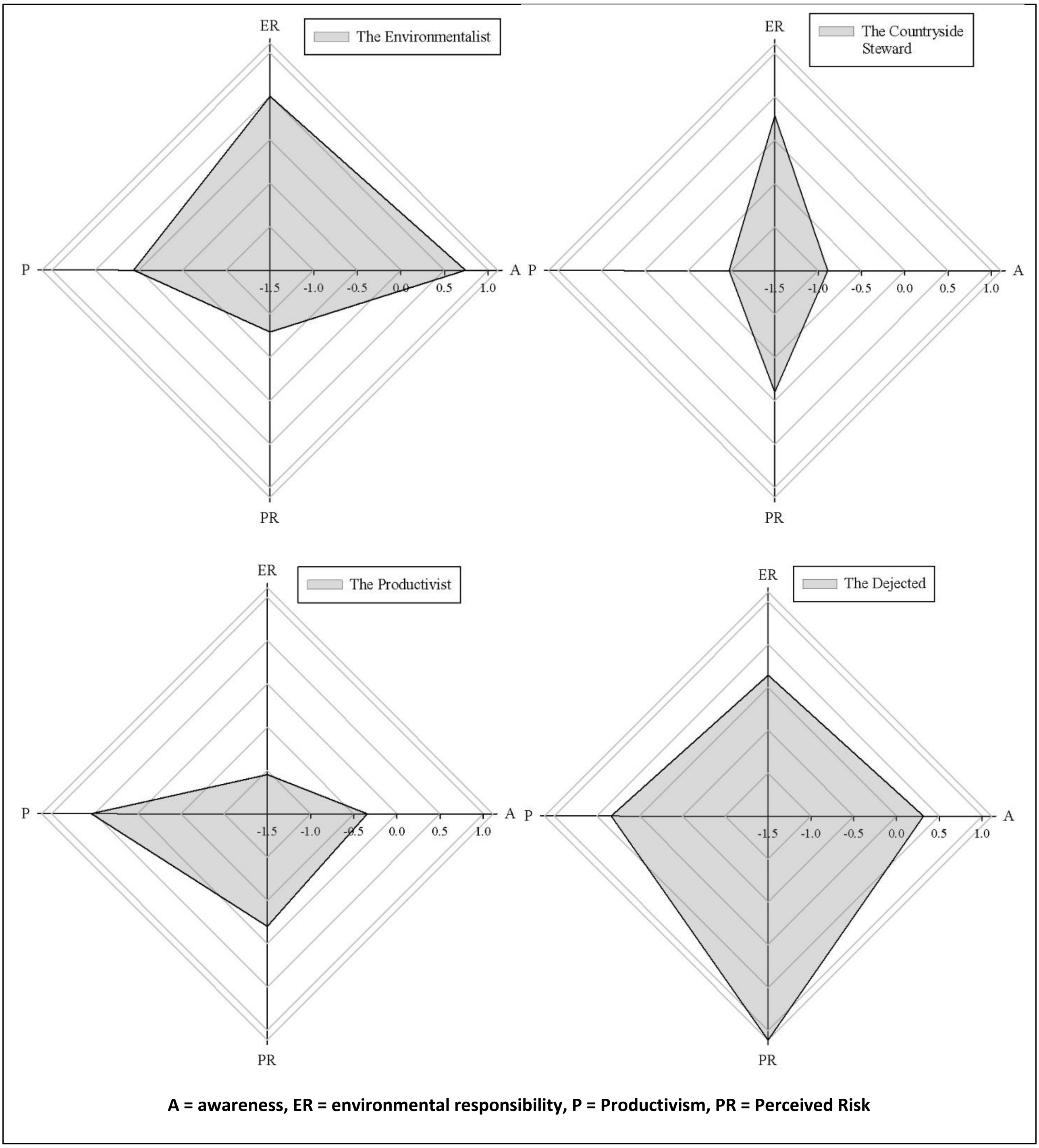

Figure 4.5. Radar diagrams showing the scores of the four identified types for the four PCA components. Derived from cluster centres from Table 4.4 (*n* = 286)

4.5.2.2 The Dejected

Members of this type projected a pessimistic and dejected disposition towards climate change as they expect it to affect them unfavourably. The factor most prevalent in characterising this group is a high sense of perceived risk, indicating an inherent high behavioural capacity to implement adaptation measures. Furthermore, The Dejected scored high in terms of awareness (Fig. 4.5), which suggests implicit willingness to consider implementing mitigation measures. Indeed, high perceptions of risk, when coupled with awareness of climate change, can be strong indications of adaptation and mitigation (Arbuckle, 2013).

Although such farmers were aware that climate change is occurring and that livestock farming contributes towards the problem, there was an evident lack of understanding concerning how emissions are generated (Table 4.5). The Dejected was aware to some extent that the management of livestock and their waste led to the emission of GHGs, but only 8% of those sampled ascribed emissions of methane to livestock as being a major cause of climate change. Indeed, 25.4% of farmers in this cluster believed that methane associated with livestock farming does not contribute towards climate change (Table 4.5). This disconnect suggests a conspicuous lack of understanding in linking agricultural emission sources with the concept of climate change.

4.5.2.3 The Countryside Steward

A high sense of environmental responsibility was evident for this particular type of farmer. The Countryside Steward was deeply concerned about the environment and see themselves as protectors of the countryside. Furthermore, they held a low disposition towards productivism (Fig. 4.5). The Country Steward’s sense of personal attachment to the land is therefore transmuted into the wider environment (Leopold 1949). Consequently, the will to adopt pro-environmental behaviours is evident.

Although The Countryside Steward’s sense of environmental responsibility was comparable to The Environmentalist, the two groupings differed greatly with regards to awareness of climate change. Indeed, The Countryside Steward scored lowest for this component (Fig. 4.5). The belief that methane associated with livestock management does not contribute to climate change significantly differentiated them from the other groups ($p < 0.01$). Evidently, 41.8% of Countryside Stewards perceived such emissions as being unproblematic (Table 4.5). Furthermore, a higher percentage of this farmer type perceived emissions from other industries as only a minor cause of climate change (Table 4.5). Such assertions allude to a forthright rejection of the acceptance of climate change and anthropogenic influences on changing global weather patterns. A low behavioural capacity to implement mitigation or adaptive measures is consequently borne from The Countryside Steward's low senses of awareness and perceived risk. Interestingly, the proportion of university-educated members was significantly lower in this cluster in comparison to the other types ($p < 0.05$).

4.5.2.4 The Productivist

Farmers within this type were defined by their lower sense of environmental responsibility, while displaying a penchant for productivism (Fig. 4.5). The disparity observed in motivational constructs suggests that production dictates management decisions. It could be argued that such farmers see their enterprise primarily as a business, where the environment provides the raw materials and resources necessary to produce a profit. Such farmers focus on the quantitative outputs of land management (Lowe et al. 1993; Wilson 2001). Other studies have also revealed farmers with characteristics that predominantly converge on profits and efficiency maximisation (Gasson, 1973; Guillem et al., 2012; Barnes and Toma, 2012) .

The Productivist was not as aware of climate change as other farmer types, nor did they perceived it to be a risk to their farming enterprise. Conversely, they denounced emissions from other industries as being a major cause of climate change, while little accountability was given towards the livestock sector (Table 4.5). Hence, The Productivist may not be as pro-active as other groups since low motivation to act pro-environmentally was coupled with a low behavioural capacity to implement both mitigation and adaptation measures.

4.6 Discussion

The purpose of this study is to establish a typology of beef/sheep farmers based on farmers self-identity and their perceptions of climate change. A limitation of the study is that the respondents were recruited by means of a convenience sample. Although convenience sampling can be representative of a population (Luschei et al., 2009) it may be a case that farmers who were more interested in climate change were more likely to participate. This may have led to undue bias in the results. Although bias is possible (Berk, 1983), its potential was considered to be negligible as every possible farmer encountered at the numerous study sites was approached on sampling days. The findings are hence robust for the 286 respondents who gave their views on climate change and provide a sound basis for future investigation. Pastoral-based livestock systems in temperate regions are similar the world over. The approach used in this study is particularly relevant to researchers who aspire to determine the perceptions of climate change from farmers who operate in such environs. Moreover, where equivalencies in farmer identity and behavioural capacity are evident, findings may be extrapolated to aid policy-makers in other temperate regions to encourage farmers in adopting measures that address climate change.

Farmers' perceptions of environmental issues are heavily influenced by political agendas (Holloway and Ilbery, 1996). Topical issues are likely to be those that are regional in their nature, where farmers have been forced to recognise issues through legislation or environmental groups. With this in mind, we found that farmers ranked climate change below food security, energy security, and water quality in terms of important issues confronting society in the future. This ranking is consistent with the general public's perception of the issue in recent years (Ratter et al., 2012). Possible explanations are issue fatigue, the impact of the global financial crisis, distrust, and the deepening politicisation of the issue (Pidgeon, 2012).

Low behavioural capacity is borne from a lack of awareness of climate change and a low sense of the perceived risks that it may bring. This acts as a barrier for both The Productivist and The Countryside Steward in adopting measures that help address climate change. It could be hypothesised that the primary reason that The Productivist would take the climate into consideration is if there are (economic) incentives in place to do so (Defra, 2010; Fleming and Vanclay, 2010). Messages which focus on low-cost 'win-win' technologies may therefore resonate (Islam et al., 2013). The costs of inaction can often be considerably greater than the economic costs of immediate action (OECD, 2012). Discourses framed in such a monetary manner may gain recognition with farmers who possess productivist tendencies. Furthermore, the concept of sustainable intensification could particularly appeal to such farmers as their production tendencies would not be compromised (The Royal Society, 2009).

Weber (1997) proposes a 'finite pool of worry', which implies that one's regard for the environment decreases as other factors gain prominence. The theory suggests that individuals have a limited capacity as to how many issues they deem relevant at any one time. Farmers like the Productivist may feel compelled to assert management decisions towards production as such an alignment may be deemed necessary for survival. Readjusting focus towards the environment may be therefore condemned as superfluous by such farmers.

Given The Countryside Steward's high environmental responsibility, their low awareness of climate change may be an example of 'availability heuristic' (Tversky and Kahneman, 1973). It could be hypothesised that they do not consider climate change as being the cause of adverse weather conditions.

It is important to recognize the complexity of climate change along with the intricacy of its causes. Notably, we observe how many farmers depict agriculture as contributing little towards GHG emissions, whereas emissions from other industries are generally perceived to be a major cause of climate change. Furthermore, none of the farmer types perceive methane from livestock as being a major cause of climate change with respect to other sources of GHG emissions, further illustrating a reluctance to accept responsibility (Table 4.5). Such displacement of blame is not unique, and blame avoidance is an important barrier for effective engagement (Kurz et al. 2005; Lorenzoni et al., 2007).

There is evidence that strongly suggests that some farmers who believe in climate change have higher quantitative perceptions of associated future hazards (direct or indirect) (Menapace et al., 2012). This in some way may decipher why farmers like The Dejected feel threatened by the issue. However, there are often uncertainties about aspects of GHG emissions even where individuals accept the overarching scientific consensus that climate change is a reality (Moser, 2010). As such, accurate understandings of the causes of climate change is an important determinant of pro-environmental behaviour and support of climate change policies (O'Connor et al., 1999). With the exception of The Environmentalist, analyses of the farmer types reveal a disconnection between agricultural emission sources and their contribution towards climate change. This is particularly evident in The Dejected, who is aware that agriculture contributes towards climate change but is unsure as to how such emissions are generated. The observed disconnect suggests emotional-focused coping to lessen risk perceptions by avoidance, denial, and desensitisation (Clayton and Myers 2009). Bruce (2013) demonstrates that beef/sheep farmers conceptualised methane emissions associated with ruminants as a natural occurrence rather than a pollutant. A perception of GHG emissions from ruminates as being environmental benign may allude to why The Productivist and The Countryside Steward are not aware of agriculture's contribution to climate change. Therefore, conceptualising methane towards the paradigm of being a negative externality requires specific attention, which should be facilitated by knowledge transfer.

Age was highly correlated with years farming (r=0.623) so it would be reasonable to assume that The Countryside Steward may be an older albeit less educated version of The Environmentalist. This exemplifies the role of education and knowledge dissemination which can be used as a tool to advance the uptake of mitigation measures. Although it is not possible to assess what types farmers fall into with further information, any information on the topic should include points which address the perceptions of all four groups found in this study The literature recommends increasing attention to the role of advice and information dissemination that leads to voluntary individual and collective action (Hall and Wreford 2012). Understanding farmers' perceptions is therefore imperative in building effective outreach strategies (Greiner et al., 2009). It is not possible to intuitively know which cluster type farmers within a population could be ascribed to. Nevertheless, the groupings from this study can be used to increase awareness and action which addresses the issue. Industry and government should disseminate information which resonates with all four farmer types and therefore engage all farmer types with mitigation and adaptation. Both primary and secondary information sources were comparable across the four farmer types (Table 4.5). Although limited, one-way information sources can be beneficial if used to support debate and raise awareness so that a common knowledge base is attained (Bizikova et al., 2014). This would be particularly advantageous in addressing the observed disconnect that farmers display between on-farm GHG emission sources and their contribution towards climate change.

Different epistemologies influence the mobilization and transformation of knowledge. The traditional knowledge-transfer approach has been criticised as it fails to adequately address heterogeneity within the farming community (Klerkx et al., 2012), and may explain the variance in awareness and risk perception amongst the types in this study. The limitations of the traditional paradigm led to the formation of non-didactic 'human development' approaches, which are based on participation and empowerment (Black, 2000; Fleming and Vanclay, 2010). Lankester (2013) demonstrates how organised collective group learning is an effective method of fostering sustainability and pro-environmental behaviour among farmers. Social learning bases its philosophy on participation and integrating knowledge from different perspectives and involves critical thinking, interactions, dialogue, and questioning assumptions that underline individual concepts (Leeuwis et al., 2002). This approach would allow the four types to discuss views on climate change with each other and experts (Carolan, 2006).

Social learning could be propitious in shifting The Productivist's sense of what is involved in being a 'good farmer' away from a production standard towards one with more environmental tendencies (McGuire et al., 2013). Group discussion would provide a platform to increase awareness and to deliberate the adoption of measures that are both environmentally and economically beneficial. The Countryside Steward has a particularly high sense of environment responsibility but is lacking in their awareness of climate change;

therefore, it is reasonable to assume that effective participatory approaches could encourage their participation in programs that focus on climate change. Social interaction can also ease unfounded risk perceptions that farmers such as The Dejected may hold (Langford, 2002; Maiteny, 2002). Communication of risks could also inspire greater action and support of climate change initiatives in other types (Leiserowitz, 2006).

Although the human development model is seen as an improvement on the knowledge-transfer approach, no single model is likely to be sufficient by itself for effective knowledge exchange and/or knowledge transfer. There is still therefore a need for access to reliable scientific information, just as there is a need to promote communication within a social system (Black, 2000). Furthermore, information sources that are trusted by farmers should be used, irrespective of the model used (Reed et al., 2014). The fact that no one paradigm suits all further illustrates the importance of recognising the heterogeneity within the farming sector. Hence, carefully planned communication, targeted at the different farmer types, can help encourage a positive change in farm management practices that reduce GHGs for all types (Garforth et al., 2004; Maibach et al., 2009).

4.7 Conclusions

The farmer types elicited in this study can be used as a tool to advance the development and uptake of mitigation and adaptation measures. Farmers are more likely to protect and sustain the environment when they are aware of an environmental problem, consider the environmental threat to be great, and feel responsible for acting (O'Connor, 1999; Story and Forsyth, 2008). We hypothesise that farmer identity influences assessments of climate change, therein affecting their behavioural capacity to implement measures that address the issue.

Mitigation and adaptation are determined through farmers' awareness of the issue and their perceptions of risks that it may bring. The Environmentalist is therefore most likely to adopt mitigation measures as their awareness is higher than the other types. The Dejected also has a high implicit behavioural capacity to implement mitigation measures. Furthermore, a high inherent capacity to implement adaptation measures is evident through their high perceptions of risk. However, we observe that while The Dejected accepts that livestock contributes towards climate change, there is evidence of avoidance, denial, and desensitisation through their lack of understanding of how exactly emissions are generated from livestock farming. Therefore, their capacity to implement climate change measures may be stifled. The Countryside Steward displays a high sense of motivation to act pro-environmentally but is lacking in their awareness of climate change, implying a low behavioural capacity to implement measures to address the issue.

Globally, environmental considerations are often in competition with other societal outcomes such as food production. Policy-makers should be aware that farmer's adoption of environmental measures depends upon the measures practicality and cost, amongst other factors (Jones et al., 2013). Such factors may contribute to the concept of a 'finite pool of worry' as individuals have a limited capacity as to how many issues are deemed relevant at any one time. Farmers are also often challenged by changing market conditions whilst also being expected to deliver an expanding range of 'public goods', such as increasing food production (Stuart and Gillon, 2013). Collectively, this means that farmers like The Productivist are less likely to adopt or support environmental measures as motivation to produce overshadows an environmental ethos. Hence, messages framed under the concept of sustainable intensification may particularly appeal to their self-identity characteristics.

The Dejected and The Countryside Steward's lack of knowledge of how exactly livestock contributes to climate change indicates how neither high awareness, nor environmental responsibility, ensure an explicit knowledge of the issue. Particular attention should be paid to addressing the evident disconnect in perceptions of agricultural emission sources and their contribution towards climate change. If such linkages are not conceptualised, it is unlikely that the migration or adaptation potentials will be fully realised across the elicited farmer types. The farmer types depicted can enable the effective transfer and exchange of knowledge which can encourage the voluntary adoption of adaptation and mitigation measures. A variety of dissemination methods should be used to facilitate farmer action which addresses climate change based on the types elicited.

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Chapter 5: "A farmer's worst enemy is his neighbour". Assessing the barriers to collaboration between Welsh farmers

“A farmer’s worst enemy is his neighbour”. Assessing the barriers to collaboration between Welsh farmers

Hyland, J.J., Jones, D.L., Williams, A.P.

5.1 Abstract

The livestock industry is under considerable pressure to reduce environmental externalities associated with production. Livestock production accounts for 14.5% of global anthropogenic greenhouse gas (GHG) emissions; and one of the most widely suggested means of reducing emissions is to increase the production efficiencies of farm enterprises. Collective action between farmers represents one methods of increasing the efficiencies of production and hence could be an effective measure in reducing emissions. However, the cultural autonomy of farmers is well established; whereby other farmers are often perceived as natural competitors, rather than allies. Therefore, the aim of this study was to assess existing forms of regional collective action between farmers and their wider perceptions of collaboration. Interviews were carried out with 35 livestock farmers in the catchment of Conwy River in North-West Wales. Although collaborative activities amongst farmers could have been greater, participants regularly met and interacted with other farmers. Participants bemoaned the financial difficulties of farming, while recognising the economic advantages of collaboration. They were however somewhat reluctant to engage in collective action beyond the levels they were currently involved and stated that trust and the fair exchange of resources to be the main barriers of collaboration. The results suggest that there is considerable level of latent social capital which can be mobilized. Initiatives to encourage collective action should therefore be developed which would facilitate efficiency gains and bring about environmental and economic benefits.

5.2 Introduction

Agricultural production is forecast to expand significantly over the coming decades as the wealth gap between developing and developed countries narrows, leading to increasing demands for food (FAO, 2006; Godfray et al., 2010). Modern agriculture produces negative externalities which contribute to the pollution of waterways, biodiversity loss, soil deterioration, and ecosystem degradation (Hester and Harrison, 2012). Furthermore, the livestock sector constitutes towards almost 14.5% of anthropogenic greenhouse gas (GHG) emissions (Gerber et al., 2013). Ecological functions occur at scales wider than the farm (Raudsepp-Hearne et al., 2010). There has consequently been a call for a more collaborative level approach towards agricultural activities through collective action. Collaboration amongst farmers can be used to help implement change. Positive attitudes engendered through collective action have been shown to alter behaviours and environmental practices on individual farms (Lockie, 2006).

Collective action from a cluster of farms, rather than at an individual farm level is increasingly recognised to be more effective in the delivery of ecosystem services and for addressing climate change (Stallman, 2011; Lyle, 2015). The environmental benefit of collaboration between farmers can be both direct and indirect. Cooperation is necessary for the direct provision of ecosystem services such as biodiversity and habitat connectivity at a catchment level. Environmental initiatives become less fragmented through collaborate spatial agreements between farmers; therefore improving the likelihood of their success. Indeed, organised collective learning can facilitate critical reflection of practices, questioning of the self, others, cultural norms and an enhanced sense of environmental responsibility (Lankester, 2013). Other benefits of cooperation are indirect; namely GHG emission mitigation. Unlike other ecosystem services, GHG mitigation is not dependent on spatial profiles. Strategies for adaptation to climate change impacts, such as extreme weather events, are often dependent on informal cooperation between farmers, as well as formal institutions and regulations. Hence, farmer collective action is also an effective adaptive measure for farming enterprises (Eriksen and Selboe, 2012; Nicholas and Durham, 2012). Baranchenko and Oglethorpe (2012) demonstrated that coincidental reduction in GHG emissions are possible when agricultural farmer cooperatives achieve efficiencies through economies of scale, knowledge and skills transfer, and the sharing of risk.

Collective action refers to the involvement of a group of individuals who share a common interest and undertake some form of voluntary common action in pursuit of a common goal (Meinzen-Dick et al., 2004). Communities of practice come into being as a means to sustain a set of practices which the individuals consider to be in their interest based on their shared visions (Wenger et al., 2002). Wenger (1999) depicts how communities of practice can foster social learning through engagement, imagination, and alignment. Engagement describes what individuals do together and how they do it; imagination describes the shared images that define the boundaries and features of the community; and alignment involves individuals coordinating their perspectives and actions with the broader community in achieving aspirations. Communities of practice may subsequently serve to generate social capital which may lead to improved learning (Hu and Randel, 2014). Social capital is defined by Putnam et al. (1994) as 'features of social organizations, such as networks, norms, and trust that facilitate coordination and cooperation for mutual benefits'. Furthermore, successful knowledge exchange within groups can increases productivity (Inkpen and Tsang, 2005). The provision of advice to farmer collectives means that that knowledge exchange can go much further, and be of more benefit, than advice that is provided to the individual alone (Mills et al., 2011).

As the price of agricultural inputs increase the likelihood that smaller farms have the scale capacity to purchase assets declines. Cost savings can therefore be attained by increasing economies of scale by cooperation as individual farm resources can be pooled together. For instance, farmers can build economies of scale by spreading the financial cost and risk of purchasing farm machinery together. Cooperation also allows farmers to share labour which allows enterprises to increase productivity and efficiency; thereby coincidently reducing emissions per unit of product. Furthermore, collaboration amongst farmers can be used to effectively transfer information on climate change which may increase acceptance of the issue and the potential adoption of mitigation measures. Farmer cooperatives can therefore serve to increase economic sustainability (Andersson et al., 2005). As social capital is built up between farmers, they become more willing to provide mutual support to one another through the mobilization of resources such as machinery and labour (Mills et al., 2011). Ergo, it has been proposed that the best way that a small farm business can acquire the benefits of being a large farm enterprise is to collaborate with others (Policy Commission on the Future of Farming and Food, 2002). It has been observed that farms who participate in cooperative sharing of resources, such as machinery and labour, are more efficient and profitable than farms who do not (Lagerkvist and Hansson, 2012; Larsén, 2010).

Switching from the farm to the landscape scale implies moving from individual to collective decision-making (Speelman et al., 2014). Collective agency cannot be imposed; indeed, it has to emerge through a learned process based on interactions between individuals (Pelenc et al., 2013). Communities are groups of people who share a collective feeling of belonging or identity (Wilson, 2010). These communities are dynamic and shaped by the individuals within them, and the individuals who perceive them (Flanigan and Sutherland, 2015). However, the cultural autonomy of UK farmers is well established; whereby other farmers are perceive as natural competitors rather than allies (Emery, 2014; Emery and Franks, 2012; Stock et al., 2014). Therefore, the aim of this study is to assess: (1) farmers' informal and formal social organisations which encompass collaborative practices and social networks with other farmers; and (2) farmers' perceived benefits and difficulties of cooperation. It is anticipated that the findings of such analysis can be used to facilitate successful collective action. Research concerning farmer-to-farmer collective action within UK agriculture tends to focus specifically on collaboration concerning joint agri-environment schemes. This study differs in that it evaluates the potential for collaboration between farmers under the guise of sustainable intensification, while also providing a baseline of the extent to which cooperation currently exists within a particular catchment

5.3 Farmer cooperation and collaboration

Despite farmers being price-takers they often depict other farmers as competitors rather than allies. Individualism resonates with neoliberal conceptions of autonomy that equate freedom with the ability to compete, unobstructed by one's peers, in the free market. However, these interpretations can inhibit the pursuit of collective interests against more structural forms of dependency, such as lenders and large buyers (Emery, 2014; Stock et al., 2014). One theory as to why UK farmers may value independence over altruism is that individualism as something culturally ingrained in wider societal values. When Macfarlane (1978) went in search of evidence of an English peasant society he denotes it was not possible to find a time when an Englishman did not stand alone; it would be therefore reasonable to suggest that such values would have manifested themselves across Britain. The peasant condition is composed of a set of dialectical relations between the environment in which peasants have to operate and their actively constructed responses aimed at creating degrees of autonomy in order to deal with the patterns of dependency, deprivation and marginalization entailed in this environment (Ploeg, 2009).The individualistic values upheld in Britain were very much in contrast to the tradition of altruism brought about from the peasant condition in many other parts of the world and may explain why farmer cooperatives are less prevalent in comparison to many countries.

Although farmers value their independence they often organise themselves collectively in many ways, such as informal groups, cooperatives, etc. (Vanni, 2014). Engagement in collaborative activities can be defined on a spectrum from the individual to the collective; in between these two ideologies there is potential for joint measures where farmers work together to achieve a common goal (Davies et al., 2004). The vast majority of cooperation that exists between farmers is for purchase and sale. Such cooperative activities can achieve considerable turnover and are popular in many countries throughout Europe. However, the UK lags behind others in terms of farmer participation in such collective ventures. It's estimated that 450 farmer cooperatives operate within the UK; a rather modest number based on its size and its volume of agricultural output. Conversely, the number of farmer cooperatives is estimated to be approximately 3,000 in both France and Germany, and 150 in Ireland; with all achieving a higher combined turnover that those operating in the UK (Cogeca, 2010).

There are even fewer types of cooperatives established by farmers in which labour and machinery are pooled together. One of the reasons for this is that such arrangements are often informal and based on reciprocal farmer-to-farmer dynamics (Emery, 2014). Although often informal, machinery sharing amongst farmers may also be formal; thereby allowing for expansion for even greater economies of scale. Machinery rings were first developed in Germany in the 1950s and have subsequently spread in prominence throughout Europe (Lagerkvist and Hansson, 2012), and the UK (Flanigan and Sutherland, 2015). The economic capital value of machinery is often very high. However, the mutual exchange of labour is inexpensive in comparison and can yield advantages to farming enterprises. Nevertheless, the sharing of labour can lead to economic advantages to individual farm enterprises (Sutherland and Burton, 2011). Cooperation can also serve as a means to collectively market produce (Stock et al., 2014). Through such collective marketing, farmers may market their produce in a way that would not be viable through individual efforts; thereby, offering opportunity to position their produce as a distinct premium brand. Farmer cooperatives can also support other activities such as input buying, producer groups, etc. (Baranchenko and Oglethorpe, 2012).

The use of farmer collective action has already gained prominence in Australia (Wilson, 2004), Germany (Prager and Vanclay, 2010), and The Netherlands (Franks and Mc Gloin, 2007), and is slowly being introduced elsewhere in an effort to upscale environmental scheme measures. In the UK, ‘regional’ and ‘targeted’ elements of landscape approaches, where farmers can act collaboratively, have been incorporated into the Welsh agri-environment scheme, Glastir (Wynne-Jones, 2013). Indeed, (Mills et al., 2011) denote how collective knowledge and learning can ensure the cultural embeddedness of environmental messages when positively discussed within the group.

5.4 Method

5.4.1 Study area and farmer recruitment

A semi-structured questionnaire was deployed in an effort to explain farmers' perceptions towards collective action within a community. Interviews were carried out between May and July 2015 and formed part of the Sustainable Intensification Research Programme (SIP) funded by Defra. Project 2 of the SIP project explores how cooperation can be encouraged. It aspires to (1) identify the SI goals that can only be achieved through coordinated activity; (2) design collaborative activities that help achieve these goals; (3) evaluate of the practical benefits of these activities; (4) understand the barriers to collaboration and how these can be overcome. The survey formed part of the SIP project and was led by the Centre for Rural Policy Research (University of Exeter) with colleagues from the Universities of Nottingham, Newcastle, and Bangor. All institutions involved contributed towards to the content of the questionnaire whereby initial drafts were circulated to relevant personnel until a final version was deemed suitable. The role of the researcher was to organise and carry out interviews. Coding of the qualitative information attained from the catchment was carried out by the same researcher who carried out the interviews of all respondents.

Potential participants were recruited from a random sample of 175 livestock farmers provided by Welsh Government; where farmers operated within the Conwy River Catchment in North-West Wales (Fig. 5.1). Farming within the region has been relatively stable, often with the same family farms operating for generations; therefore, the catchment was likely to harbour strong social capital. Forestry and agriculture dominate the catchment, where land quality ranges from relatively unproductive in the uplands regions to more fertile lowland areas (Gibbons et al., 2014). Sheep are reared in the upper catchment located predominantly in the south of the basin; whereas a more mixed livestock system prevails in the northerly lowland segment (Natural Resources Wales, 2015).

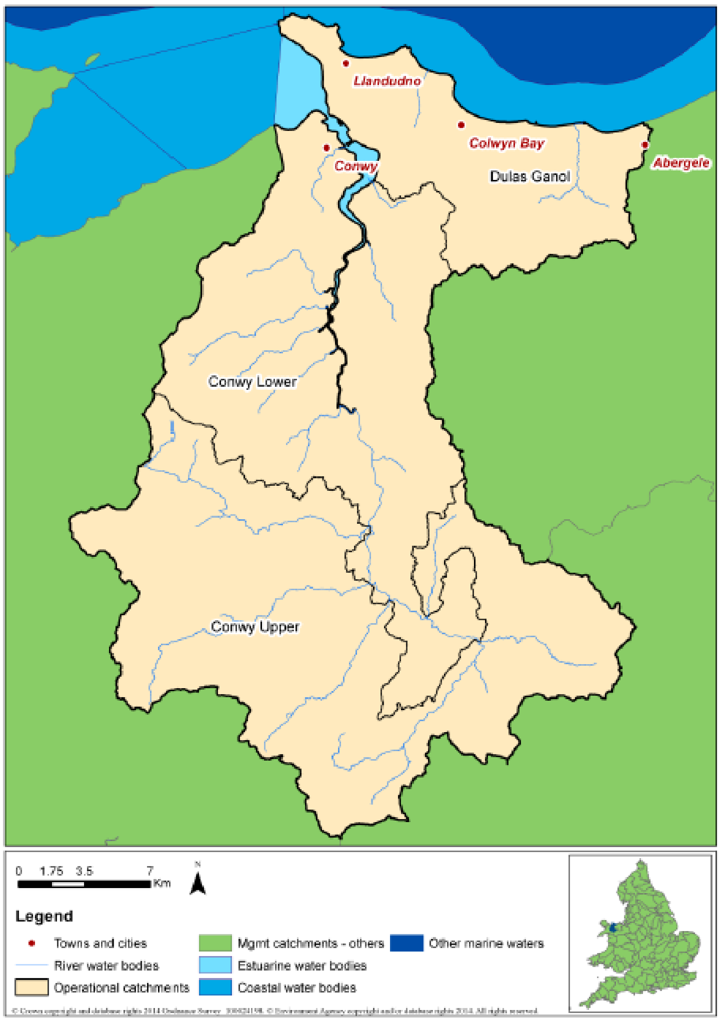

Figure 5.1. Location of the Conwy Catchment in Wales

All 175 farmers on the initial sample provided by government were contacted by post and allowed five working days to opt out of participation. Farmers who did not opt out of the project were subsequently contacted by phone with a view of arranging an interview. This process continued until a target of 35 completed interviews was reached. In total 83 farmers could not be contacted when called by phone, and 57 declined to take part.

5.4.2 Questionnaire design, data collection, and data analyses

The validity of the study questionnaire was established through lengthy consultation between various experts in the fields of agricultural, social and environmental sciences across the many academic institutions involved in the SIP project. None of the survey questions used in this study focuses explicitly on climate change; nevertheless, the survey aims to understand the barriers to collaboration within Welsh farming and how these can be overcome. This information can therefore be used to help policy makers provide provisions for ecosystem services both directly and indirectly through collective action. Instead, interview questions concentrated on three main themes; sustainable intensification, community and quality of life, and cooperation. Overall, 35 questions were included in the final questionnaire, and from this the ones most applicable to the research questions of this study were used for analyses (Appendix D).

To ensure reliability, all interviews were conducted by a single researcher in English, thereby ensuring neither inter-interviewer nor inter-coder problems with reliability. Interviews were face-to-face and were conducted in the respondent's home; lasting between 30 minutes and 120 minutes and were audio-recorded. Qualitative information from the interviews was transcribed and assessed using the software package NVivo 10 (QRS International Pty Ltd, Melbourne, Australia) and involved the development of nodes and categories from coded data (Bazeley and Jackson, 2013).

For the qualitative approaches a thematic analysis was carried out on the data following best practice guidelines (Braun and Clarke, 2008).Other established accounts of thematic analysis were also considered (Boyatzis, 1998). Thematic analysis is a method for identifying, analysing, and reporting patterns within a dataset (Braun and Clarke, 2008). It minimally organises and describes your data in rich detail. An inductive or bottom-up thematic analytic approach was adopted, which bears similarity to the approach of grounded theory (Glaser and Strauss, 2009). This involves a data-driven approach, developing codes based on the reading of the raw data and not forcing preconceived codes onto the analysis. For each of the qualitative studies in this thesis, Braun and Clarke's (2008) 6-step guide to thematic analysis was employed (see Table 5.1).

Table 5.1. The six phases of thematic analyses (Braun & Clarke 2008)

Phase	Description of the process
1. Familiarising yourself with the data	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas
2. Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code
3. Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme
4. Reviewing themes	Checking if the themes work in relation to the coded extracts and the entire data set, generating a thematic 'map' of the analysis
5. Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme
6. Producing the report	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis

5.5 Results

5.5.1 Respondents' demographics and characteristics

The majority of farmers who participated in the study were either sole proprietors of their farm business or were involved in a partnership with a parent or a spouse. The average age and level of education of participants, their farm size and land classification are shown in Table 5.2. Employment within the farm enterprise mostly consisted of one full-time member who received casual and part-time help from family members. The employment of other individuals, on a full-time or part-time basis, was not common practice. Contractors were used for a wide range of farming activities such as silage making, fencing, dry-stone walling, slurry spreading, etc.

Table 5.2. The mean/mode values of some farmer and farm characteristics

	%
Age	
<30	8.6
30-40	11.4
40-50	17.1
50-60	31.4
>60	31.4
Farm size (ha)	
<50	20.0
50-150	25.7
150-300	37.1
>300	17.1
Land type	
Less favourable area (LFA)	85.7
Highest formal education	
Prefer not to disclose	5.7
School education (Left at 16 or before)	5.7
A Levels	22.9
Technical qualification (NVQs, BTEC, OND, HND)	48.6
Degree	17.1

The majority of farmers described the economic position of their farm as being 'fair' and earnings were somewhat similar to the average Welsh farm business income of £29,300 for the financial year 2013/14 (Welsh Government, 2014). The majority of participants were subsequently ‘satisfied’ with the physical production from their farming enterprise.

5.5.2 The concept of sustainable intensification

Collaboration could help achieve sustainable intensification, consequently reducing emissions through increases in efficiencies. In an effort to determine how farmers viewed the concept of sustainable intensification, participants were asked what they understood the term to mean. Overall, a sizable amount of farmers (n=17) were not sure as to what sustainable intensification (intensifying production without negatively impacting the environment) implied and could not hazard a guess when prompted. Of those who were able to give an assessment of what the term conveyed, most (n=9) thought that it exclusively alluded to production and output rather than any elements of environmental sustainability:

> Sustainable means for a long time and intensive just means intensive doesn’t it.
> Intensive is more stock, and sustainable is not going into too much debt.

The appraisal of sustainable intensification noted signifies the potential of the maladaptation of terms and concepts by farmers. Such misrepresentation presents challenges to the industry in terms of knowledge dissemination. Without education on the implicit meaning of concept, farmers may adhere to a representation that aligns to their own ethos; an ethos which may be at odds to the overarching aims of a concept.

5.5.3 Perceptions of the industry

Farmers were asked about their perceived importance of agriculture towards their local community. Overall, participants deemed farming as being essential to the locality; namely through enhancing the economic wellbeing of the catchment:

> Just talking about myself like, because this is an intensive farm…there is a lot of people…even though we only employ 3 full time, there is a lot of work that we generate for other people. It multiplies and multiplies and everything stays within 10 miles from here.

Agriculture's economic contribution to the local community was depicted as the primary benefit to the locality. Farmers identified the flow of money from agriculture to other industries and noted how it sustained other forms of rural businesses such as local garages and agricultural merchants. Hence, agriculture bolstered employment beyond the farm gate. However, farming was deemed to provide more than just monetary benefits to the community; its cultural significance was also widely documented, which special attention paid to the Welsh language:

> We're quite lucky, all the farmers around here are Welsh and it helps the community and keeps everybody together. Farming helps the language, you go to the market on Tuesday and you know, except the odd one, it's mostly Welsh speaking. You know if you had a lot of English farmers coming in you'd lose it.

To assess farmers' perceptions of working in the industry, respondents were asked to describe "what it is like to be a farmer in 2015". The question provides a backdrop to the lifestyle that farming life provides. While farmers were assertive in their assessments of the importance of farming to the community, they bemoaned many aspects of general farming life. Overall respondents depicted farming life as being quite difficult. The most frequent raised factor was that of financial hardship, with many respondents commenting on the fluctuation of market prices for their stock; which, unsurprisingly reflected market volatility during the first half of 2015:

> If you asked me two years ago I'd have said quite good, but now it seems to be getting more difficult; you don't know what you're going to get for your stock from day-to-day and it's more uncertain now from what it has been for a few years. I don't know how many lambs we've sold; I'd take a guess and say somewhere around 400 lambs and I'd say that they're down £20 a head from last year. And it doesn't matter who you talk to, whether it's milking, or beef, or grain, everything is down.

A plentiful domestic supply of red meat, along with a strong pound coupled with increased imports meant a decline in financial returns during the period (HCC, 2015). Market conditions aside, farmers assessed their occupation as being quite difficult and stressful, with long working hours. Furthermore, farmers also expressed grievances with the government, the volume of paperwork they have to endure, regulations they have to adhere to, and perceptions that the public and the government held of the industry.

5.5.4 Current and previous forms of cooperation involvement

Participants reported regular interaction with other farmers in the community, with engagement in some form or another occurring at least once a week. Interactions with other farmers were typically non-formal and happened as participants went about their daily business. Nevertheless, a wide range of collaborative activities were undertaken by the farmers in this study; albeit most were not adopted at a high rate. Indeed, most respondents were involved, or had been previously involved, in some form of collaborative arrangement (Fig. 5.2). However, many of the collaborative activates were informal and sporadic in their nature, and usually between farmers who were well known to one another.

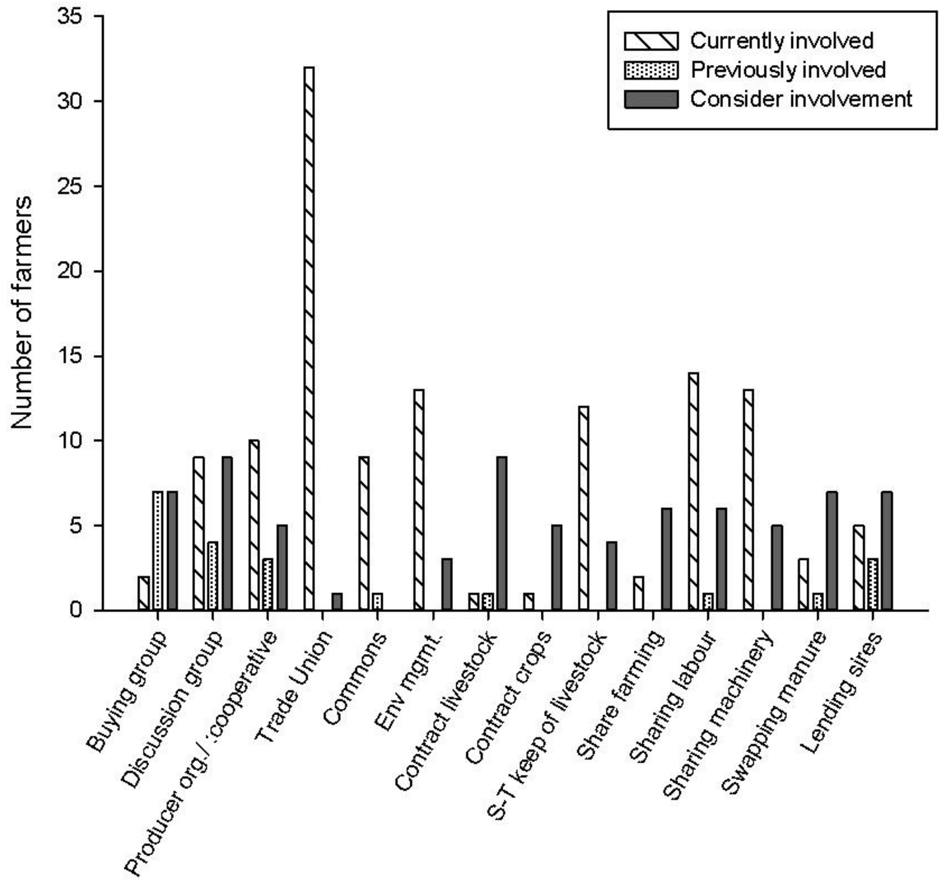

Figure 5.2. Current and previous levels of farmer participation in collaborative activities. Consideration of collaborative actives is also considered

The most prevalent form of cooperation that the respondents were involved was with a farming trade union, with 32 out of 35 actively involved. The union's significance was exemplified when farmers were asked to state the most important form of cooperation that they were, or had been, involved in:

The NFU [National Farmers Union] are good when things get a bit sticky, they can

> phone BCMS [British Cattle Movement Service] or whoever, and say we have a client without naming anyone. Where, if you ring them direct they want a holding number before they even talk to you. They are also useful for filling out forms.

Many of the farmers stated that farming unions helped them with legal issues, paperwork, and were also influential in steering government decisions. Other forms of collaboration were also represented, with some farmers sharing labour and machinery, and involved in the short-term keep of livestock, etc. However, only seven participants stated that the sharing of resources, such as labour and machinery, to be the most important form of cooperation in which they were involved in. Many lamented the fact that less cooperation was undertaken compared to the past. Despite this, the majority of participants stated that they were never involved in the setting up of cooperative activities. There was also some consideration for engaging in collaborative activities in future; but overall there was no great enthusiasm for further engagement.

5.5.5 Motivations for joining cooperation activities and benefits attained

As previously mentioned, participants were assertive in their assessments of the financial hardship of working in the sector. Despite this hardship, the majority of farmers were unwilling to engage in collective activities beyond their current levels of participation. Therefore it was somewhat surprising to learn of the widespread recognition of the economic benefits of joining collaborative activities, with one participant, who was involved in many collaborative activities, stating:

> To improve your own business structure basically and all targeted towards your own business. You don't do it to improve someone else's profitability as we're all in it for our own needs obviously.

Although the financial aspect of cooperating with other farmers was depicted as the main benefit of collaboration, other benefits also arose. Farmers who cooperated with other farmers widely noted the sharing of knowledge and resources to be of particular benefit to their enterprise:

> It saves you time and money doesn't it because you don't have to pay someone to help you, you just help them back. I think you learn how other people do things, especially when you're young anyway.

While the economic health of the farm business was the foremost motivation to joint collaborative ventures, other benefits were noted which did not include monetary gain. Referring to the general openness that comes from working together as part of a discussion group, one participant (a dairy farmer) reflected:

> I'm less in competition with my neighbour now, especially with the industry we're in. We're in this discussion group and you've got that feeling, you know, of being close knit; where everyone wants to help each other more than put a knife in someone else's back. There's a Welsh saying see, 'a farmer's worst enemy is his next door neighbour ' - 'Gelyn mwya ffermwr yw y ffermwr drws nesa'.

5.5.6 Difficulties of cooperation and factors which enable its progress

Farmers were asked of potential difficulties they perceived that cooperation may bring. Of the factors brought up during the interviews, the issue of a fair exchange of resources was deemed the most problematic. Many respondents referred to unfair exchange of labour; whereby they would assist others but gained little in return:

> I was a member of a selling group, about a third of us worked quite hard while the others were happy to just take a backseat. I was good at selling lambs, and others weren't so good, so I would have to go and try to sell their lambs as well. I haven't got time for that anyway. Some were working hard and some weren't and everyone was getting the same price for their lamb and it didn't work out; nobody fell out or anything like that but we brought it to an end.

This feeling of aggravation was also reflected in the sharing of machinery; where many stated that they were apprehensive about the fair allocation of use. Furthermore**,** participants were somewhat hesitant of working with other farmers as the potential for conflict may arise with those who do not share a similar temperament. This was consequently referenced by many participants as a stumbling block for collective action:

> With some farmers they can be very pushy and can't accept changes and different ideas. Some can be very hot-headed, can't they; especially if there is a change and they don't like it!

The majority of respondents felt that there was potential for others to 'free-ride' on the exertions and efforts of others. This feeling of scepticism may feed into the prominent viewpoint that trust is a factor which enables cooperation among farmers to work well:

> If you can't trust somebody there is no point in being there is there. Some farmers would rather 'farm at night'.

Trust was depicted as an essential component of farmer-to-farmer relationships when working together. Many farmers felt that although the level of trust was quite high amongst farmers, it was essential when working with informal contracts. Most farmers preferred not to work under the constraints of formal contracts, stressing that formality only added to unnecessary complexity. Therefore, farmers may feel that without trust in informal cooperation that they may be positioning themselves in a situation where they are exposed to risks from others not fulfilling their obligations. In addition to trust, farmers also felt it was imperative that those involved in cooperation got along with one-another. The ease at which individuals interact was thereby widely referenced as being advantageous to collective action.

5.6 Discussion

Farmer cooperatives have been widely advocated as an effective means of providing public goods through a less fragmented landscape approach to agri-environment schemes (McKenzie et al., 2013). However, other forms of farmer cooperation are seldom identified as a method of reducing environmental externalities. Nevertheless, several authors denote the effectiveness of collective action in terms of reducing GHG emissions in somewhat different contexts (Darnall et al., 2008; Sprengel and Busch, 2010). It has been subsequently demonstrated that cooperation between farmers serves to inadvertently reduce GHG emissions through increasing efficiency, knowledge dissemination, and innovation (Baranchenko and Oglethorpe, 2012). Collaborative efforts amongst farmers also increases the adaptive capacity of farming enterprises; making them more resilient to climate variability which may become increasingly prevalent in the future due to anthropogenic climate change. Farmer collaboration should be encouraged and facilitated as climate change continues to be an ever-more pressing issue for pasture-based production systems.

Through this study, the propensity to collective action among farmers in the Conwy Catchment in North-West Wales was evaluated through qualitative measures from interviews with livestock farmers in the region. Overall, farmers in the catchment viewed farming as an important industry to the locality, both in terms of economic and cultural capital. Participants were all too aware of the economic hardships of farming. A strong agricultural presence in the community was thought to promote and protect the Welsh language. Farming was judged as particularly important for the preservation of the Welsh language. Many of the farmers were aware how intertwined the economic wellbeing of farming was towards sustaining the local economy and thereby enabling the Welsh language to flourish. A strong sense of agriculture's importance to the catchment may therefore entice farmers into collective action as they may intuitively recognise its necessity in sustaining farming in the region. Indeed, collection action is often dependent on socio-economic and socio-cultural backgrounds (Henrich et al., 2010; Prediger et al., 2011).

It is anticipated that farmer cooperation can assist in the sustainable intensification of the livestock sector and thereby reduce emissions through efficiency gains. As the concept of sustainable intensification becomes ever more prevalent, it is important that farmers acknowledge all components of the ideology for it to be successfully implemented. Individuals are inclined to frame problems from their own point of view, based on their own perceptions of the problem (van Bueren et al., 2014). The majority of participants in this study did not know what the term sustainable intensification implied. Of those who could hazard a guess to what the meaning of the concept, most thought of it to signify production over environmental sustainability. Such misconceptions may result in maladaptation of the concept where one element is foregone in favour of another. The appraisal of sustainable intensification noted signifies the potential for maladaptation of the concept by farmers. Such misrepresentation presents challenges to the industry in terms of knowledge dissemination. Without education on the implicit meaning of concept, farmers may adhere to a representation that aligns to their own ethos; an ethos which may be at odds to the overarching aims of a concept.

The degree to which individuals interact with each other is made on the premise of the dividends that network capital brings (Urry, 2007). A strong sense of community and belonging are fostered through such engagements between farmers; thereby contributing towards resilience (McManus et al., 2012). It is through these networks that the resilience capacity of an agricultural region is increased. Eriksen and Selboe (2012) demonstrated the importance of cooperation for the adaptive response of farming towards climate variability; namely, by the sharing of agricultural machinery, exchange of labour, and mutual assistance. Collective action in this sense is important in managing climate events such as particularly wet summers with short growing seasons and limited windows in which harvesting can take place – access to equipment, access to labour, and experience and knowledge in collective planning can ensure that crops are harvested in appropriate condition (Eriksen and Selboe, 2012). Participants in this study alluded to being open to the idea of collaboration with other farmers, but overall participation was quite low. Most farmers did not take part in some of the more important cooperative activates which increase mitigation and adaptive potential. Indeed, the most prevalent form of cooperation that participants had experience of was that of trade unions. Most farmers were quick to recognise their importance in assistance with paperwork that was deemed challenging. The forms of collaboration which could potentially allow farms to sustainably intensify beyond current operational levels, i.e. the sharing of labour and machinery, were only modestly adopted. Autonomy was observed from most farmers who choose to not share machinery, nor labour; with only modest interest in resource mobilization. The hesitancy of farmers to embrace capital exchange may therefore impend on the potential of farms to reduce their carbon footprint through efficiencies which could be gained through cooperative measures. It is worth nothing however that all farmers were previously involved in some form of collaboration even if they were not currently undertaking collaborative activities.

Even though collaboration with other farmers could have undoubtedly been greater, participants acknowledged the benefits that cooperation could bring to their farming enterprise. Surprisingly, most farmers referenced the financial importance of cooperation as being of primary benefit. Although most farmers depict farming as being financially difficult they were somewhat reluctant to engage in collaboration beyond the levels in which they participated even. However, it is unlikely that the farmers in this study exhausted all forms of profitable cooperation as most had not being involved in previous collaboration which may have helped attain economic benefits. Considering the favourable light in which most respondents depicted the benefits of collaboration it is somewhat plausible to suggest that further cooperation is likely. Consolidation of farming enterprises in the future may arise which would possibly increase the average farm size of the farms within the region as farmers in the catchment drop out of the industry. Although consolidation would increase economies of scale at the farm level it would not diminish the need for collective action. The restructuring and merging of farms into larger units has been observed over many decades; yet as farm inputs and market forces become ever more volatile the benefits have not been requited in real terms. Farmer collaboration is consequently necessary for the wellbeing of the industry now and in the future.

Emery (2014) depicts how farmers value autonomy and this may be one reason as to why participants would rather not engage in further collective activities even though they recognized the potential economic benefits that it may bring. Many conveyed that collective action helps evoke a sense of togetherness, and that it is useful means of attaining advice. The fair exchange of resources, and the ease at which one could interact with other farmers, were widely accepted as barriers for collective action between farmers. Conversely, trust was projected as an enabling factor necessary for cooperation to work well. The concepts of fairness and trust signify 'reliability' as denoted by Ritchie and Lewis (2003). This could explain why even though farmers widely acknowledged trust as being high between farmers that it is was still an integral component of cooperation. Such perceptions would suggest that the main trust issues concerning farmers were if others could be trusted to do their fair share. In any case, trust plays an integral role of individuals' likelihood of working with others (Raymond, 2006). It has been observed that participants involved in collective action decide to trust others, based on their reputation in past collective action situations. However, by increased positive experiences of collaboration, trust can be developed (Ostrom, 1990). Reciprocity and exchange also help build trust and it is this trust which 'lubricates cooperation' (Pretty and Ward, 2001).

Although cooperation has many advantages it is not prevalent within the culture in which farming is set. It is widely recognised that farmers value independence, and explains why collaboration is not popular among farmers (Emery, 2014; Emery and Franks, 2012; Stock et al., 2014). The modernization of agriculture has meant farmer cooperation has become less important than what it had been for previous generations (Sutherland and Burton, 2011). However, the findings suggest that there is considerable level of latent social capital which can be mobilized. Often, policy-making takes place within 'narrow corridors of the possible', where decisions are made within established pathways (Wilson, 2013).

Respondents' perceptions of the hardships faced in today's farming environment postulates the viability of increased cooperation between farmers. Furthermore, farmers recognised the benefits of working with others. If collaboration can be brought about it is likely that production would become more efficient and GHG emissions would be reduced per unit of produce. Emission reductions could be brought about through the collective purchasing of machinery, contract rearing of livestock, construction of anaerobic digestors and wind turbines etc. Nevertheless, there is a need to assist and facilitate collaborative activities among farmers. Initiatives should be created which engage actors and support opportunities for shared learning and collaboration. Policies can encourage collective action by developing initiatives in an inclusive manner, reflecting diverse values; thereby building a common platform for action (Hyland et al., 2015; O'Brien and Wolf, 2010). The benefits of cooperation need to be made more apparent to participants. Broadening the role of advisory farm advisory services and strengthening existing farmer networks may help to foster a culture where collective action can prosper. Government funded agencies which provide information to farmers could provide templates and models for a number of collaborative activities (Teagasc, 2014). Hence, familiarising farmers of the benefits that collective action can bring. Such organizations could also act as a bridging organisation which facilitates collaboration amongst farmers (Berkes, 2009). Government could also set aside funding to launch schemes which explicitly to cover some of the costs incurred by famers when entering into collaborative agreements. With increased awareness, participation can increase which can thereby assist the industry in addressing climate change issues as well as offering a gateway for other services such as group training and learning; in addition to greater financial resilience.

5.7 Conclusions

The livestock sector is marked by the inherently high carbon footprint associated with the rearing of ruminant animals. It has been widely reported that the most effective way in which the carbon footprint of beef and lamb can be reduced is to increase farm efficiencies. One of the many ways in which such efficiency gains can be achieved, is through collective action. The concept of collective action refers to the involvement of a group of individuals who share a common interest and undertake some form of voluntary common action in pursuit of a common goal. Both formal and informal collaboration between farmers has been shown to increase efficiencies and consequently serve as a mitigation measure in which GHGs are reduced. Further, it can also increase the adaptive capacity of the industry since farming enterprises that collaborate are more resilient and capable of managing climate variability. This study illustrates the relatively low levels of collective action between farmers in the Conwy Catchment in Wales. Participants were somewhat reluctant to get involved in additional collaboration with farmers; although many conveyed a scene where farming is characterised as being financially difficult. This was in spite of the benefits of collective action being widely acknowledged and seen as a potential method of improving the economic health of their respective enterprises. Such individualism reflects the autonomy which characterises farmers in the UK. Nevertheless, the farmers in this study were familiar with the concept of cooperation and most were involved, or had been previously involved, in some form of collaboration. This familiarity allowed respondents to appreciate the benefits of collective action. Barriers to collaboration were identified; most notably trust, the fair exchange of resources, and the demeanour of other farmers. Although collaborative actions amongst farmers could have been greater, participants regularly met and interacted with other farmers. Initiatives to encourage collective action should be developed which reflect the range of diverse values held by farmers in relation to production and the environment; thereby building a common platform for participation. If the level of observed latent social capital is realised then production efficiencies, economic resilience, GHG mitigation potential, and climate change adaptive capacities should all increase. Furthermore, collaborative networks between farmers may also serve as a gateway for collective training and learning; thereby further increasing the production efficiencies and the environmental performance of the sector.

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Chapter 6: Discussion

Discussion

The aim of this thesis was to reduce GHG emissions associated with the Welsh red meat sector. The research carried out focused on a multitude of scales; the field scale, the farm scale (farm and farmer type), and the community scale. Chapter 2 concerns the field scale and determined the environmental and production of incorporating clover into grass swards compared to conventional approaches which use synthetic N. It was found that grass swards which had both red and white clover varieties were comparable in terms of yield but had significantly lower emissions when compared to grass monocultures receiving N fertiliser. These results are of particular interest as the sector continues to promote the concept of sustainable intensification. Chapter 3 evaluates the CF from 15 farms in Wales at two time periods. Although there was no significant difference in the CF between bother years for beef and lamb there were considerable differences between farms with high and low CFs. The efficiencies of the lower emitting farms allowed them to have lower although the volume of production was the same for both sets of producers. To reduce emissions and further mitigate emissions at farm level it is important to consider the varying perceptions of farmers towards climate change; Chapter 4 elicited four types of farmers based on such perception. It was observed that farmers differed in their awareness of livestock's contribution towards climate change. It is suggested that targeted information dissemination and group learning can assist farmers in gaining awareness of the sectors contribution to anthropogenic GHG emissions. Collaboration amongst farmers can be used as an implement for change and is therefore the focus for Chapter 5. Positive attitudes engendered through collective action have been shown to alter behaviours and increase the mitigation potential of individual farms. Consequently, farmers within the Conwy Catchment in Wales were asked of the opportunities and barriers to collaboration. Farmers recognised the importance of collaboration but participation was modest. Barriers included the fair exchange of resources and trust. To encourage cooperation within the farming sector it is suggested that industry promotes the many benefits of collective action.

6.1 Productivity and GHG emissions

The sustainable intensification of agriculture has been promoted as a feasible method of reducing negative externalities per unit of production. The principle of the concept is based on efficient use of inputs (The Royal Society, 2009). Chapters 2 and 3 convey how GHG emissions can be reduced without compromising productivity. Central to climate change responses is the role of the individual and their likelihood of adopting climate change measures. Previous research carried out by Bangor University found that farmers deem the adoption of legumes as being the most practical measure they could adopt to mitigate GHG emissions (Jones et al., 2013). Chapter 2 affirms the importance of the legumes as a mitigation measure; demonstrating the viability of grass-clover systems as a alternative to synthetic N fertilisers. Grass swards incorporated with multiple species of clover showed no significant difference in DMY when compared to grass only swards receiving conventional amounts of N fertiliser (RWC-G: 9.7 t DMY ha^{-1}; Low N: 8.8 t DMY ha^{-1}). However, advantages of incorporating clover into grass swards goes beyond that of just yield. Grass swards which incorporated bother red and white clover varieties were particularly advantageous in terms of lowering cumulative emissions; displaying significantly lower N_2O emissions (263.4 g kg N ha^{-1}) than the experimental control (298.3 g kg N ha^{-1}). The higher crude protein content may also be advantageous in finishing animals quicker than with grass only swards and may thereby reduce the reliance on concentrate feed.

6.1.1 The effect of productivity on the carbon footprint

While Chapter 2 concentrates on a single mitigation measures, Chapter 3 is concerned with emissions at the farm scale by use of a CF. It was demonstrated that both the total volume of slaughter weight and emissions associated with inputs did not vary significantly between high and low emitters for beef and lamb. Higher emitting enterprises required more carrying stock to reach these production levels which exemplifies the importance of efficiency with respect to emissions related with production. Therefore, simplified economic theory can be used to illustrate the how the variance in the total slaughter rate affected the final CF; consequently illustrating the importance of production efficiency. A simplified Cobb-Douglas function for the liveweight of livestock brought to slaughter (Y_R; output) can be assumed based on inputs (K_R) and animal numbers (N_R):

$$(1)\ Y_R = F(K,N) = K_R^{\alpha R}\, N_R^{\beta R}$$

Production involves the utilization of natural resources (materials) by a certain technology (F). Non-material inputs serve to transform the material inputs into the desirable output (Ebert and Welsch, 2007). Therefore, output (Y_R) is influenced by the aggregate of material inputs (K_R) and the number of ruminants (N_R) (non-material inputs). Farmers can increase output by using more inputs or by having more animals. The effect on production of using more inputs is given by α_R, and by β_R for increasing animal numbers. It is assumed that emissions (E_R) associated with the production can be represented as follows (adapted from Blandford et al., 2014):

$$(2)\ E_R = \left(\frac{K_R}{N_R}\right)^{\rho R} \times\ Y_R,\ \ \rho_R > 0$$

The level of emissions depends on a chosen production technique. For instance, if a technique is uses a lot of inputs it will generate more emissions than a less intensive technique. The strength of such an effect is known as the intensity effect. However, the volume of output is particularly important and is known as the production effect (ρ_R). To increase output a farmer can increase K but this will increase emissions associated with the increased levels of input. The farmer can also increase the amount of animals but this will also lead to an increase in K and consequently an increase in emissions. Therefore, emissions are determined by the intensity of the use of K and also the scale of production. Farmers should aspire to keep the ratio of inputs to animal numbers (K: N) as low as possible for a given production level (Y). The chapters in this thesis can aid farmers in reducing emissions according to the equation above. Chapter 3, highlights how lower CFs were associated with more efficient use of inputs, while Chapter 1 depicts how inputs can be lowered without necessary impacting on the overall production levels of a farm.

6.2 Farmer behaviour

Whilst most policies focus upon technological and economical instruments for reducing climate change, less attention is bestowed on changing human behaviour (Spence and Pidgeon, 2010). Individuals are inclined to frame problems from their own point of view, based on their own perceptions of the problem (van Bueren et al., 2014). Unless it is examined how individuals perceive climate change, along with the factors which influence mitigation and adaptation behaviours, it is unlikely that society will act effectively (Clayton and Myers, 2009). Actions which address climate change are carried out on the basis of the beliefs and risk perceptions of an individual towards the concept. From such beliefs, climate change decisions are implemented on a farm scale based on a range of farmer specific characteristics (Arbuckle et al., 2013). Farmers must be therefore engaged with the issue of climate change to best address the issue.

Heterogeneity is inherent in an individual's perceptions of climate change; the results elicited from the research carried out in Chapter 4 postulates that livestock farmers' perceptions of the issue also vary. Tailored approaches to knowledge dissemination are therefore warranted. The study found four distinct types of farmer based on perceptions of climate change, namely: The Environmentalist (28%); The Countryside Steward (26%); The Productivist (23%); and The Dejected (23%). Of the four farmer types depicted, The Environmentalist displayed the highest acceptance and awareness of climate change. Conversely, the other farmer types were less knowledgeable in their assertions of the concept. Both The Countryside Steward and The Productivist possessed low levels of acceptance and awareness of livestock's contribution to anthropogenic GHG emissions. Of particular interest was The Countryside Steward's high level of environmental responsibility which was not associated with acceptance of the livestock sector's contribution towards climate change. The Productivist's primary concern was that of production, and had the lowest level of environmental responsibility of the four groups. Incidentally, as The Productivist is production-driven, he may have the lowest footprint per unit of liveweight brought to slaughter as efficiencies on his enterprise may be higher. The Dejected was somewhat knowledgeable of livestock's contribution towards climate change, while also displaying a high sense of the perceived risks that climate change may bring. The results suggest that climate change messages can be tailored to reflect the characteristics of each group. Framing climate change in terms of any advantages involved in mitigation increases positive perceptions towards mitigation, while also increasing the perceived risks of climate change impacts (Spence and Pidgeon, 2010). Win-win measures which do not impact on the production output of an enterprise would appeal to The Productivist; whereas, messages which address a sense of environmental responsibility would entice The Countryside Steward. It was observed that while The Dejected accepts that livestock contributes towards climate change. Nevertheless, there is evidence of avoidance, denial, and desensitization through The Dejected's lack of understanding of how exactly emissions are generated from livestock farming. Therefore, their capacity to implement climate change measures may be stifled. Various methods of knowledge dissemination are suggested, such as targeting the specific groups through the more traditional linear knowledge-transfer approach, and collective group learning. The specific groups could be targeted when climate change information is disseminated. Although it is not possible to assess what types farmers fall into with further information, any information on the topic should include points which address the perceptions of all four groups found in Chapter 4.

The final research Chapter moves onto the community scale. It examines the collective behaviour of farmers by investigating existing collaboration between farmers in a geographic region, and their perceptions of collective action. Such information important as collaboration is a viable means of increasing efficiencies and consequently reducing emissions associated with production; it also can build resilience and increase the adaptive capacity of a region. The cultural autonomy of UK farmers is well established; results from semi-structured interviews in The Conwy Catchment in North-West Wales suggest that farmers in the region are no different. Although the degree of collaboration could have been greater, most farmers interacted with other farmers and were involved in some form of collective action. Farmers were assertive in their depiction of the financial struggles involved with livestock farming, while also recognising the economic benefits that collaboration may bring. The results therefore find there is a considerable amount of latent social capital that can be mobilized. Initiatives to encourage collective action should be developed which would therefore facilitate the inadvertent reduction of GHGs while also increasing the adaptive capacity of the industry to combat anthropogenic induced climate variability.

6.3 Further research & recommendations

The findings of this PhD can assist the industry in lowering emissions through assessments of individual and farm scale mitigation measures, as well as outlining the importance of farmer behaviour. However, such is the nature of the time constraints associated with a PhD that there are some aspects which could be investigated further. The appraisal of N_2O emissions from grass-clover swards over the lifetime of a ley (4-5 years), from establishment to reseeding, would be of value and provide a robust assessment of emissions assigned to production over its lifetime. Furthermore, analysis of the inclusion of clover into grass swards could be carried out on different soil types, while also assessing the impacts of higher clover on animal N excretion in a grazing experiment using the same treatments used in Chapter 2. Despite research suggesting that farmers deem legume crops as being the most practical mitigation measure they can adopt (Jones et al, 2013), the use of clover has actually decreased for pastoral-based livestock systems in recent decades (Phelan et al, 2015). Therefore, the opinions and concerns of farmers about clover crops need to be established to enable better tailoring of research to meet such concerns.

In an effort to capture the overall environmental impact of beef and lamb production, a life cycle assessment could be carried out per kg of liveweight slaughtered. This would provide a more holistic evaluation of the environmental impact of production (Baumann and Tillman, 2004). To capture the inherent variability of one farming year to the next, a CF of the same set of farming enterprises used in Chapter 3 could be monitored annually over a designated time period. From such appraisals a truly representative CF can be determined per kg of liveweight produced which would take into account annual climate and market variabilities. Conversely, some farming enterprises could adopt specific mitigation measures; therefore empirically allowing the quantification of emission reductions for a particular measure per kg of slaughtered liveweight. Although the CF of beef and lamb is inherently high due to enteric fermentation, there is a need to consider the nutritional value of red meat in dietary terms and not use carbon footprinting as a standalone measure. Indeed, the replacement of red meat with equi-calorific amounts of fruit and vegetables has been shown to increase net dietary GHG emissions (Vieux et al. 2012).

Emission targets apply to total emissions, as opposed to per kg of product, therefore further work needs to be done to disentangle the relationship between CF per kg of liveweight slaughtered and total emissions or emissions per hectare. One aspiration of reducing total emissions, and emissions per kg of slaughtered liveweight, would be for all enterprises to match the efficiencies of low CF enterprises. Furthermore, many farmers could effectively 'afford' to plant trees on less productive areas of their farm without compromising greatly on production. Thereby, reducing total emissions whilst not losing productivity – central to the goal of sustainable intensification. Such a measure could be incentivised through agri-environment payments. However, the planting of trees should only be carried out on unproductive land; if famers have only productive land they should use it solely for such purposes. This may not be an option for The Productivist, but it could be for other farmer types. Collective learning and discussion groups should be encouraged in such a scheme which would consequently increase 'good farming practice', knowledge exchange, and social capital.

European agriculture is currently experiencing lower number of new entrants while the age profile of the sector increases, both of which inhibits dynamism and innovation. The lack of new entrants into farming has been identified as a barrier to greater efficiency and innovation which lead to higher levels of production and economic development (Zagata and Sutherland, 2015). An important question is therefore how transitions towards mitigation can be induced or stimulated? On-going innovation at farm level can be used to stimulate smaller changes that in the longer term may have great effects and puts an emphasis on learning (Elzen et al., 2012). Subsidies or grants for the adoption of mitigation activities may have a direct impact on uptake of measures which address climate change. To achieve maximum benefit such provisions could be aligned with conditional attendance at meetings which focus on climate change. Environmental and economic indicators normally take precedence in the sustainability framework. However, social indicators should be also incorporated into environmental and economic measurements of agriculture. These indicators can be used to gauge the quality of life of farming communities and therefore give a thorough appraisal of sustainability under the pillars of economic, environmental, and social wellbeing. To evaluate which method best facilitates changes in perceptions of climate change, different groups of farmers could be subjected to different forms of dissemination, or a combination of various methods. This would allow the industry to establish the most effective means of disseminating climate change information. Moreover, attempts to enhance the mitigation and adaptation capacity of the sector must explicitly link climate change objectives to the social dimension. Indeed, climate change policy should place special attention on social learning. Especially designed objectives to facilitate joint learning should be therefore incorporated into agri-environment schemes. Glastir payments could further incentivise cooperation amongst farmers which would enhance social capital and the likelihood of further collaboration. Agencies such as Farming Connect could provide information on the considerable economic advantages of collective action to farmers and be used as a bridging organisation to facilitate such behaviour. Although collective action is promoted as a way in which efficiency can be increased through the sector, there is a need for empirical analyses to quantify any reduction in emissions brought about from collaboration.

The research carried out in this thesis offers opportunity to the industry to lower its emissions. However, despite promising results the industry is faced by many barriers if it is to meet its reduction strategies. Chapter 1 illustrates the potential of grass-clover swards to lower emissions without compromising yields when compared to conventional applications of fertiliser. However, although clover is not a new technology its uptake is quite low among farmers. The low prevalence of adoption of leguminous crops is borne from negative perceptions of older varieties and problems of mismanagement. If the sector is to increase farmer's adoption of grass-clover swards then such barriers must be overcome. Chapter 2 highlights the role of efficiency for low CFs. While the margin between farms operating at high and low efficiencies can undoubtedly be lowered, some farms may not have the resource endowment to close the gap. The difference in perceptions that farmers hold towards climate change are observed in Chapter 4 and highlight the difficulties in engaging farmers with the issue. If farmers are not engaged it is questionable if the lowering of on-farm emissions will become anything more than an afterthought in decision making. Knowledge dissemination to increase awareness of climate change can be effective through group learning and discussion, while collaboration amount farmers can yield economies of scale which can reduce emissions. However, farmers are defined by their inherent individualism (Chapter 5). The points outlined above should not serve to diminish the obvious potential that the sector has to reduce its emissions, rather they should serve as a gentle reminder that the path towards sustainability is one that is not without its obstacles.

6.4 Conclusions

Despite its many positive contributions to society, agriculture is responsible for some negative externalities; one of which is greenhouse gas (GHG) emissions. The contribution of livestock towards climate change is particularly important as the sector accounts for 14.5% of total global anthropogenic GHG emissions. The sector is therefore under considerable pressure to reduce its CF, and industry roadmaps have been adopted outlining emission reduction targets. This thesis aims to assist the industry in reducing sectorial emissions by incorporating both environmental and social sciences. The research carried out outlines the potential of individual and farm-scale mitigation measures, while also assessing the importance of addressing farmer behaviour for the adoption of mitigation and adaptation measures. The two opening research Chapters highlight measures which farmers could adopt to lower emissions; one being environmentally friendly (grass-clover swards to displace N fertiliser) and the other being very much based on productivist idealisms (increase production efficiency). Four farmer types are subsequently found which were based on farmers' perceptions of climate change. By tailoring messages towards each of the farmer types elicited knowledge dissemination can become more effective and farmers can become more engaged in the concept of climate change. The final research Chapter focuses on collective action between farmers at a regional scale. Collaboration can be used as an effective mitigation and adaptation measure while also assisting in knowledge transfer. Most participants were involved in some form of collection action but levels could have been higher. Nevertheless, there was considerable latent social capital that could be mobilized and used to establish greater collaboration between farmers.

The challenge to reduce emissions concerned with livestock production is difficult, given the inherently high CF associated with ruminant animals. However, the research carried out in this thesis suggests that there are various ways that sectorial emissions can be lowered; for instance: by the adoption of individual mitigation measures, increases in efficiency at a farm scale, effective knowledge dissemination using farmer types, and by encouraging collaboration amongst farmers at a community scale.

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Appendix A: Bangor University carbon footprint questionnaire

1 Farm details - please do not include any common-land rights in this section

1.1	Farm address, Customer Reference Number (CRN) and holding number	
1.2	Year for which footprint is calculated ("sample year"; see notes)	
1.3	Name of agri-environment scheme(s) in which your farm participated in the sample year: please include if your farm is certified Organic	
1.4	Year of joining listed scheme(s)	
1.5	Total area of farm (in ha) - excluding any common-land rights or short-term summer grazing (these are in separate tables)	
1.5.1	Area of farm used for grazing	
1.5.2	Area of improved grassland	
1.5.3	Area of unimproved grassland	
1.5.4	Area of woodland	
1.5.5	Area of arable / crops (including energy crops e.g. willow, miscanthus)	
1.5.6	Area of grassland ploughed per annum	
1.5.7	Use of ploughed grassland e.g. reseed/arable rotation (see notes)	
1.5.8	Area of land use change since 1990 (see notes)	
	Describe type of land use change (e.g. forest to arable)	
1.6	What types of soil does your farm have? (add boundaries to farm maps if appropriate)	
1.6.1	Approximate % of farm on each soil type	

2 Common land rights, rented short-term summer and rented tack grazing

Please make a note if you use any other areas of land during the sample year that are not included in the questionnaire. Also please ensure that any diesel used for transporting stock to / from common land or rented land is included in the farm diesel use stated in section 3 at the bottom of this sheet.

2.1 Common land agreements

2.1.1	Do you graze stock on any common land?			
2.1.2	How many stock do you have rights to graze on this common land?			
	[if applicable, state sheep and cattle separately]			
2.1.3	How many head grazed on common land in the sample year?			
	[please state which months, separately for sheep/cattle]			
2.1.4	What area of common land is allocated to you under the Single Payment or Tir Mynydd scheme? (Ha)			
2.1.5	Please describe in as much detail as you can the soil and plant cover of the common land, e.g. proportions of heath, rough grassland, exposed bedrock etc.			

2.2 Short-term summer grazing [if applicable, please answer separately for sheep and cattle]

2.2.1	Do you graze stock on land rented or leased in summer?	
2.2.2	How many ha rented summer grazing did you have in the sample year?	
2.2.3	How many head of stock used this rented summer grazing in the sample year?	
2.2.4	In which months did you use this rented summer grazing in the sample year?	
2.2.5	How much did you pay for grazing this land in the sample year? (we need this information for the economic allocation of farm footprints to products)	
2.2.6	Please state or describe the grassland type or soil/plant cover of this summer grazing land e.g. improved grassland, lowland rough grassland	

2.3 Livestock sent away for grazing (e.g. sheep to tack / other owned land/youngstock grazed elsewhere)

2.3.1	Do you send livestock away for grazing?	
2.3.2	How many animals of what category/categories	
2.3.3	For how long (and which months)?	
2.3.4	How much did you pay for tack in the sample year (if not rented please describe other arrangement)	
2.3.5	Where do they go (how far away) and is the diesel used to transport them included in 3.1/3.2?	
	(if not, add details here or describe/state engine size of vehicle used)	

2.4 Livestock from other farm businesses grazed on your land (rented grazing/tack)

2.4.1	Do you graze other farmers' stock?	
2.4.2	How many animals of what category/categories	
2.4.3	For how long (and which months)?	
2.4.4	How much did you pay for tack in the sample year (if not rented please describe other arrangement)	
2.4.5	Where do they go (how far away) and is the diesel used to transport them included in 3.1/3.2?	
	(if not, add details here or describe/state engine size of vehicle used)	

3 Energy use by the farm business during the sample year

3.1	Diesel use per year (litres) for the farm business	
3.2	Diesel use per year by contractors (litres) (see notes) [if unknown, specify area & type of work done by contractor]	
3.3	Other fuel use (ethanol, biogas, petrol) for the farm business (see notes). Please state units clearly.	
3.4	Electricity use (kWh per year) for the farm business (see notes)	

4 Chemical fertiliser applied during the sample year (see notes)

	Product name	Formulation (NPK)	Amount applied (kg)	Crop / grass type	Month of application
4.01					
4.02					
4.03					
4.04					
4.05					
4.06					
4.07					
4.08					
4.09					
4.10					
4.2	Sulphur (or S-containing treatments) (kg)				
	...is this each year or every few years? How often do you apply sulphur? (e.g. every 2 years)				
	Product name or formulation				
4.3	Lime (kg)				
	...is this each year or every few years? How often do you apply lime? (e.g. every 2 years)				
	Is it ground (=100% lime) or pelleted (=52% lime)?				

5 Manure management and bedding used in the sample year (see notes)

5.1	Manure management (choose most appropriate from the reference table) for each category of animals				
Livestock type (e.g. dairy cow, young stock < 1 year, ewes)					
Number of animals					
Average weight of these animals					
Housed for how many weeks / months, and which weeks/months per year?					
Most similar standard manure management system (see reference sheet					

	Bedding materials	Sheep	Beef	other
5.2	What material is used for bedding housed animals?			
5.3	Do you buy in bedding? (straw, sawdust, woodchip)			
5.4	For each type, tonnage & distance brought from (if relevant)			
5.5	Is the diesel used for transporting this bedding included in 3.1/3.2?			
5.5	If no, please state estimated amount (litres) or vehicle used and approximate mileage			

6 Animal feed bought, grown and fed in the sample year

6.1	Concentrates fed to sheep (See notes)		1	2	3
6.1.1	Bag label (feed ingredients and origin) provided?				
6.1.2	If not, name and known composition?				
6.1.3	Bought from where? (inc. distance)				
6.1.4	Is the diesel for transporting concentrates to the farm included in 3.2?				
6.1.5	If no, please state estimated amount (litres) or vehicle used and approximate mileage				
6.1.6	Amount fed in sample year	Fed to adult stock			
6.1.7		Fed to lambs or stores			

6.2	Concentrates fed to beef (See notes)		1	2	3
6.2.1	Bag label (feed ingredients and origin) provided?				
6.2.2	If not, name and known composition?				
6.2.3	Bought from where? (inc. distance)				
6.2.4	Is the diesel for transporting concentrates to the farm included in 3.2?				
6.2.5	If no, please state estimated amount (litres) or vehicle used and approximate mileage				
6.2.6	Amount fed in sample year	Fed to adult stock			
6.2.7		Fed to calves or stores			

6.3	Concentrates fed to dairy (See notes)		1	2	3
6.3.1	Bag label (feed ingredients and origin) provided?				
6.3.2	If not, name and known composition?				
6.3.3	Bought from where? (inc. distance)				
6.3.4	Is the diesel for transporting concentrates to the farm included in 3.2?				
6.3.5.	If no, please state estimated amount (litres) or vehicle used and approximate mileage				
6.3.6	Amount fed in sample year	Fed to adult stock			
6.3.7		Fed to calves or stores			

6.4	**Concentrates fed to Other Stock (See notes)**		1	2	3
6.4.1	Bag label (feed ingredients and origin) provided?				
6.4.2	If not, name and known composition?				
6.4.3	Bought from where? (inc. distance)				
6.4.4	Is the diesel for transporting concentrates to the farm included in 3.2?				
6.4.5.	If no, please state estimated amount (litres) or vehicle used and approximate mileage				
6.4.6	Amount fed in sample year	Fed to adult stock			
6.4.7		Fed to youngstock			

	Home-produced feed, Other feed and silage		**Fed to sheep**	**Fed to beef**	**Fed to dairy**
6.5	Do you grow feed on the farm (e.g. barley) for these livestock categories?				
	Amount of home-grown feed grown and fed in sample year	Fed to adult stock			
		Fed to calves or stores			
6.5.0	Silage fed in the sample year				
6.5.1	Proportion of this in bales				
6.5.2	a) Total amount of silage in clamp at year start				
6.5.3	b) Total amount of silage in clamp at year end				
6.5.4	c) amount in bales (please specify size/weight) at year start				
6.5.5	d) amount in bales (please specify size/weight) at year end				
6.5.6	Amount of silage made on farm in sample year (bales, bale size, tonnes)				
6.5.7	Amount of silage bought-in in the sample year (bales, bale size, tonnes)				
6.6	Any other feed stuffs (type, amount)				

7 Sundries and consumables bought in the sample year

7.1 Baling	Silage wrap (make, amount used in sample year)	
	Baler string (make, amount used in sample year)	
7.2 Cow mats	Make, type and number on farm	
	Number of years used before replacement	
7.3 Packaging	Pallets	
	Sacks (numbers, materials)	
	Other	
7.4 Fencing material	Electric	
	Conventional (wooden posts, rails, wire, staples etc)	
	Other	

7.5 Dairy consumables bought in sample year		**Product name**	**Formulation (includes % active ingredient)**	**Amount used during year**
7.5.1	Disinfectants, washes			
7.5.2				
7.5.3				
7.5.4	Bulk tank refrigerants			
7.5.5	Other			
7.5.6				
7.6	Any other consumables bought in the sample year? Please give details and amounts			

8.1 Field agrochemicals (pesticides, herbicides, fungicides)

Please give as much information as possible including trade name and active ingredient (if known).

	Product manufacturer and name	Active ingredient and % a.i.	Amount used	Crop / grassland type treated
8.1.01				
8.1.02				
8.1.03				
8.1.04				
8.1.05				
8.1.06				
8.1.07				
8.1.08				
8.1.09				
8.1.10				
8.1.11				
8.1.12				
8.1.13				
8.1.14				
8.1.15				
8.1.16				
8.1.17				
8.1.18				
8.1.19				
8.1.20				

8.2 Sheep dips and pour-on parasite treatments for sheep and cattle

Do not include Injectable and drench treatments.

	Product manufacturer and name	Active ingredient and % a.i.	Amount used	Month and number of animals treated
8.2.01				
8.2.02				
8.2.03				
8.2.04				
8.2.05				
8.2.06				
8.2.07				
8.2.08				
8.2.09				
8.2.10				
8.2.11				
8.2.12				
8.2.13				
8.2.14				
8.2.15				
8.2.16				
8.2.17				
8.2.18				
8.2.19				
8.2.20				

9 Livestock - sheep

9.1.1	How far is the slaughterhouse /market from the farm?			
9.1.2	Is the diesel for the transport of lambs to slaughter and cull ewes from farm included in 3.1/3.2?			
	If no, please state estimated amount (litres) or vehicle used and approximate mileage			
9.1.3	Breed(s) of sheep stocked: if more than one please indicate how many of each			
	FOR EACH BREED: Lamb birthweight (kg)			
	FOR EACH BREED: Adult ewe maintenance weight			
	FOR EACH BREED: Adult ram maintenance weight			
	FOR EACH BREED: Ewe lamb weight when first put to ram			
9.1.4	What is your lambing average? (lambs per ewe REARED)			

9.2 Stock-take figures at sample year-start and year-end

	Category	At year start (number)	(average live weight)	At year end (number)	(average live weight)
9.2.1	Breeding ewes (>1yr old)				
9.2.2	Lambs for replacement ewes (<1yr old)				
9.2.3	Lambs intended for slaughter (<1yr old)				
9.2.4	Other sheep >1yr old (rams etc)				

9.3 Sheep sales (for economic allocation) per year

	Category	Destination	Number	(average) live weight	Killing-out weight (average if known)	(average) price
9.3.1						
9.3.2						
9.3.3						
9.3.4						

9.4 Sheep leaving the farm business (e.g. sold, culled) per month

Month	Slaughter lambs (number)	Store lambs (number)	Ewes (number)	Couples (number)	Rams	
Apr						
May						
Jun						
Jul						
Aug						
Sep						
Oct						
Nov						
Dec						
Jan						
Feb						
Mar						

9.5 Sheep entering the farm business (e.g. bought-in, also number of ewes lambed) per month

Month	Ewes lambing	Slaughter lambs (number)	Store lambs (number)	Ewes (number)	Couples (number)	Rams
Apr						
May						
Jun						
Jul						
Aug						
Sep						
Oct						
Nov						
Dec						
Jan						
Feb						
Mar						

10.1.1	How far is the slaughterhouse / market from the farm?			
10.1.2	Where do the cull animals go?			
10.1.3	Is the diesel for the transport of animals to slaughter and cull cows from farm included in 3.1/3.2?			
	(if not, add details here or describe/state engine size of vehicle used)			
10.1.4	Breed(s) of cattle stocked: if more than one please indicate how many of each			
	FOR EACH BREED: Calf birthweight (kg)			
	FOR EACH BREED: Adult cow maintenance weight			
	FOR EACH BREED: Adult bull maintenance weight			
	FOR EACH BREED: Heifer age/weight when first put in calf			

10.2 Stock-take figures at (footprint) year-start and year-end

	Category	**At year start** (number)	(live weight)	**At year end** (number)	(live weight)
DAIRY	Dairy cows				
	In-calf heifers for replacement				
	Calves (<4 months old)				
	Other dairy youngstock				
	Bulls				
BEEF	Suckler cows				
	In-calf heifers for replacement				
	Calves (<4 months old)				
	Stores 4-12 months old				
	Stores over 1 year old				
	Other beef youngstock				
	Bulls				
	Breeding bulls				

10.3 Cattle sales per year - for economic allocation

	Category	**Number**	**Live weight**	**Killing-out weight (average)**	**Average price**
DAIRY	Dairy cows				
	In-calf heifers				
	Calves (<4 months old)				
	Other dairy youngstock				
	Bulls				
BEEF	Suckler cows				
	In-calf heifers for replacement				
	Calves (<4 months old)				
	Stores 4-12 months old				
	Stores over 1 year old				
	Other beef youngstock				
	Bulls finished				
	Cull Sucklers				

10.4 Cattle leaving the farm business (e.g. sold) per month - for stock emissions

Month	Finished stores / bulls (number)	(live weight)	Dairy / suckler cows (number)	(live weight)	Calves / youngstock (number)	(live weight)
Apr						
May						
Jun						
Jul						
Aug						
Sep						
Oct						
Nov						
Dec						
Jan						
Feb						
Mar						

10.5 Cattle entering the farm business (e.g. bought-in, calves born) per month - for stock emissions

Month	Stores for finishing (number)	(live weight)	Dairy / suckler cows (number)	(live weight)	Calves / youngstock (number)	(live weight)
Apr						
May						
Jun						
Jul						
Aug						
Sep						
Oct						
Nov						
Dec						
Jan						
Feb						
Mar						

11 Livestock - any other livestock in the farm business (e.g. horses, swine, poultry)

Please only include livestock that contribute financially to the farm business. E.g. horses for grazing or livery, swine, poultry

11.1	Does your farm business include livestock other than sheep and cattle?			
11.2	Category(s) and number(s) of livestock that form part of the farm business.			
11.3	Approximate annual income (as % of farm business) from each category of livestock other than sheep and cattle			

Stock-take figures for other farm-business livestock at sample year-start and year-end

11.4	**Category**	**At year start**		**At year end**	
		(number)	**(average live weight)**	**(number)**	**(average live weight)**
11.4.1					
11.4.2					
11.4.3					
11.4.4					
11.4.5					
11.4.6					
11.4.7					
11.4.8					
11.4.9					

11.5 Other Stock sales per year - for economic allocation

	Category	**Number**	**Weight (live for stock)**	**Killing-out weight (average)**	**Average price**
EGGS					
SPENT BIRDS					
POULTRY (FOR MEAT)					
SWINE					

11.6 Other Stock leaving the farm business (e.g. sold) per month - for stock emissions

Month	category		category		category	
	(number)	(live weight)	(number)	(live weight)	(number)	(live weight)
Apr						
May						
Jun						
Jul						
Aug						
Sep						
Oct						
Nov						
Dec						
Jan						
Feb						
Mar						

11.7 Other Stock entering the farm business (e.g. bought-in, born) per month - for stock emissions

Month	category		category		category	
	(number)	(live weight)	(number)	(live weight)	(number)	(live weight)
Apr						
May						
Jun						
Jul						
Aug						
Sep						
Oct						
Nov						
Dec						
Jan						
Feb						
Mar						

12 Grazing, products and crops

12.1 Please note the time your stock spent grazing over the sample year - so we can estimate emissions from manure deposited directly on the fields

	Category of animals	Number	Number of months spent grazing	Which months spent outside?
12.1.1	Adult cows – dairy and/or suckler herd, bulls			
12.1.2	Growing stock - heifers, stores >1year old			
12.1.3	Youngstock (< 1 year old but excluding calves)			
12.1.4	Calves <4 months old			
12.1.5	Sheep under 12 months old			
12.1.6	Sheep over 12 months old			
12.1.7	Other Stock - type / category			
12.1.8	Other Stock - type / category			
12.1.9	Other Stock - type / category			
12.1.10	Other Stock - type / category			

12.2 Milk production

12.2.1	Amount of milk sold per year (litres or state unit)	
12.2.2	How far is the dairy you use from your farm?	
12.2.3	Average farm gate price per litre?	
12.2.4	Is the diesel used to transport milk off-farm included in 3.1/3.2?	
	(if not, add details here or describe/state engine size of vehicle used)	

12.3 Wool production

12.3.1	Amount of wool sold per year (kilogrammes or state unit)	
12.3.2	How far is the wool transported from your farm?	
12.3.3	Average farm gate price per kilo / (other unit)?	
12.3.4	Is the diesel used to transport wool off-farm included in 3.1/3.2?	
	(if not, add details here or describe/state engine size of vehicle used)	

12.4 Eggs production

12.4.1	Amount of eggs sold per year (dozens or state unit)	
12.4.2	How far is the buyer/distributor from your farm?	
12.4.3	Average farm gate price per dozen?	
12.4.4	Is the diesel used to transport eggs off-farm included in 3.1/3.2?	
	(if not, add details here or describe/state engine size of vehicle used)	

12.5 Crops, including energy crops (e.g. willow, miscanthus)

Do you grow crops (not including silage)? If yes, for each crop type(s):		beet	oats	
For each crop type	Number of fields and area (ha) under this crop in sample year			
	Yield (tonnes) in sample year			
	Tonnes sold per year			
	Price per tonne			
	Average mileage for transporting this crop if sent off-farm			
	Is the diesel used to transport this crop off-farm included in 3.1/3.2?			
	(if not, add details here or describe/state engine size of vehicle used)			

13 Details of trees, fields and habitats on the farm - representing potential carbon sinks and stores

Information for the sample year only please. If you have more than three woodland areas on your farm, please provide information for those areas in the same format on a separate sheet and include it with the questionnaire.

13.1 Trees - woodlands and orchards on the farm.

For any areas of natural woodland on your farm		Area 1	Area 2	Area 3
For each woodland area or parcel	Area of woodland parcel (ha)?			
	How old (in years) is the woodland area? (see notes)			
	Describe the tree species or mix in the woodland (see notes)			
	Tree height (average to top of canopy)			
	Is the tree canopy completely closed (dense woodland)?			
For any areas of planted woodland on your farm (includes orchards)				
For each woodland area or parcel	Area of woodland parcel (ha)?			
	How old is the plantation? (years)			
	Describe the tree species or mix in the woodland			
	Tree height (average to top of canopy)			
	Tree density or spacing			
	Is the tree canopy completely closed (dense woodland)?			
	If the area was planted in the sample year, in which month and what was it converted from? (e.g. June, from improved grassland)			

13.2 Trees - woodland active management and wood harvesting.

For each woodland area or parcel	Management or intervention (eg. firewood, clearfelled, thinned, coppiced)			
	Area or proportion managed			
	Volume (or description) of wood removed			
	What did you do with the brash (waste)? (e.g. left to decompose *in situ* , burned)			
	Is this management typical annual management?			
	If not typical, please describe management in a typical year, or management and normal interval			

13.3 Trees not in woodlands - e.g. mature / emergent trees in hedges, trees in fields or in parkland.

13.3.1	Estimate how many trees (in this category and >5m tall) your farm has.	
13.3.2	Species (most to least common)	
13.3.3	Average age (approx, estimated is fine)	
13.3.4	Number managed (e.g. pruned, coppiced, felled) in the sample year	

13.4 Hedges - please estimate as carefully as you can and mark hedges (but NOT fences) clearly on the farm map.

		Hedges bordering public roads	Hedges NOT bordering public roads
13.4.1	Length (in m) of woody hedge		
13.4.2	Length or proportion flailed in sample year		
13.4.3	Length or proportion of double-fenced hedges (present in sample year)		
13.4.4	Height of hedges (including any bank)		
13.4.5	Height of hedge banks (where appropriate) and proportion with banks		
13.4.6	Average width of hedges		

13.5 Scrub habitat - please do not include common land

13.5.1	Estimate how much scrub your farm has (ha)	
13.5.2	Is this area included under grazing land area? Which grassland type?	
13.5.3	Woody (tree or shrub) species (most to least common)	
13.5.4	Age (approx) of the scrub area	
13.5.5	(if <1 year old, land type converted from)	
13.5.6	% of scrub area covered by woody species	
13.5.7	% of area covered by dense bramble	
13.5.8	Describe remaining cover (e.g. rough grass, 0.5m tall)	

13.6 Bracken - please do not include common land

13.6.1	Estimate how much bracken your farm has (ha)	
13.6.2	Is this area included under grazing land area? Which grassland type?	
13.6.3	Age (approx) of the bracken-covered area	
13.6.4	How do you manage the area (none, cutting, spraying etc)	
13.6.5	% of area managed in sample year	
13.6.6	Normal management frequency (every year, every 2 years etc)	

13.7 Heathland - please do not include common land

		DRY upland heather / gorse	Lowland / coastal heath
13.7.1	Estimated area of heathland (ha)		
13.7.2	Is this area included under grazing land? Which grassland type?		
13.7.3	Average height of heath vegetation (m)		
13.7.4	Age of heathland (permanent, years)		
13.7.5	(if <1 year old, land converted from)		
13.7.6	Management in the sample year (cutting, burning, grazing)		
13.7.7	Normal management interval or planned intervals?		
13.7.8	Area or proportion managed in the sample year		

13.8 Permanent bog, swamp, reedbeds and wetlands: please do not include common land

		Bog and swamp	Reedbeds/other vegetated wetland
13.8.1	Estimated area (ha)		
13.8.2	Is this area included under grazing land? Which grassland type?		
13.8.3	Type and average height of vegetation (m)		
13.8.4	Age of wetland (permanent, years)		
13.8.5	(if <1 year old, land type converted from)		
13.8.6	Underlying soil type if known		
13.8.7	Area of open water (ha or sq. m.)		

13.9 Saltmarsh or coastal grazing marsh - only applicable to coastal farms

13.9.1	Estimate how much salt/grazing marsh your farm has (ha)	
13.9.2	Is this area included under common or grazing land? Which grassland type?	
13.9.3	Age (approx) of the marsh area	
13.9.4	Is the marsh grazed or managed? How often?	
13.9.5	% of area managed or grazed in sample year	
13.9.6	Estimated grass sward height (average throughout the year)	

14 Grassland, crops and grassland management

Please provide details of grassland and crops in this section

14.1 **Grassland** - this is the main body of the field and excludes any field margins that are managed differently (such as not fertilised or left unsprayed, fenced margins, bird cover crop strips etc)

		Area (ha)	Soil type	Sward height (m) (see notes)	Silage cuts/year (number, bales/ha)	Fertiliser / pesticide use (amount/ha in sample
14.1.1	Rough grassland					
14.1.2	Unimproved acid grassland					
14.1.3	Unimproved neutral grassland					
14.1.4	Unimproved lime grassland					
14.1.5	Semi-improved grassland / hay meadow					
14.1.6	Marshy grassland					
14.1.7	Improved grassland					
14.1.8	Crops (for each crop type/s)					

14.2 Additional information about improved grassland management

14.2.1	Ley mix used (ryegrass, clover etc) and name if known	
14.2.2	Age of current ley (and planned reseeding interval)	
14.2.3	Length of time this area has been 'improved'	
14.2.4	Area and number of fields with clover in the ley	
14.2.5	% clover cover of fields with clover in the ley	

14.3 **Margins** - field margins under different management from the main body of the field

	Category	Area (ha)	Soil type	Sward height or height and type of vegetation	Wildlife cover crop seed mix if known	Age and management (ploughed/sown or sown
14.3.1	Fenced streamside					
14.3.2	Unsprayed margin					
14.3.3	Unfenced rough grassland (permanent margin)					
14.3.4	Hedge banks					
14.3.5	Wildlife cover crop					
14.3.6	Other (please describe)					

Further use of these data

Bangor University will use these data in continuing research into farm carbon footprints.
Data use in research is and will remain completely anonymous.

Name:

Address:

NOTE: make sure farmer chooses the most appropriate system (or systems, ask for % manure handled by each chosen system). Each farm's system is subtly different but these differences can't be modelled individually, so please help them choose the system 'most like' theirs.

1	Dairy cattle Beef cattle Sheep	**Solid storage:** manure is stored in unconfined piles or stacks, typically for a period of several months. Manure is able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
2a	Dairy cattle	**Liquid/slurry WITH natural crust cover:** manure is stored as excreted or with some minimal addition of water to facilitate handling and is stored in either tanks or earthen ponds.
2b	Dairy cattle	**Liquid/slurry WITHOUT natural crust cover:** manure is stored as excreted or with some minimal addition of water to facilitate handling and is stored in either tanks or earthen ponds.
3	Dairy cattle	**Uncovered anaerobic lagoon:** anaerobic lagoons combine waste stabilisation and storage. Lagoon supernatant (water) is usually used as flush water to remove manure from the sheds/yards to the lagoon. Storage time varies (up to a year or greater), depending on climate, volatile solids loading rate and other operational factors. The water from the lagoon may also be used to irrigate and fertilise fields.
4	Dairy cattle	**Daily spread:** manure is routinely removed and applied to cropland or pasture within 24 hrs of excretion.
5	Dairy cattle	**Dry lot:** a paved or unpaved open confinement area without any significant vegetative cover where accumulating
6	Dairy cattle	**Pit storage below animal confinements:** collection and storage of manure usually with little or no added water
7		**Anaerobic digester:** designed and operated for waste stabilisation by the microbial reduction of complex organic
8	Beef cattle	**Deep-bedding:** as manure accumulates, bedding is continually added to absorb moisture over a production cycle and
9		**Composting – in-vessel:** composting, typically in an enclosed channel, with forced aeration and continuous mixing.
10		**Composting – static pile:** composting in piles with forced aeration but no mixing.
11		**Composting – intensive windrow:** composting in windrows with regular turning for mixing and aeration.
12		**Composting – passive windrow:** composting in windrows with infrequent turning for mixing and aeration.
13		**Aerobic treatment:** The biological oxidation of liquid manure with either forced or natural aeration. Natural aeration

	Product	% ai	Formulation
6.01	Alistell	28%	220 g / l 2,4-DB, 30 g / l linuron and 30 g / l MCPA
6.02	2,4-D Amine 500	50%	500 g / l 2,4-D
6.03	Ally Sx	20%	200 g / kg metsulfuron-methyl
6.04	Ally Max SX	28.60%	143 g / kg metsulfuron-methyl and 143 g / kg tribenuron-methyl
6.05	Ally Express	50%	40 % w/w carfentrazone-ethyl and 10 % w/w metsulfuron-methyl
6.06	Asulox	40%	400 g / l asulam
6.07	Beet up	11.40%	114 g / l phenmedipham
6.08	Betasan	16%	160 g / l phenmedipham
6.09	Blazer	33%	330 g / l pendimethalin
6.10	Bravo 500	50%	500 g / l chlorothalonil
6.11	Bravo Xtra	41.5	375 g / l chlorothalonil and 40 g / l cyproconazole
6.12	Broadsword	35%	200 g / l 2,4-D, 85 g / l dicamba and 65 g / l triclopyr
6.13	Cadou Star	58%	480 g / kg flufenacet and 100 g / kg Isoxaflutole
6.14	Callisto	10%	100 g / l Mesotrione
6.15	Caramba	6%	60 g / l metconazole
6.16	Clik	5%	50 g / l dicyclanil
6.17	Clinic	36%	360 g / l glyphosate
6.18	Clinic Ace	36%	360 g / l glyphosate
6.19	Compitox	60%	600 g / l mecoprop-P
6.20	Corbel	75%	750 g / l fenpropimorph
6.21	Crovect	1.25%	1.25% w/v cypermethrin
6.22	Cycocel	11.80%	
6.23	Doxstar	20%	100 g / l fluroxypyr and 100 g / l triclopyr = 200 g / l
6.24	Dursban	75%	75 % w/w chlorpyrifos
6.25	Envoy	14.75%	62.5 g / l epoxiconazole and 85 g / l pyraclostrobin
6.26	Finish	40%	67 g / kg metsulfuron-methyl and 333 g / kg thifensulfuron-methyl
6.27	Firebird	60%	200 g / l diflufenican and 400 g / l flufenacet = 600 g / l
6.28	Glyphosate	36%	360 g ai per litre
6.29	Golden Fleece	60%	
6.30	Goltix 90	90%	90% ai w/w
6.31	Grazon 90	30%	60g / l clopyralid and 240 g / l triclopyr = 300 g / l
6.32	Grounded	99%	99% ai
6.33	Hallmark	10%	100 g / l lambda-cyhalothrin
6.34	Hive	73%	730 g / l chlormequat
6.35	IPU	80%	80 % w/w isoproturon
6.36	Joules	50%	500 g / l chlorothalonil
6.37	MCPA 25%	23.50%	235 g / l MCPA
6.38	MCPA 500	50%	500 g / l MCPA
6.39	Metrorex Amber	3.50%	low amounts of ai which seem to vary between 2-5%
6.40	MPCC	60%	600 g / l mecoprop-P
6.41	Opus	12.50%	125 g / l epoxiconazole
6.42	Pedict	78.60%	Norflurazon (78.6%)
6.43	Roundup	36%	360 g / l glyphosate
6.44	Roundup Ace	45%	450 g / l glyphosate
6.45	Roundup Amenity	36%	360 g / l glyphosate
6.46	Roundup Biactive	36%	360 g / l glyphosate
6.47	Roundup Biactive 3G	36%	360 g / l glyphosate
6.48	Roundup Biactive dry	50.28%	50.280 % w/w glyphosate
6.49	Roundup Energy	45%	450 g / l glyphosate
6.50	Roundup Express	45%	450 g / l glyphosate
6.51	Roundup GC	12%	120 g / l glyphosate
6.52	Sahara	10%	100 g / l fluquinconazole
6.53	Samson	4%	40 g / l nicosulfuron
6.54	Sheep dip (Ectomort)	8%	
6.55	Slug pellets	3.50%	low amounts of ai which seem to vary between 2-5%
6.56	Stomp	40%	400 g / l pendimethalin

6.57	Vetrazine	50%	

Sheep dips and pour-on parasite treatments				
	Product	**% ai**	**Amount used**	**Date and number of animals treated**
7.01	Coopers Ectoforce			
7.01	Osmonds Gold Fleece			
7.01	Paracide Plus			
7.01	Auriplak Fly and Scab Dip			
7.01	Ecofleece			
7.01	Robust			
7.01	Clik pour-on	5%		
7.01	Coopers spot-on			
7.01	Crovect Pour On			
	Cydectin	0.1%		0.1% moxidectin
7.01	Dysect Sheep pour on			
7.01	Vetrazin Pour-on	6%		
7.01	**Zermasect Sheep pour-on**			
7.01	Dectomax			

Appendix B: Emission factors used in the Bangor University carbon footprint model

GHG source	Activity data used for calculation	Reference	Emission factor	References
CH_4				
Enteric fermentation (sheep > 1 year)	Monthly stock numbers	Farm stock diary	1/12 × 8 kg/head/yr	IPCC (2006)
Enteric fermentation (lambs < 1 year)	Monthly stock numbers	Farm stock diary	1/12 × 3.2 kg/head/yr	Webb et al. (2014)
Excreta and managed manure (sheep > 1 year)	Monthly stock numbers	Farm stock diary	1/12 × 0.48 kg/head/yr	Webb et al. (2014)
Excreta and managed manure (sheep <1 year	Monthly stock numbers	Farm stock diary	1/12 × 0.129 kg/head/yr	Webb et al. (2014)
Enteric fermentation (cattle > 1 year)	Monthly stock numbers	Farm stock diary	1/12 × 50.5 kg/head/yr (cows > 1 year) 1/12 × 48 kg/head/yr (heifer, all others > 1 year)	Webb et al. (2014)
Enteric fermentation (cattle < 1 year)	Monthly stock numbers	Farm stock diary	1/12 × 32.8 kg/head/yr (calves < 1 year)	Webb et al. (2014)
Excreta and managed manure (cattle > 1 year)	Monthly stock numbers	Farm stock diary	1/12 × 13 kg/head/yr	Webb et al. (2014)
Excreta and managed manure (cattle < 1 year)	Monthly stock numbers	Farm stock diary	1/12 × 11 kg/head/yr	Webb et al. (2014)
N_2O (direct)				
N additions to soil:				
Mineral fertiliser	N applied in fertiliser	Farm records	0.01 kg N_2O-N/kg N	IPCC (2006)
Manure	Monthly stock numbers housed and liveweights N excretion rate Fraction of N lost in manure management	Farm records IPCC (2006) IPCC (2006)	0.01 kg N_2O-N/kg N	IPCC (2006)
Crop residues	Crop yield and fraction of residues removed N content of above and below ground residues	Farm records IPCC (2006)	0.01 kg N_2O-N/kg N	IPCC (2006)
Drained or managed peat soil	Area of managed peat soil	Farm records	0.25 kg N_2O-N/kg N	Scottish Executive (2007)

Excreta deposited on pasture	Monthly stock numbers grazing and liveweights N excretion rate	Farm records IPCC (2006)	0.01 kg N_2O-N/kg N	IPCC (2006)
Managed manure	Monthly stock numbers housed and liveweights N excretion rate	Farm records IPCC (2006)	0.005 kg N_2O-N/kg N excreted (solid storage) 0.01 kg N_2O-N/kg N excreted (deep bedding, liquid slurry with crust cover)	IPCC (2006)
N_2O (indirect)				
N volatilised from soil and re-deposited	N applied in fertiliser, manure and excreta Fraction of applied synthetic and organic N volatilised	Farm records IPCC (2006)	0.01 kg N_2O-N/kg N/kg NH_3-N + NO_X-N volatilised	IPCC (2006)
N leaching and runoff from managed soil	N applied in fertiliser, manure, excreta and crop residues Fraction of applied N lost through leaching and runoff	Farm records IPCC (2006)	0.0075 kg N_2O-N/kg N leaching and runoff	IPCC (2006)
Managed manure	Monthly stock numbers housed and liveweights N excretion rate Fraction of N volatilised in manure management	Farm records IPCC (2006)	0.01 kg N_2O-N/kg N/kg NH_3-N + NO_X-N volatilised	IPCC (2006)

Appendix C: Questionnaire used to determine farmer type based on perceptions of climate change

PRIFYSGOL
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Farmers' perceptions of climate change: identifying types

This survey is part of a PhD project that is trying to understand what farmers think of climate change and environmental issues in general.

The questionnaire is anonymous. All information you provide will be kept **confidential** and will only be used for the purposes of this research. It should take approximately 20 minutes to complete all the questions.

Please answer <u>all</u> questions. There is no 'correct' answer to any of the questions, so please state whatever you feel.

THANK YOU FOR PROVIDING YOUR TIME TO HELP THIS PROJECT

For further information on this project, please contact Mr John Hyland at Bangor University by e-mail: afpe69@bangor.ac.uk.

Section 1: Demographics

(Please tick/fill in appropriate box)

1.1 Are you a full time/part time commercial farmer?

☐ Full Time ☐ Part Time

1.2 Gender:

☐ Male ☐ Female

1.3 Your age:

☐ 18-25
☐ 26-35
☐ 36-45
☐ 46-55
☐ 56-65
☐ >66

1.5 What is the highest level of education that you have received?

☐ Primary School
☐ GCSE's/O-Levels
☐ A-Levels/NVQ
☐ HNC/ HND
☐ University undergraduate degree or higher

1.6 How many acres/hectares do you farm?

☐ <100 acres (<40.47ha)
☐ 101-300 acres (40.5ha-121.41ha)
☐ 301-500 acres (121.81ha – 202.34ha)
☐ >501 acres (>202.753ha)

1.7 What sector of the livestock industry do you represent?

☐ Beef only
☐ Sheep only
☐ Mixed (cattle and sheep)

1.8 How many years have you been farming?

☐ 0-10 years
☐ 11-20 years
☐ 21-30 years
☐ >31

Section 2: Perceptions

(Please tick the box corresponding to your opinion on the following statements. Options include strongly agree, agree, unsure, disagree or strongly disagree)

(Please note that there are no right or wrong answers in this section, only your opinion)

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
Q1 Climate change is an important global issue.					
Q2 When making decisions I take the environment into consideration even if it lowers profit.					
Q3 It is possible to reduce greenhouse gas emissions from my farm without lowering production levels.					
Q4 Other industries pollute more than livestock farmers and should therefore be penalised more.					
Q5 Livestock farmers should share responsibility towards the industry's impact on climate change.					
Q6 Environmental regulations are important for the future of farming.					
Q7 The government should financially support farmers in adapting to climate change.					
Q8 The government should encourage food production in the UK to reduce reliance on imports.					
Q9 Being seen primarily as a food producer is important to me.					
Q10 I accept that man-made climate change is happening.					
Q11 Livestock farming contributes to climate change.					
Q12 Climate change will affect farming in Wales over the next 10 years.					
Q13 Climate change poses more opportunities than challenges for farmers.					
Q14 Climate change will lead to lower productivity on my farm due to disease and pests.					
Q15 Climate change poses more of a threat to farming in the next 10 years than that of a general recession.					
Q16 Any climate change reduction strategies must make economic sense to the individual farmer.					
Q17 Beef or lamb produced with low emissions should be sold at a higher price.					
Q18 The best climate change mitigation strategies are too costly for farmers to adopt.					
Q19 Farmers should be allowed to maximise production, whatever the environmental cost.					

(Please tick the box corresponding to your opinion on the following statements. Options include strongly agree, agree, unsure, disagree or strongly disagree)

(Please note that there are no right or wrong answers in this section, only your opinion)

	Strongly disagree	Disagree	Unsure	Agree	Strongly agree
Q20: Uncertainty due to variable weather patterns caused by climate change will negatively influence my ability to farm successfully.					
Q21 Climate change is a global problem; whatever changes I carry out on my farm is of little value.					
Q22 I want to farm as environmentally friendly as possible					
Q23 I am interested in trying different technologies and/or systems to reduce my farm's greenhouse gas					
Q24 The way farming colleagues think about my farm is important to me.					
Q25 Others in my family think that I should farm as environmentally friendly as possible.					
Q26 Switching to more environmentally friendly farming methods would not involve much change from my current operation.					
Q27 I plan to actively reduce my farm's greenhouse gas emissions and environmental impact over the next 10 years.					
Q28 I find information on climate change easy to understand.					
Q29 As a farmer I have an obligation to maintain or improve the environment for future generations.					

Section 3: Further questions

(Please note that there are no right or wrong answers in this section, only your opinion)

3.1 **What is the main benefit you think that climate change may bring to your farm?**

(Please circle <u>one</u> option)

a. No opportunities
b. Longer growing season
c. Producing energy
d. New markets
e. Better prices per for produce
f. Reduced costs
g. Increased biodiversity
h. Diversification
i. Carbon capture and storage
j. Better conditions for livestock
k. Other
l. Don’t know

3.2 **What is the main risk you think that climate change may bring to your farm?**

(Please circle <u>one</u> option)

a. No risks
b. Unpredictable/extreme weather
c. Lower price for produce
d. Increased costs
e. Crop failure/reduced yields
f. Increased taxes/regulation
g. Animal husbandry issues (e.g. heat stress, disease)
h. Nutrient loss through run-off
i. Soil erosion
j. Price/profit volatility
k. Other
l. Don’t know

3.3 **How would you describe the greenhouse gas emissions associated with each of the following on your farm?**

(For each of the options indicate if you think your farm emits greenhouse gases, stores greenhouse gases or it is neutral by ticking the appropriate box)

	Emits	Neutral	Stores
Livestock and their waste			
Energy usage on-farm			
Fertiliser use			
Crops and pasture			
Soils			
Farm forest and vegetation			

3.4 **What is the main medium where you get information on climate change?**

(Please circle one option)

a. Levy board
b. Farming unions
c. Government
d. TV/Radio
e. Farming Connect
f. Press
g. Open days/Industry events
h. Internet
i. Energy companies
j. Other

3.5 **Of the following environmental issues, which do you see as being most important facing society in the future?**

(Assign numbers 1, 2, 3, 4, 5, and 6 to the options in the box below)

(1 being the least risk to society, 6 being the greatest)

	Rank 1 to 6
Energy supply	
Water quality	
Climate change	
Air pollution	
Waste management	
Food security	

PLEASE TURN OVER TO THE LAST PAGE

3.6 **Please indicate whether you think each of the following is a cause of climate change:**

	Major cause	**Minor cause**	**Not a cause at all**
Pollution from other industries (not including agriculture)			
Pollution from car use			
Pollution from fossil fuel-burning power stations			
Destruction of tropical rainforests			
Manufacturing and use of fertilisers			
Methane from cows/sheep			

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

Appendix D: Sustainable Intensification Platform baseline farm survey

SUSTAINABLE INTENSIFICATION PLATFORM

BASELINE FARM SURVEY

Farmer interview schedule

SECTION A. SUSTAINABLE INTENSIFICATION – YOUR VIEWS AND PRACTICES

1.3 Have you heard of the term Sustainable Intensification? (*Tick one box)*

☐Yes

☐No

☐Not sure

If YES, in what context have you been made aware of this term?

…….

…….

2. What do you understand Sustainable Intensification to mean?

…….

…….

3. a. The following are some examples of Sustainable Intensification activities. Please indicate if you are already involved in carrying out these activities, would consider introducing them or increasing usage of them in the future, or if they are not applicable to your farming system.
(Tick all that apply)

Activity	Already carry out	Would consider increasing/ introducing	Would not consider using	N/A to farming system
Grow crop varieties with increased tolerance to stresses such as drought, pests or disease				
Reduce tillage to minimum or no till				
Incorporate cover crops, green manures and other sources of organic matter to improve soil structure				
Improve animal nutrition to optimise productivity (& quality) and reduce the environmental footprint of livestock systems				
Reseed pasture for improved sward nutrient value and / or diversity				

Predict disease and pest outbreaks using weather and satellite data, and use this information to optimise inputs				
Adopt precision farming: using the latest technology (e.g. GPS) to target delivery of inputs (water, seeds, pesticides, fertilisers, livestock manures)				
Monitor and control on-farm energy use				
Improve the use of agriculturally marginal land for natural habitats to provide benefits such as soil improvement, pollution control or pollination, and allow wildlife to thrive				
Provide training for farm staff on how to improve sustainability / environmental performance				

3b. Are there any particular barriers that would prevent you from considering these practices?

…….

…….

SECTION B. QUESTIONS ABOUT YOU AND YOUR FARM BUSINESS

4. What is your role in the farm business? (*Tick one box)*

☐ Sole proprietor

☐ Partner with parent

☐ Partner with son/daughter

☐ Partner with other relative

☐ Partner with non-relative

☐ Director/manager

☐ Other (*please tell us*) ____________________

5. What is your total area that you farm? …….acres ………. hectares

6. a. How many people are working in your business, including yourself and your family?

	Full-time (year round)	Part-time (year round)	Casual
You and your Family			

Employees			

b. Do you use contractors?

☐Yes

☐No

If YES, what for? ....

2.1.2 Approximately, what proportion of your total household income is derived from each of the following sources: *(Tick one box in each row)*

Farming	....
Non-farming (diversified) enterprises	....
Your off farm employment:	....
Off farm employment by other members of farm's main household	....
Savings, investments & pensions	....
Other (please tell us)	....

2.3 Taking all of your income sources into account, how would you describe the current economic position of your farm business? (*Tick one box):*

☐	☐	☐	☐
Poor	Fair	Good	Excellent

2.2.5 The average net profit for Wales from the 2013/14 financial year was £29,300. In comparison to this, was your farm business income *(Tick one box):*

☐	☐	☐	☐	☐
Considerably lower	Similar	Somewhat greater	Considerably greater	Prefer not to disclose
(less than £21,500)	*(less than £5000 away from £43,000)*	*(greater, but less than £86,000)*	*(more than £86,000)*	

2.4 How much are you satisfied or dissatisfied with the overall level of physical production / yield of the farm business? *(Tick one box)*

☐ ☐ ☐ ☐

Not satisfied at all | Less than satisfied | Satisfied | More than satisfied

2.3.4 Does the farm business make use of any software, including apps, or specific guidance documents, such as the RB209 fertiliser manual, to inform decisions? (*Tick one box):*

☐ Yes ☐ No

If YES, please provide the name of up to three that you find most useful?

1……………………… 2……………………… 3………………………..

SECTION C. RECENT AND ANTICIPATED CHANGES IN THE FARM BUSINESS

2.5 Has there been any significant change in this farm business over the last 5 years? If so, what AND why?

Prompt for changes in area farmed, farm infrastructure (eg buildings, slurry store), enterprise mix, changes in land management, changes in livestock numbers or breeds, changes in crop types/varieties and the adoption of new technology

……

……

……

……

……

……

……

2.4.4 Have you any firm plans to make any significant changes to this farm business in the next 3 years? If so, what AND why?

Prompt for changes in area farmed, farm infrastructure (eg buildings, slurry store), enterprise mix, changes in land management, changes in livestock numbers or breeds, changes in crop types/varieties and the adoption of new technology

……

……

……

……

……

SECTION D. ENVIRONMENTAL AND RESOURCE MANAGEMENT

3.2 Do you have, and use, any of the following management plans for your farm business? *(Tick one box in each row)*

	Have and actively use	**Have but do not actively use**	**Do not have formal plan**	**N/A to farming System**
Manure management plan				
Nutrient management plan				
Energy efficiency plan				
Crop protection plan / Integrated Pest Management plan				
Soil management plan				
Wildlife / biodiversity management plan				
Water management plan				
Pollution risk assessment and corresponding action plan				
Animal health plan				
Other (please specify)				

5.2 If you do have one or more of the above plans, can you give examples of where a plan has led to a change in your management.

……

……

16. Are you involved in any farm assurance schemes?

Examples: Red Tractor, LEAF Marque, Other retailer scheme, LEAF Audit

……

……

17. a. Do you generate any energy on your farm that is used within your business? (*Tick one box):*

☐ Yes ☐ No

If **YES**, please estimate the percentage of your total energy use (other than diesel and petrol) that you generate………….%

b. What type of renewable technology do you have on the farm (if any)? (e.g .Wind, AD)

………

18. a. What area, if any, of your land is certified organic? ....Acres *or* .... Hectares

b. Do you have any land under organic conversion? ....Acres *or* .... Hectares

5.6 Do you currently have an agri-environment scheme agreement? (*Tick one box):*
[Note – NOT including the new 'greening' measures following CAP reform]

☐ Yes *(Go to Q20)* ☐ Yes *(Go to Q21)*

9.4 If *YES* (you have an agri-environment scheme agreement):

In which scheme(s) are you participating and for how long?

………

Were you in another scheme before this?

☐ Yes ☐ No

If YES, for how long? ………………………

c. **What are the main management activities you are carrying out under this/these agreement(s)?**

………

d. **What area (or proportion) of the farm is covered by the agri-environment management activities?** [Note – include rotational options and woodland creation]

………

e. **Does the agreement involve formal cooperation with other farmers?**

☐ Yes ☐ No

(Now go to Question 22)

21. If *NO* (you do not have an agri-environment scheme agreement):

a. **Have you had an agri-environment scheme agreement previously?** ☐ Yes ☐ No

b. **Which scheme(s) did you participate in and for how long?**

………

c. **What were the main management activities you carried out under the agreement(s)?**

………
…

d. **What area (or proportion - % area) of the farm was covered by the agri-environment management activities?** [Note – include rotational options and woodland creation]

………
…

22. What do you consider to be the main activity on the farm that benefits the environment?

………
……

………
……

12.2 Do you feel that any of your farming activities have an avoidable detrimental impact on the environment?

☐Yes

☐No

☐Not sure

Please explain:

………
…

………
…

SECTION E. COMMUNITY AND QUALITY OF LIFE

24. Typically, how much contact (eg face-to-face, phone, email) do you have with other local farmers? (*Tick one box)*

☐	☐	☐	☐
None	Less than once a week	Once a week	More than once a week

If YES (you have contact with other local farmers), in what capacity / context?

………
…

……
…

……
…

25. Typically, how much contact (eg face-to-face, phone, email) do you have with non-farming members of the local community? (*Tick one box)*

☐	☐	☐	☐
None	Less than once a week	Once a week	More than once a week

If YES (you have contact with non-farming members of the local community), in what capacity / context?

……
…

……
…

……
…

26. Typically, how much contact do you have with the individuals, organisations or companies to whom you sell your products? (*Tick one box)*

☐	☐	☐
Less than once a week	Once a week	More than once a week

In what capacity / context?

……
…

……
…

27. a. How important do you feel farming is to the local community?

☐	☐	☐	☐	☐
Essential	Quite important	Neither important or unimportant	Not particularly important	Not important at all

b. Why do you say that?

……
…

………
…

28. a. Have your levels of contact with non-farmers changed over the last five years?

☐ Increased ☐ Stayed the same ☐ Decreased

b. Why is that?

………
…

………
…

………
…

29. Please describe what it is like to be a farmer in 2015

………
……

………
……

………
……

SECTION F. COOPERATING WITH OTHERS

30. Are you involved, either formally or informally, in any of the following forms of cooperation/joint working with other farmers?

	Currently involved	**Previously involved**	**Considering involvement**	**Not involved**	**Do not regard as cooperation /joint working**
Membership of buying group(s)					
Membership of discussion group(s)					
Membership of producer organisation/co-operative(s)					
Membership of trade union(s) (e.g. NFU)					
Commons agreement (any					

type, including AES)					
Environmental management (e.g. joint agri-environment scheme agreement)					
Contract rearing of any livestock – for / by other farmers					
Contract growing of any crop - for / by other farmers					
Short term keep of livestock - for /by other farmers					
Share farming					
Sharing labour					
Sharing machinery					
Swapping manure and straw					
Lending breeding sires					
Other (please specify)					

31. ***Farmers who have never cooperated with others GO TO Q34***

What do you consider to be the most important form of cooperation which you are / have been involved in, AND WHY?

..

..

32. a. Thinking about when you cooperate with others, do you have a preference for formal (e.g. involving payments / contracts) or informal cooperation?

☐ Formal

☐ Informal

b. Why do you say that?

....

33.

a. What are your main <u>reasons</u> / motivations for cooperating with others?

....

....

....

b. In your opinion, what are the main <u>benefits</u> arising from cooperation?

……

……

……

c. In your opinion, what are the main <u>difficulties</u> / problems arising from cooperation?

……

……

……

d. In your opinion, what are the main factors that enable cooperation with others to work well?

……

……

……

e. Have you ever been involved in setting up cooperative activities?

☐ **Yes** ☐ **No**

If YES, what activity and how did this come about?

……

……

(NOW GO TO QUESTION 36)

34. ***(For farmers who have never cooperated with others):***

What do you consider to be the potential benefits, if any, from cooperating with others?:

……

……

35. What do you consider to be the potential problems / difficulties in cooperating with others?:

………

………

SECTION G. PERSONAL INFORMATION

36. What is your highest level of formal education? (*Tick one box)*

- ❐ Prefer not to disclose *(If this box is ticked go to Q38)*
- ❐ School education (left at 16 or before)
- ❐ A' levels
- ❐ Technical qualification (NVQs, BTEC, OND, HND, etc)
- ❐ Degree
- ❐ Post-graduate qualification
- ❐ Other (*Please tell us*) ______________________

37. Was your highest level of education related to agriculture? (*Tick one box*)

❐ Yes ❐ No

38. **What is your age?** ....

Thank you for your co-operation in completing this interview.

Would you be willing to be contacted as part of further research within the SIP project? This might involve taking part in another interview or being part of a discussion group with other farmers. If you agree to take part in further research for the SIP project we may share you contact details with selected members of the project team for the purpose of this research only. **YES**☐ **NO** ☐

Would you like to be kept informed of the results of our research? YES ☐ **NO** ☐

IF YES would you prefer that we contact you by post or email? Post ☐ **email** ☐ **email address:…………………………………………………**