University of Reading

Spatial Patterns in the Sustainability of Beef and Sheep Farming in the English LFA

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Declaration

I confirm that the current work is my own and the use of all material and data from other sources has been appropriately and fully acknowledged.

The empirical Chapters of the present Thesis (Chapter 4, 5 and 6) have been prepared for publication as journal papers with joint authorship of Georgios Vittis, Dr Yiorgos Gadanakis and Professor Simon Mortimer. Chapter 4 and 5 are currently in the stage of review by the referees whereas Chapter 6 will be submitted after the first two have been published.

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Summary

Sustainable development of the agricultural sector has become the leading edge of the agricultural scientific debate and policy making both in the UK as well as in the international level. This has arisen due to the need for an agricultural sector that is continuously able to provide food, generate economic outputs and preserve environmental quality.

This study uses physical and financial farm-level data on farm businesses in the Less Favoured Areas of England, as well as data regarding environmental, weather and landscape characteristics, to create a framework enabling the sustainable development of hill farming systems. Statistical techniques including a Principal Component Analysis (PCA) and a Multiple Linear Regression (MLR) were used to identify drivers of performance within upland farms, whilst mathematical programming methods that regard Linear Programming (LP) modelling were incorporated to study the impacts of farm management, environmental conditions and socioeconomic context. Furthermore, through a spatial analysis within Geographic Information Systems (GIS), this study reveals geographical insights regarding the sustainable development of the uplands, creating knowledge for the design future policy support.

The empirical results highlight a range of parameters that trigger leading or lagging performances relative to farm-level management decisions such as financial dependency and the social characteristics of the farmer as well as inherent landscape characteristics that regard proximity to abattoirs or level of physical disadvantage. Additionally, in examining practices that promote sustainable development, results point out that integration of crop and livestock production systems (ICLS) allows enhanced farm-level performance and sustainability. Moreover, results from the geographical analysis point out the spatial variability of such factors among the regions of Cumbria, Northumberland and the Peak District, highlighting the need for a new agricultural policy that will spatially target support by taking into consideration the potential opportunities as well as the natural handicaps that exist across the various landscapes.

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Abbreviations

AGM: Annual Gross Margin

DA: Disadvantaged Areas

EO: Enterprise Output

FBS: Farm Business Survey

GIS: Geographic Information Systems

Ha: Hectares

ICLS: Integrated Crop and Livestock Systems

LFA: Less Favoured Areas

LP: Linear Programming

LU: Livestock Units

MLR: Multiple Linear Regression

PCA: Principal Component Analysis

SDA: Severely Disadvantaged Areas

PART I

Chapter 1

Introduction

1.1 General background

In England a total of 2.2 million hectares or 17% of the total farmed area is classified as Less Favoured Areas (LFAs) (Harvey and Scott, 2017) and around 4% of the total population in England lives permanently in LFAs (DEFRA, 2011a). The main agricultural activity within hill farming systems comprises grazing livestock production that includes production of sheep and beef cattle. In England, 44% of breeding sheep and 29% of beef cattle are on LFA grazing livestock farms[1].

The English LFAs are nationally and internationally important areas of environmental value with significant biodiversity and natural resources (DEFRA, 2011b). Furthermore, a wide range of public goods and services is provided. For example, 70% of UK drinking water is supplied from upland catchments and significant quantities of carbon are stored within the English peatlands, while potential solutions exist for production of renewable energy (English Nature, 2013a).

The designation of areas as LFAs utilised criteria related to climatic conditions (slow growing season due to low temperatures), lower soil productivity (poorly drained, shallow or stony soils) or steep slopes (slopes greater than 15%) (European Commission, 2005a). A range of constraints for agricultural production emerge from such conditions, resulting in lower yields along with higher production and transportation costs (Harvey and Scott, 2017). The LFAs within the UK are further classified into two distinct

[1] Data from Defra, June Survey of Agriculture and Horticulture, 2013

categories a) Disadvantaged Areas (DAs) and b) Severely Disadvantaged Areas (SDAs) (DEFRA, 2005a). The uplands land classification, conducted by DEFRA (2005a), defines DA and SDA as land inherently suitable for extensive livestock production in which crop production is not greater in quantity than that required to feed the livestock. DA land differs from SDA in that DA is agricultural land of higher quality with better accessibility conditions and generally more options to exploit the potential uses of the land (Harvey and Scott, 2015).

However, the LFA designation criteria do not only reflect economic interests. Lower profitability of farm businesses in the LFAs may potentially lead to reduction or cessation of farming activities and consequently land abandonment along with a sequence of social and environmental risks relative to change in land cover, depopulation and impacts on rural communities (European Commission, 2010, 2005a). For this reason, historically, the EU has provided financial support to hill farmers in order to make their businesses economically viable, while maintaining services and populations in these areas (Acs et al., 2010).

Before 2001, hill farmers in the UK were supported by the Hill Livestock Compensatory Allowance which was paid to farmers according to the number of livestock. Production-based payments used such an approach due to the expected social benefits that would result from sustained food production (Barclay, 2011). However, the latter provided motive for the farmers to increase livestock numbers which caused damage to vegetation and loss of biodiversity through overgrazing of grassland and moorland (English Nature, 2013b).

Accumulation of surplus production was among the central issues for the 2003 CAP reforms which resulted in the decoupling of financial support from level of production. Thus, the Hill Farm Allowance (HFA) and Single Farm Payment (SFP) were introduced (2001 and 2003 respectively) and were provided according to the area used for the grazing livestock production. The latter signified a replacement of headage payments with area-based payments which aimed to address environmental outcomes (DEFRA, 2005b). Furthermore, the implementation of Upland Entry Level Stewardship (UELS) followed in 2010, promoting the maintenance and improvement of landscapes and the environment which as a policy differentiated from the compensating nature that the previous support tools had (Barclay, 2011).

In 2011, DEFRA conducted the Government's review of uplands policy which highlighted the need for encouraging hill farmers to improve the competitiveness of their business through delivering public goods (DEFRA, 2011b). This proposed a series of actions including support of sustainable upland communities and hill farmers, deliverance of public goods and environmental benefits (ecosystem services) from upland environments and supervision of change. Furthermore, it was suggested that farmers should incorporate more efficient agricultural practices to derive a greater proportion of their income through their produce and also deliver broader ecosystems services towards sustainable development.

The policies of Natural England are in line with the Uplands Policy Review goals, aiming to address them through the delivery of Agri-environment schemes (AES) and payments for ecosystem services (PES) to enable a wide range of public goods and environmental benefits within the English uplands (English Nature, 2013a). AES were first introduced by the CAP and aimed towards enhancing the environmental quality through measures that protect or enhance biodiversity, soil, water, air quality and climate change mitigation (European Commission et al., 2017). More specifically, such measures included options for integrated production, reduction of inputs of fertilisers and pesticides as well as management of livestock to provide appropriate grazing regimes that do not put grassland species under pressure while avoiding risks for soil erosion (European Commission et al., 2017). In the context of English agriculture, the current scheme is called Countryside Stewardship. Ecosystem services comprise the variety of benefits derived from the natural environment. These include the production of food, the provision of water and timber, flood and climate change regulation as well as essential underlying processes such as nutrient cycling and soil formation (DEFRA, 2013). PES correspond to a process in which payments are provided to land managers in order to maintain practices enabling and ensuring the provision of a flow of ecosystem services (DEFRA, 2016).

1.2 Rationale

According to DEFRA (DEFRA, 2018a), in 2016, agriculture contributed 0.45% of the total net UK economy and 2% to the UK rural economy. More specifically, in the same year, agriculture generated £23 bn worth of produce, with £15 bn of this amount consumed resulting in a net contribution to the UK economy of £8 bn. Within the generated worth of produce, more than 60% is derived from the livestock sector (£12.7 bn in 2016). Furthermore, the livestock sector occupies 12 million hectares of land which is approximately 70% of the total utilised agriculture area (UAA) (comprising permanent grassland, temporary grassland and areas of common-rights rough grazing). Within the agricultural sector, almost half a million people are employed, which is approximately 1.5% of the total UK workforce. More specifically, with regards to the grazing livestock sector, although it is the least labour intensive (2 workers per farm on average), it employs the greatest number of people in English agriculture (31% of the total English agricultural employment).

The European Commission has recognised that agricultural production within areas that are designated as less favoured is more challenging due to the presence of natural barriers, for which CAP has designed and provided policy support since 1975 (European Commission, 2005a). In a similar context, the UK Government acknowledges these challenges for hill farmers that constrain them from obtaining their full income purely from agricultural production which mainly regards livestock (DEFRA, 2011b). More specifically, they expect all hill farmers to respond to challenges emerging from the natural environment but also from changes in the structure of policy support. Thus, DEFRA intends to assist hill farmers to increase the competitiveness of their businesses through exploiting new opportunities, increasing cost-effectiveness and diversifying production, while providing public goods such as high-quality food and environmental benefits (DEFRA, 2018b). Meeting this target is also discussed within the context of land sharing and land sparing that regard biodiversity-friendly farming practices (former) and increased yield practices (latter) aiming towards environmental (biodiversity) and production outputs (yields) objectives (Green et al., 2005).

Many new challenges arise for British farming in the post-Brexit era (Morris et al., 2017) as new trade and agricultural policies, payments and legislation (plant health and animal welfare standards) will emerge replacing the existing CAP (DEFRA, 2018b). Furthermore, some indirect issues relating to changes in supply of agricultural labour will drastically affect the growth and competitiveness of the sector. In addition to these emerging challenges, hill farms will also have to overcome the harsh conditions of the uplands that relate to remoteness, poor climate and difficult terrain that limit production performance.

Agricultural production within the LFAs plays an essential role in maintaining the cultural character of the uplands while stimulating the local economy, contributing to the maintenance of the upland rural communities (Acs et al., 2010; DEFRA, 2004; Harvey & Scott 2015). Furthermore, the English uplands are nationally and internationally important areas for biodiversity and natural resource value (DEFRA, 2010; English Nature, 2013a). In addition, the LFAs are broadly acknowledged as significant sources of ecosystem services such as provision of food and fibre, supply of water and climate regulation, on which people depend (Battaglini et al., 2014; Bonn et al., 2009; English Nature, 2013a). Thus, it is essential that agricultural land in the uplands is managed in a sustainable manner so that the future goals for production of high quality food and deliverance of multiple ecosystem services will be met. Therefore, hill farmers will have to adopt new management practices that will sustain their farm businesses while preserving the environmental values of the LFAs. Increasing efficiency in exploiting natural resources, production inputs and adopting emerging technologies may provide solutions to increase financial and production performance and at the same time minimise the negative environmental impacts (Finneran and Crosson, 2013; Garnett et al., 2013).

Towards the direction of identifying efficient farming practices, recent literature has attempted to point out particular factors relative to management choices, climate and landscape characteristics that may enhance or hinder agricultural performance (Battaglini et al., 2014; Finneran and Crosson, 2013; Giannakis and Bruggeman, 2015; Goswami et al., 2014; Morgan-Davies et al., 2012; Morris et al., 2017). Giannakis and Bruggeman (2015) investigate for the parameters triggering differentiation of performance examining a set of variables that relate to environmental, economic, technological, policy and farm organisation factors. Through a regression analysis they found that higher age of farmer impacts negatively and higher education level positively on financial performance. Furthermore, they suggest that higher proportion of farm area in LFAs impact negatively on financial performance while higher performances are associated with higher levels of public payments. In a similar context, Flaten (2017) study the factors affecting the continuity of the Norwegian sheep farming systems. A statistical analysis is employed using Principal Component Analysis (PCA) and regression analysis using data of 100 sheep farms derived from the Norwegian Farm Business Survey. With regards to financial performance, which is found to be a strong factor influencing farmers' intentions to continue farming, their study concludes that size of flock as well as experience of farmer affects positively farm performance.

Furthermore, as a sustainable solution for addressing challenges in the development of the agricultural sector emerges the integration of crop and livestock production systems (ICLS) (Duru and Therond, 2015; Martin et al., 2016; Moraine et al., 2016; Sneessens et al., 2016). Among the literature there exist a range of competing definitions of ICLS that differ in that they suggest integration either at regional or farm level. While they both provide benefits, the present study focuses on farm level organisation plans, performance and utilisation of natural resources and thus in the current analysis ICLS refers to different enterprises being integrated at the farm level. Within this context, Sneessens et al. (2016), investigate the effects of various levels of crop-livestock production integration on the sustainability of farming systems at the farm level by examining the different enterprises. They assess the latter using the indicators of profitability, production, N balance, greenhouse gas (GHG) emissions and energy consumption. Through their study, they test the effects of various scenarios of integration within a mathematical model comparing environmental and economic interactions. They conclude that particular levels of integration can increase the levels of sustainability of the farming systems while their effects can be understood in more depth when examining changes in the agricultural land organisation.

The main objective of this research is to construct a holistic framework for the discussion and assessment of the sustainable development of hill farming systems.

Specifically, this study focuses on livestock farms based in the English LFAs and uses data derived from the Farm Business Survey (FBS) in order to a) identify the drivers of financial and production performance that relate to climate, farm-level management decisions and landscape characteristics b) investigate the optimisation of integrated crop-livestock production systems to increase profitability and resource use efficiency and c) study the spatial implications derived from a geographic analysis, investigating spatial patterns in drivers of performance, environmental barriers, constraints on production inputs and leading and lagging performances.

1.3 Scope of the study and Research Questions

The present study attempts to answer three core research questions that relate to the evaluation and enhancement of sustainable development of farm businesses based in the LFAs of England. To address these objectives a range of modelling approaches was developed using methods such as Principal Component Analysis (PCA) and Multiple Linear Regression (MLR) as well as Linear Programming (LP), while Geographic Information Systems (GIS) were also employed to conduct the spatial analysis. Data is derived from the FBS which is a comprehensive dataset providing financial and physical information of farm businesses in England, the Meteorological Office and the Food Standards Agency. The research questions, followed by a description of their content, are presented below.

Research question 1: What are the drivers of financial and production triggering leading and lagging agricultural business performances? -Sub-question: How can such knowledge inform the policy making for developing hill livestock farming sustainably?

The main objective of this research question is to point out aspects triggering leading or lagging farm business performances within the study area. Various socioeconomic and environmental limitations may contribute to underperforming agricultural productivity and profitability.

Environmental circumstances are described both as natural advantages (Robinson, 2009) and constraints for production that influence agricultural performance (Pretty and Bharucha, 2014). However, here the environmental conditions relate more to natural barriers rather than advantages, due to the harsh conditions that exist in the uplands. Furthermore, researchers suggest that the characteristics of the farmer can reveal patterns of trading (Pangbourne and Roberts, 2015) as well as the ability to develop and adopt new strategies of production and management (Van Vliet et al., 2015). The parameter of location is also considered in this context as the characteristics of remoteness, accessibility and proximity to required infrastructure emerge as challenges for the sustainable development of the sector (Dethier and Effenberger, 2012).

The components thought to affect and differentiate the performance of farms relate to the characteristics of the human capital operating them, such as the age and educational level of the farmer, the environmental conditions and climate, and finally the spatial characteristics of each farm business referring to distance from facilities required for processing the agricultural products. In addition, parameters related to the operation of each farm, such as the technology used as well as the specialisation of production, will be considered in order to narrow down aspects that may also potentially impact on the performance of LFA farms.

Research question 2: How can livestock production in the LFAs be optimised to ensure economic viability of hill farming systems? -Sub-question: What are the financial and spatial implications of integrating crop and livestock production?

The central aim of this research question is to examine how the organisation of hill farming systems and utilisation of available resources can be optimised. Specifically, this is accomplished through studying the integration of crop and livestock production systems as a solution enabling the sustainable development of LFA farms.

The rationale of addressing this question is derived from recent literature suggesting that appropriate levels of crop-livestock integration can increase profitability, enabling the sustainable production of food while delivering ecosystem services (Bonaudo et al., 2014; Lemaire et al., 2014). However, there is evidence that there must be particular conditions in order for the ICLS to allow such higher sustainability performances (Veysset et al., 2014). Thus, the present research question examines particular levels of integration between crops and livestock production through constructing distinct optimisation scenarios. The parameters of profitability, N balance, stocking densities and land use change are considered as indicators to examine the effects on sustainability of the hill farming systems.

Research question 3: What does the spatial analysis reveal that is relevant to the sustainable development of the LFA farming systems?

This research question aims to identify policy implications through a geographic analysis of the drivers of performance and the factors that limit agricultural production within the study area. Specifically, the geographic analysis investigate spatial commonality between the above factors to identify areas in which agriculture has higher or lower potentials for future development based on presence of fixed landscape characteristics. Furthermore, the analysis will demonstrate the areas in which ineffective farm management decisions are used, calling for policy interventions to facilitate networks of transferable knowledge.

1.4 Contributions to the literature and decision making

Research literature has attempted to identify factors that affect agricultural production, triggering leading or lagging performances (Morris et al., 2017; Poulopoulou et al., 2017;

Rojas-Downing et al., 2017). A number of studies also have as a goal the identification of policy implications from such findings (Dillon et al., 2016; Merckx and Pereira, 2015; Weindl et al., 2015). Furthermore, of particular interest is the development of specific policy interventions as well as strategies for the sustainable agricultural development that arise from such findings. The present study contributes in the development of this discussion both in the context of creating outputs for scientific literature, as well as in the design of the forthcoming decision making and policy support. Furthermore, this analysis adds value to the research on solutions aiming to accommodate natural handicaps and sustain agricultural production within agricultural systems. This is of significant value and relevance especially in the context of England leaving the EU, which calls for designing new strategies that will enable the sustainable development of the agricultural sector.

Recent literature has pointed out that ICLS can be a solution for the sustainable development of farming systems (Martin et al., 2016; Ryschawy et al., 2017). Through the present research, the effects of integration are studied in detail through the assessment of the application of the ICLS concept in hill farms of England. Furthermore, this study contributes in examining the extent to which LFA livestock farms are compatible with such organisational changes especially from the perspective of suitable types of land use. Additionally, this study contributes to increasing the understanding of the ICLS showing that various rates of integration have different effects on the economic and environmental performances. Moreover, this study demonstrates how the LP modelling proposed by Hazell and Norton (1989) can be used in order to conduct optimisation of farm organisation plans within the agricultural sector of the English uplands.

Finally, this research contributes to the literature and the policy analysis for the sustainable development of the uplands by incorporating a range of factors relative to environmental barriers, landscape characteristics and performance constraints into a Geographic Information Systems (GIS) environment. Various geostatistical techniques are used to examine for spatial variations and commonality across the aforementioned parameters enabling the provision of valuable insights and knowledge. Additionally, to the extent of the researcher's knowledge, this is the first approach to combine a multivariate statistical analysis and a mathematical programming approach into a geographical modelling method within GIS using financial and physical data of UK hill farming systems.

1.5 Structure of the research

This study is organised into three main parts. The first part demonstrates the general background, research questions and objectives, the methodology that is used and a literature review on studies that assess the level of sustainability within agricultural systems. The second part demonstrates the three empirical chapters in which evidence on the assessment and the sustainable development of hill farms is provided. The third part presents the main conclusions derived from this research along with the discussion of the policy implications.

Chapter 2 presents the background of the statistical, mathematical and geographical methods that are employed to construct the modelling of this approach. Specifically, the chapter discusses the statistical background behind Principal Component Analysis (PCA) and Multiple Linear Regression (MLR). Furthermore, a detailed description of the mathematical processes and inputs of the Linear Programming modelling is presented. Moreover, the statistical background of geostatistical processes that take place in the geographic analysis are demonstrated.

Chapter 3 reviews literature on agricultural sustainability studies. The review focuses on the areas of interest that dominate the literature with regards to the three dimensions of sustainability namely, economy, environment and society. Studies evaluating the level of sustainability within agricultural systems are the central aspect of this chapter. Additionally, the review explores the historic development of the debate on agricultural sustainability, identifying under-researched areas. Furthermore, this chapter provides a comprehensive review of studies decomposing variations in agricultural performance, examining the integration of crop and livestock production systems and applying geographical methods in the research of agricultural systems.

Chapter 4 is the first of the three chapters providing empirical evidence on the performance and sustainability of farming systems within the LFAs. The analysis of this chapter is developed in two main stages. The first stage regards the identification of core underlying factors within a large dataset through PCA. The dataset includes variables related to the categories of management decisions, weather and landscape characteristics. Through this methodological step the dimensionality of the initial dataset is reduced, formulating a new set of principal factors. In the second stage of this analysis, these factors are imported into the MLR model as independent variables to examine their explanatory power in variations of financial and production performance.

Chapter 5 studies the optimisation of production plans within hill farming systems through ICLS. In order to address this, an LP model is developed incorporating a range of environmental and economic constraints. The objective of this chapter is to explore potential opportunities that exist within the LFAs and that hill farms may exploit in order to make their farm businesses more sustainable. This enables the study to create a framework of knowledge addressing both the farmers' interests and policy making, highlighting options on diversified production plans enabling economic viability and environmental conservation. The parameters of the modelling relate to profitability, feeding requirements, housing capacity, stocking densities, labour and land use. The methodological approach of this chapter constructs four distinct optimisation scenarios that represent a gradual range of quality of agricultural land. Thus, the effects of variable levels of integration on economic as well as environmental performance are identified.

Chapter 6 suggests that significant evidence and insights are to be derived from a spatial analysis using economic and environmental data. More specifically, this method seeks to identify spatial commonality between findings on drivers of performance and the factors that constrain production within the LFAs. The identification of these spatial factors is carried out in two main stages. The first comprises a geostatistical analysis within GIS in which the data is examined for spatial autocorrelation with the use of Global Moran's Index and then visualised with the use of Hot Spot Analysis. This tool assists the process by estimating statistically significant spatial aggregations of higher or lower values. In the second stage, the scores of the geostatistical analysis are plotted against each other in charts in order to identify clusters that correlate spatially.

Chapter 7 summarises the main findings and of this study regarding the sustainable development of farming systems in the English LFAs. Of essential importance is the discussion of the policy implications that arise from this research, as they may contribute to the development of future policy solutions concerning the uplands. Additionally, the future steps of the research are demonstrated along with the limitations and potential future improvements of the FBS dataset.

Chapter 2

Literature review

2.1 Introduction

Agricultural sustainability is at the forefront of scientific and policy debate, as an enhanced agricultural sector that continuously provides food, resources and services is of essential importance in the face of a growing global population (Velten et al., 2015). Thus, a number of studies have emerged which attempt to assess sustainability and understand the components of sustainable agriculture by examining the state of each of the three dimensions namely, economic, environmental and social. It is argued that within the sustainability assessments, an in-depth understanding of the drivers of sustainability is crucial, otherwise there is the risk of targeting obstacles without considering the underlying triggering factors (Pham and Smith, 2014). Such knowledge is essential for the design of development strategies for the agricultural sector promoting sustainability. In that context, studies have emerged which aim to identify the influencing drivers and constraining factors that generate variations in agricultural sustainability and performance. These factors relate to natural, socio-economic and management backgrounds (Battaglini et al., 2014; Bernués et al., 2011; Finneran and Crosson, 2013; Pham and Smith, 2014). Furthermore, concerning the latter, approaches have investigated various strategic management options and evaluated their impacts on the agricultural sector to enable sustainable development (Bocquier and González-García, 2010; Surahman et al., 2018). Specifically, studies have examined the integration of crop and livestock production systems as a strategy to increase sustainability at the farm level, reducing negative environmental impacts of agriculture, providing ecosystem services and maintaining viable financial conditions (Duru and Therond, 2015; Peyraud et al., 2014). Additionally, with regards to environmental drivers of agricultural sustainability, approaches have highlighted that challenges for different systems vary spatially (O'Sullivan et al., 2015). Thus, policy solutions should account for this geographical variability and design meaningful strategies addressing detailed location-specific environmental issues to target farming systems rather than through the use of broad national approaches (Bignal and McCracken, 2000; Gil et al., 2016; O'Rourke et al., 2016). Towards this direction, relevant studies have conducted geographic analyses to reveal spatial insights and identify policy implications, concerning the distribution of natural handicaps, drivers and constraints on agricultural sustainability (Kourgialas et al., 2017; Straume, 2013; Zolekar and Bhagat, 2015).

In the context of studying and enabling the sustainable development within the LFAs, studies have attempted to provide evidence on policy design that will effectively target and mitigate the natural handicaps of farming in the uplands. A discussion has emerged highlighting the need to redefine the delimitation criteria for future policy support within the LFAs (Eliasson et al., 2010; Kowalczyk et al., 2014). This is suggested as LFAs remain at risk of discontinuation of agricultural activity and land abandonment due to CAP measures that failed to provide effective solutions (Spulerová et al., 2016). Furthermore, approaches have attempted to provide recommendations for revising the funding systems to meet environmental goals (Rudow, 2014) and targeting support spatially to address the heterogeneous natural handicaps (O'Rourke et al., 2016; O'Sullivan et al., 2015) of the LFAs.

All these approaches create vital knowledge associated with the sustainability of agricultural systems, informing farmers, stakeholders and policy makers on the underlying notions while encouraging them to apply this information in practice. In order to address the aforementioned objectives, scientific research concerning agricultural development has incorporated various methods including systematic reviews, statistical analyses, mathematical and geographical modelling. The aim of this chapter is to provide a review of relevant literature that has attempted to evaluate sustainability and create policy recommendations on the sustainable development of agriculture using the above methods.

The remainder of the chapter is organised as follows; the first section provides an overview of agricultural sustainability assessment studies and it consists of two subsections examining the development of the scientific debate and demonstrating review studies. The second section demonstrates the literature that has attempted to identify the drivers of sustainability triggering leading or lagging performances and to explain variations of agricultural performance. Following this, the next section outlines studies that investigate farm organisation plans through the strategic option of integration of crop and livestock production systems as a way of enhancing sustainability. Finally, the last section of this chapter presents applications of spatial modelling in the agricultural sector that attempt to identify spatial implications for the sustainable development of the agricultural sector.

2.2 Agricultural sustainability assessment studies

2.2.1 The development of scientific literature

Sustainability has come to the forefront of scientific debate, policy making and strategic planning (Dethier and Effenberger, 2012; Roy and Chan, 2012). The 'Brundtland report' first introduced sustainability as a goal, classifying it in three core pillars namely, environmental, economic and social (Brundtland et al., 1987). Due to diverse attributes that correspond to the three pillars, relative to biodiversity, soil quality, land degradation, climate change and rural societies (Rivera-Ferre et al., 2013), sustainability remains an ambiguous concept (Roy and Chan, 2012).

In order to assess agricultural sustainability, studies have investigated financial and production performance through the examination of the surrounding systems and the identification of drivers and constraining factors (Fernandes and Woodhouse, 2008; Marconi et al., 2015; Pretty and Bharucha, 2014; Roy and Chan, 2012; Sydorovych and Wossink, 2008; Van Cauwenbergh et al., 2007). Sets of single use or composite economic, social and environmental indicators have been employed as a tool in these methods for the direct or indirect quantification of phenomena that are not easily or directly countable (Mitchell et al., 1995). However, the multifaceted relationships between the environment, economy and society make these approaches challenging (Bossel, 2001).

In a similar context, an ongoing discussion has emerged regarding the development of the way that studies approach agricultural sustainability. Specifically, Fernandes and Woodhouse (2008), point out that even though the discussion on sustainable development generally considers all dimensions of sustainability, studies that focus on them equally remain indefinite. Furthermore, authors report an imbalance in the analysis of indicators that represent the pillars of sustainability, with many assessments focusing more on the economic and environmental and less on the social dimensions (Fritz J. Häni et al., 2007; Ness et al., 2010; Payraudeau and van der Werf, 2005a).

To examine in more detail the developments that this discussion has undergone, the present analysis constructs a citation network in order to facilitate visualisation of the scientific literature pathways. In order to visualise this development, the CitNetExplorer software was employed[2]. This software algorithm uses the full record of articles (Author, source, references and DOI) and calculates the citation connections between articles within particular disciplines (Liu et al., 2013). The estimated citation network often indicates that there is more than one link between the cited studies. Such studies are grouped according to the number of times that they refer to the cited document. Therefore, in case of multiple links, the most dominant in terms of citation rate per article, define the group in which each article is assigned to. These are the links that will be mentioned as direct in this analysis.

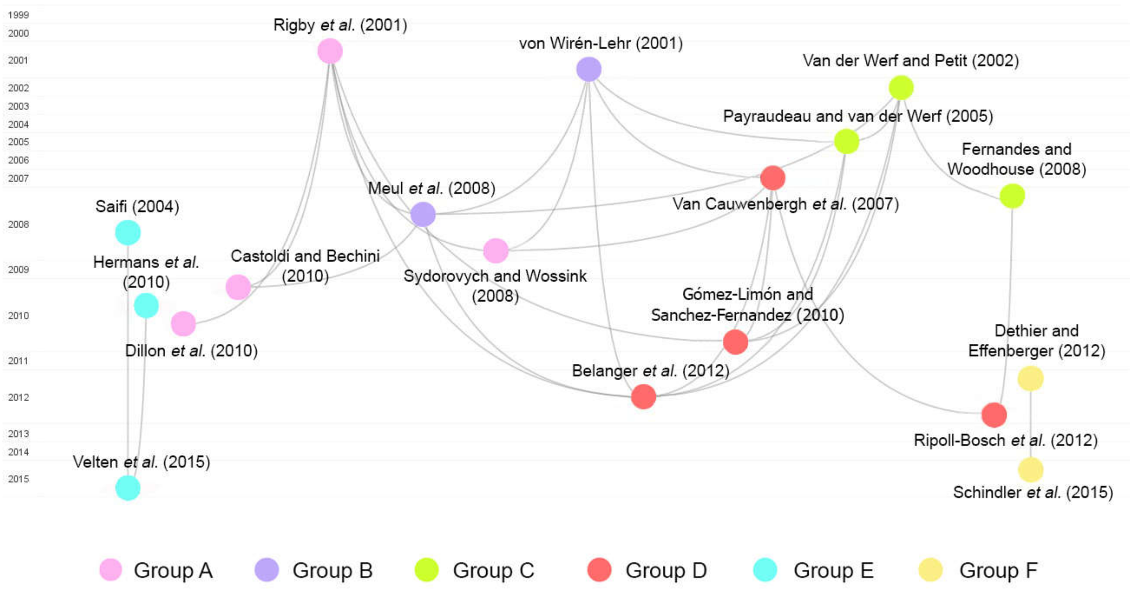
Relevant literature has been extracted through the ISI Web of Science search engine using the keywords of "sustainable agriculture", "environmental sustainability", "social sustainability", "economic sustainability". Results from this search include articles from scientific journals published during the years of 2001 – 2015. Additionally, publications from organizations were considered such as the OECD, FAO, European Commission and the World Bank. The examined studies consider issues of production performance, biodiversity, climate and soil characteristics and finally provision of food and food safety. The derived articles from this search were further investigated to examine whether they fit to the examined objectives by considering the abstracts.

[2] Further information regarding the CitNetExplorer software is available in the following link: http://www.citnetexplorer.nl/

The results from this visualisation are presented in Fig. 2.1. The network presents nodes (articles) and links that indicate the citation connection between them. The constructed network consists of six distinct groups of literature of which four are interconnected with each other.

The beginning of the agricultural sustainability debate was made in the Brundtland Report[3] by the World Commission on Environment and Development where the first induction of the term 'sustainability' (Brundtland et al., 1987) was presented. That term did not relate specifically to agriculture per se, however the components of both were linked. Therefore, the discussion of environmental conservation, economic viability as well as social robustness has come to the forefront of the agricultural debate.

Fig. 2.1 Literature development paths in agricultural sustainability studies



Following the beginning of the agricultural sustainability debate, the next significant stage starts at the early 2000's and is divided by the citation network into four main paths (group A, B, C and D). Additionally, the two more recent groups of E and F are

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[3] This particular report is not projected on the citation network. This is for two main reasons. Firstly, the Brundtland report is a document that was conducted and published by the United Nations which means that it is a document that does not have a DOI. Hence the software is not able to handle such information. Secondly, this report gets cited in several ways (e.g. report of the World Commission on Environment and Development or 'Brundtland report') which does not allow its representation through a single node linking to other nodes- articles. Finally, although the current section considers scientific approaches published in the last fifteen years, Brundtland Report is the most commonly cited source of sustainability as a term, as this was where it was first introduced.

visualised, being independent from the rest of the development knowledge paths. The first four groups are initiated by four key articles (Rigby et al., 2001; Van Cauwenbergh et al., 2007; van der Werf and Petit, 2002 and von Wirén-Lehr, 2001) providing the debate with the general conclusion that multidimensionality emerges as an essential way to approach the agricultural sustainability research. Furthermore, a significant difficulty in combining the various indicators of sustainability is reported by the key articles. These arguments point out essential issues for the debate indicating specific underdeveloped areas within the research and thus, influencing the development of later studies. Specifically, some of the articles (Meul et al., 2008; Sydorovych and Wossink, 2008) point out particular gaps in the relevant research that relate to the social dimension of sustainability.

Group A has as key node the Rigby et al.(2001) study which creates 4 direct links with more recently conducted publications, two of which are common with von Wirén-Lehr's (2001) path. Castoldi and Bechini (2010) is the third node which has an economic-led orientation as it constructs indicators reflecting economic as well as ecological measures of sustainability. On the contrary, the fourth study by Sydorovych and Wossink (2008), has a social orientation as it recognises the absence of a consensus regarding social sustainability within agricultural research. The authors suggest considering the involvement of stakeholders in the agricultural production as an indicator that measures social interests.

Continuing with group B, the key author is Von Wiren Lehr creating a path of one primary link which leads to the study of Meul et al (2008). Similarly, to the key article, Meul et al. (2008) suggest that although a majority of indicators have been considered, there is a lack of studies taking into account the representation of social themes within agricultural sustainability. Within this context, the authors acknowledge all dimensions of sustainability as backgrounds of equal importance and construct a framework examining dimensions of sustainability holistically.

Concerning the development of these two first groups, the research can be classified on the basis of whether it has developed towards a more holistic interpretation or analysed sustainability focusing specifically on environmental, economic or social aspects. Using the latter as a measure of development we can conclude that the three articles by

Sydorovych and Wossink (2008), Van Cauwenbergh et al. (2007) and Meul et al. (2008), introduced a more coherent interpretation, whereas Castoldi and Bechini (2010) focused on economic and environmental issues specifically.

The paper of Van der Werf and Petit (2002) constitutes the beginning of the third group (C) which presents two direct links. The authors in that study attempt to evaluate and review indicators-based models that assess the environmental impacts of agriculture in reference to achieving sustainability. The study points out the importance of considering the spatial scale of analysis within research. In fact, this highlights the innovation of that group since both of the links adopt this feature in their approach. More specifically, Payraudeau and van der Werf (2005) emphasize the holistic interpretation of sustainability's dimensions, as well as investigation of the spatial level of analysis, as it has been acknowledged that different spatial scales acquire different planning and implementation. Similarly, Fernandes and Woodhouse (2008) identify indicators within the environmental, economic and social dimensions of farming systems. Their study also attempts to classify those criteria according to the various spatial scales of analysis (farm, local and regional).

Group D seems to be closely related and affected by the first two groups (A and B). The publication of Van Cauwenbergh et al. (2007) is the key node of this group and suggests that it is essential to consider and integrate all pillars of sustainability as well as to address their interconnections. As a result, the study creates a framework for sustainable agricultural production which takes into consideration all sustainability dimensions proposing criteria and indicators that reflect environmental, economic and social interests. Later on, the citing articles of Gómez-Limón and Sanchez-Fernandez (2010), Bélanger et al. (2012) and Ripoll-Bosch et al. (2012) follow the same trajectory with the cited study. More specifically, these articles emphasize the holistic examination of sustainability's dimensions. In addition, they investigate the interactions between the various factors of agricultural production.

The last two groups E and F appear not to have a connection, neither with the rest of groups or between them. However, their findings coincide by means of acknowledging that the literature provides a holistic view of sustainability examining all dimensions and considering their interrelations. These two groups appear to be the more recent which may provide an explanation for the contrasting findings in comparison to the remaining groups. In fact, this finding indicates that awareness has been raised through previous studies on the underdeveloped parts of the literature which led in more recent studies to adopt a more holistic point of view.

2.2.2 Studies reviewing agricultural sustainability assessments.

Of essential importance for the current approach investigating agricultural sustainability studies, is the cross examination of the findings outlined in the above section. This is achieved through the analysis of conclusions that relevant studies have suggested in reviewing agricultural sustainability assessments. Further to that, the review studies reveal the methodological approaches that relevant analyses have incorporated to assess sustainability and identify its drivers.

Roy and Chan (2012), conducted a review on agricultural sustainability assessments in the context of agricultural intensification in Bangladesh. The study reviews the literature using secondary data including articles, books and research reports regarding agricultural sustainability and development. The authors analyse the selection criteria of indicators with regards to achieving agricultural sustainability. In order to achieve that, the study examines the allocation of indicators within the pillars of sustainability. The findings of this review study propose an integrated set of indicators that covers equally economic, environmental and social aspects providing a holistic evaluation of sustainability.

Payraudeau and van der Werf (2005), review assessments for environmental impacts of agriculture. The study grouped the examined literature based on the various methods used (Linear Programming, Multiagent System Approaches, Life Cycle Analysis) which in turn reflect the objectives of each approach (social, economic, environmental). Findings suggested that such methodologies reflect the complexity of farming systems which call for adopting integrated approaches providing holistic methods for sustainability assessment. Specifically, a holistic view could be better addressed with the use of Life Cycle Analysis or Multiagent Systems approach.

Pham and Smith (2014), attempted to review drivers of agricultural sustainability in developing countries using approaches that employ agro-environmental, economic and social indicators. Methodological approaches of the reviewed studies include principal component analysis, regression analysis, geographical analysis and multicriteria decision making analysis. The study points out that there is a need for incorporating the drivers of agricultural sustainability in addition to the use of indicators and also consider the interactions between them. Furthermore, the study highlights the spatial scale of the analysis as an essential principle within the agricultural sustainability assessments. According to the results, indicators of higher spatial scale function differently in lower scales (from regional to farm level). Finally, the study constructs a framework to assess agricultural sustainability enabling a balanced interpretation of sustainability considering economic, environmental and social backgrounds.

Schindler et al. (2015) review methods that evaluate sustainability of farming systems using indicator and participatory based approaches, multiple goal linear programming and multicriteria analyses. The study groups selected scientific articles according to the objectives of each approach, the representation of dimensions of sustainability and level of stakeholder involvement. Regarding the representation of the sustainability dimensions the study considers the number of indicators with each dimension. Through this analysis it was found that several approaches have focused more on the economic and environmental aspects while the social dimension was represented to a smaller extent.

Velten et al. (2015), review approaches developed within the discussion for agricultural sustainability. The study identifies differences in the examination of various objectives among the dimensions of sustainability. A clustering of the analysed literature is proposed whereas six groups are identified reflecting the main objectives. These refer to anthropocentric, productivity aimed, systems thinking, comprehensive and knowledge and science approaches. According to the findings of this study, non-production-related social and environmental issues have received less attention and consideration within the scientific literature.

In conclusion, the methodology of agricultural sustainability studies, is predominantly based on the use of indicators as well as simulation modelling (mathematical programming), which in turn highlight the particular areas of interest within the pillars of sustainability. Studies reviewing the assessments most commonly conduct classifications of the considered indicators into three groups, economic, environmental and social. The examined review studies find that research has considered economic and environmental backgrounds to a greater extent, while the social aspects have been considered less. For this reason they conclude that there is an emerging need for frameworks and approaches that will provide a holistic view on the aspects of sustainability.

2.3 Drivers of sustainability within agricultural production systems

Following the examination of agricultural sustainability assessments, as discussed above, it is essential to obtain a thorough and holistic understanding of the factors affecting agricultural sustainability to avoid the risk of focusing merely on negative indications without addressing the underlying factors. For this reason, a range of methods and techniques has been employed by the relevant literature in the agricultural sector; in an effort to decompose the variability of performance that exists amongst agricultural production systems. Such approaches examine financial and production performance explaining differentiations that result either from farm-level management choices or inherent environmental constraining factors (Giannakis and Bruggeman, 2015). Among the factors that relate to farm-level management decisions, literature examines the social characteristics of the farmer (Battaglini et al., 2014; Morgan-Davies et al., 2012), labour allocation (Goswami et al., 2014), adoption of technology (Hansson, 2007), self-sufficiency of production inputs (Kilcline et al., 2014), specialisation of production and dependency on public payments (Karlsson and Nilsson, 2014; Kazukauskas et al., 2014). On the other hand, with regards to landscape-fixed characteristics, research considers the parameters of climate (McCann et al., 2010), accessibility and remoteness (Darnhofer et al., 2010; Krishna and Veettil, 2014) and altitude (Kowalczyk et al., 2014).

Goswami et al. (2014) conducted an analysis of factors that trigger heterogeneity in agricultural performance of farming systems in India. In the analysis, a wide group of variables was considered including social (farmers' social characteristics and objectives), managerial (allocation of labour, adaptation in new technologies) and physical (climate, accessibility and remoteness) backgrounds. They employed two consecutive multivariate statistical techniques, namely a PCA and a Cluster Analysis (CA). According to Goswami et al. (2014), access and control over natural resources are the most important factors affecting differentiation of performance while education of farmer has found to be not important in this economic classification. On the other hand, Morgan-Davies et al. (2012) applied the same statistical methods (PCA and CA) and showed that the level of education of the farmer is positively correlated to the performance of Scottish hill farms. Similar findings are demonstrated by Giannakis and Bruggeman (2015) and Hansson (2008). A potential explanation for the contrasting results may be that the studies examine different case studies which differentiate in terms of performance and the corresponding affecting factors (Giannakis and Bruggeman, 2015).

Furthermore, with regards to the social perspective, the age of the farmer is a factor that has been considered in the research of determinants of agricultural performance. Specifically, the approaches conducted by Finneran and Crosson (2013), Kelly et al. (2012) and Lordkipanidze and Tauer (2000), used efficiency analysis employing a data envelopment analysis (DEA) to investigate associations of economic efficiency with management and demographic features. Their methods suggest conflicting results as Kelly et al. (2012) and Lordkipanidze and Tauer (2000) found a negative relationship between age and performance (technical efficiency) (in Lordkipanidze and Tauer it is positive until the middle age). However, in Finneran and Crosson (2013) there is no statistically significant relationship between the demographic variable of age and income efficiency. Although results among the various studies are controversial, Ondersteijn et al. (2003) suggests that age correlates with experience to a degree, hence differences in farmers' age may explain variation in agricultural performance. In addition, the study of Lordkipanidze and Tauer (2000) indicates that this relationship is also affected by the adoption of technologies, which according to their study is highest in the middle ages coinciding with the highest positive relationship between age and performance.

Technology adoption is another factor that may largely affect the performance of farms. In particular, according to English Nature (2006), technological advancements have changed the feeding and delivering methods, affecting the wintering practices in livestock hill farming. Moreover, higher adoption of technology has been found to lead to higher levels of profitability in the context of allocation of production inputs (labour, capital) (Hansson, 2007). In a similar context, Bernués et al. (2011) points out that technologies such as Global Positioning System (GPS) or Geographic Information System (GIS) applications for grazing management can reduce farm workload and optimise the distribution of livestock on grasslands.

Self-sufficiency of forage area and dependency on external inputs for feeding stuffs are considered as parameters that affect the financial performance of farms. Kilcline et al. (2014), attempted to identify the underlying factors driving concentrate feed usage on Irish farms within the context of management decisions and price effects. The study employed a regression analysis using panel data methods to examine for such drivers. Their results suggest that grass and concentrates as feeding stuffs have a substitutable relationship which can enable greater cost effectiveness when grass is increased while the demand for concentrates decreases. However, it has been suggested that farmers tend to increase the supply of concentrates fed to livestock in order to increase productivity which in turn leads in a decrease of grass as a feeding type (Mena et al., 2017). In the context of hill farming this implies a dependency on external supplies for concentrates as it is less common to cultivate land in the uplands. Thus, economic viability of hill farming relies heavily on cereal prices fluctuation. Within this context, Mena et al. (2017), examine options for the sustainable development of grazing systems in mountainous areas using the two stage multivariate analysis of PCA and CA. According to their findings, productivity can increase adequately without having to increase the supply of concentrates significantly. Thus, they highlight that attempts to reduce purchased feeding stuff would improve profitability drastically. Similar findings and recommendations are presented in Dillon (2007), Finneran and Crosson (2013), Finneran et al. (2012), Ripoll-Bosch et al. (2012) and Toro-Mujica et al. (2015) who found that high levels of concentrate feed use are a significant barrier to income efficiency of livestock farm businesses.

According to DEFRA (2010) and Natural England (2009), continuity of upland farming systems depends on the family intentions to continue the farming activities. Glauben et al. (2009) investigate the drivers of probability of succession in German family farms. Their analysis includes a two stage econometric approach that included a Probit model and a Linear Regression analysis. Their findings suggested that more profitable farms are significantly more likely to have a family-member successor. More specifically, Cavicchioli et al., (2015) through a Probit regression analysis found that the characteristics of the farm in a general context do not affect succession. Rather, intra-family succession was found to be greatly dependent on whether sales had increased during the past. Furthermore, similar studies have found a positive relationship between succession and on-farm diversification (Sottomayor et al., 2011) and an increased likelihood of disinvestment and passive management attitudes in the cases that no successor exists (Wheeler et al., 2012).

Public payments have been an essential component for the economic viability of grazing livestock systems in the LFAs. According to Harvey and Scott (2015), the Single Farm Payment (SFP) along with Agri-Environment payments account for more than a third of the total revenue of farm businesses in the English uplands. A number of studies have attempted to assess the financial implications derived from public support, suggesting contrasting results (Gelan and Schwarz, 2008; Karlsson and Nilsson, 2014; Morgan-Davies et al., 2012). Acs et al. (2010), modelled the effects of decoupling the direct payments as well as removal of payments on hill farms within the Peak District National Park in northern England. Their analysis used an LP modelling method to examine for such impacts. According to their findings, decoupling causes reduction of the stocking rates while the removal of SFP would lead to negative farm incomes and land abandonment. Similarly, Morgan-Davies et al. (2012) suggest that the area-based payments that replaced production-based support triggered decreasing numbers of livestock and reductions in productivity in a broader context. Kazukauskas et al. (2014) examined the same effects by employing a MLR method. Their findings suggest that decoupling of direct policies had significant positive effects on farm productivity while triggered higher levels of specialisation of production. A possible explanation for these contrasting results is that more recent studies allowed more time for the farmers to adapt and the impacts to stabilise enabling the interpretation on a longer-term context.

Concerning weather characteristics, research has suggested that it is likely that climate factors impact negatively on the growing patterns and quality of pasture (Chapman et al., 2012) as well as the grazing of livestock, especially in the context of climate change (Henry et al., 2012; Rojas-Downing et al., 2017). McCann et al. (2010) investigated factors related to the mortality and morbidity of dairy cattle in England and Wales. Their methodology incorporated a MLR analysis and developed a series of spatial models with the use of GIS. According to their findings, the climate variables of rainfall and temperature are significant drivers of livestock morbidity. In relation to the latter, Giannakis and Bruggeman (2015) suggest that forthcoming agricultural practices should be more adaptable to the climate change challenges and adopt mitigating strategies that will enhance climate resilience.

Landscape characteristics relating to altitude and slopes have been examined as potential determinants of agricultural performance. Ruíz-Guevara et al. (2018) studied the effects of different altitudes on livestock farms technology and profitability. In order to address these, they conducted a one way analysis of variance examining performance in three different zones of altitude. According to their findings, farm businesses located in the middle and lower zones estimated higher indicators of performance in comparison to the farms of the upper altitudinal zone. Moreover, Charlier et al. (2016), conducted an analysis of morbidity factors for livestock. They found that livestock located on landscapes with higher slope, have higher levels of exposure in certain diseases but this declines faster, as a rate, in herds that are based in higher altitude.

2.4 Investigation of farm - level organisation plans to enhance agricultural sustainability

Studies have highlighted the significance of farm structural change for developments within the agricultural sector and its impacts on agricultural sustainability (Espinosa et al., 2016; Mandryk et al., 2012). Integrated crop and livestock production systems (ICLS) have been examined as a strategy for developing agricultural systems sustainably (Dumont et al., 2013; Garrett et al., 2017) either at farm or regional level (Moraine et al., 2017). ICLS are designed farming systems comprising of spatial and temporal interactions between crop and animal production (de Moraes et al., 2014). Positive impacts can be identified through the implementation of ICLS among the three dimensions of sustainability (Martin et al., 2016; Thornton and Herrero, 2015) while the provision of ecosystem services is enhanced (Moraine et al., 2017). Specifically, ICLS allow for higher efficiency of external production-input use through allocation of resources among the crop and livestock enterprises (Bell et al., 2014; Botreau et al., 2014). Moreover, ICLS enable interactions among various land use systems which make agricultural ecosystems more environmentally efficient in terms of nutrient cycling, enhancing soil quality and biodiversity (Lemaire et al., 2014). With regards to the social dimension, Martin et al. (2016) found that integration on a regional level delivers wide social benefits. These include the collective empowerment of farmers through participation in workshops with multiple stakeholders, consultants and researchers.

In an attempt to evaluate these effects and contribute to the decision making process, recent literature incorporated the use of mathematical techniques and specifically LP modelling. Gameiro et al., (2016) developed an LP model to examine the potential financial impacts that would emerge from integration of crop and livestock production activities. The study investigated a Brazilian dairy farm business. The model consists of an objective function that maximises farm profitability according to a set of constraining factors relative to production-associated costs, land, labour, water consumption and application of fertiliser. According to their findings, higher levels of integration corresponded to greater profitability and decreased levels of fertiliser application. However, arable crops delivered greater profits which in turn triggered a decrease in the livestock production, since farmers chose to sell the crops rather than use them as feed for their livestock.

In a similar context, Sneessens et al., (2016) assess ICLS, examining in detail the particular implications for sustainability from various scenarios of integration. Such scenarios represented various types of organisation between crop and livestock production systems. The analysis employed a mathematical programming method that maximised annual gross margin according to a range of constraining parameters. The findings indicated that although ICLS allowed for more sustainable performances, the organisation of crop and livestock triggers trade off relationships between the dimensions of sustainability. The authors concluded by suggesting that future policies should have an in depth understanding of the crop-livestock organisation effects and promote the adoption of ICLS.

Within this context Garrett et al. (2017), assess the extent to which public policy favours and promotes the adoption of ICLS in the United States, Brazil and New Zealand. Their analysis finds that the least favourable conditions are provided in the United States. They propose that if the implementation of ICLS is desired, then future policies should change towards the direction of providing more incentives for reducing pollution as well as fewer restrictions on land use allocation (presence of livestock in crop areas). More specifically, Ryschawy et al. (2017) suggested that agro-environmental measures could favour crop and livestock integration through incentives supporting farm-level feed self-sufficiency and reduced application of mineral fertilisers. Furthermore, findings of relevant research (Asante et al., 2017) highlight that forthcoming policy tools should invest in educating farmers as well as in providing assistance through established networks in the process of implementing integrated production systems (Gil et al., 2016).

However, findings from relevant approaches point out that the adoption of ICLS is influenced by labour availability, as they may require greater workload (Lemaire et al., 2014; Poffenbarger et al., 2017), local supply chain infrastructure (e.g. storage plants, production-input suppliers) and financial capital to invest in the new production systems (Garrett et al., 2017). Within this context, Gil et al. (2016) attempt to identify the factors affecting the farmers' decision to adopt integrated production systems. Their method examined farming systems based in Brazil incorporating a multiple linear regression analysis. According to their findings, higher availability of financial capital, access to knowledge and information and supply chain attributes (e.g. presence of slaughterhouses or storing and processing facilities) are drivers of adoption of integrated production systems. Similarly, Asante et al. (2018) attempted to highlight the determinants of diversification within integrated crop-livestock systems. Their study examined farming systems in Ghana incorporating a two-step regression model. Their findings indicate that diversification of crop production systems was affected by the access to production inputs (tillage equipment, fertiliser) and good infrastructure (road network). Furthermore, diversification of livestock production was affected by the same factors as the crop and also distance to market.

Although ICLS have been claimed to provide a solution for the sustainable development of farming systems (Gil et al., 2016), there exist a range of factors that have discouraged farmers from adopting them (Veysset et al., 2014). Within the economic and political framework, historically, mass-production incentives promoted the development of economies of scale which in turn favoured specialisation of production and increased farm sizes (Ryschawy et al., 2013). Furthermore, farm structure and knowledge of the different dynamics between crop and livestock systems is another issue as many farmers lack the skills and information (Martin et al., 2016). On the other hand, adoption of ICLS is also subject to feasibility of landscape and climate of each region (Byrne et al., 2010). In areas with fair conditions, cash crops are preferred due to the high-yield potentials (Gil et al., 2015), while areas with harsher conditions do not allow cultivation of land. This explains why ICLS are to be maintained in intermediate areas, in which crop production is feasible but does not result in high yield production (Bonaudo et al., 2014).

2.5 Applications of spatial modelling in the agricultural sector

Agricultural sustainability studies have highlighted that, agriculture is inherently a spatial phenomenon in which influencing factors such as soil conditions, climate and topography vary across space and thus, agricultural and environmental modelling should incorporate spatial methods (O'Sullivan et al., 2015; Peeters et al., 2015). A number of approaches have been developed with the use of Geographic Information Systems (GIS) attempting to contribute in the analysis of agricultural planning and the design of policy tools. Studies have developed spatial models to explore nitrogen (Mueller and Sassenrath, 2015; Paz et al., 2009; Franzen in Pierce and Clay, 2007) and water resources management (Johnson, 2009; McKinney and Cai, 2002), map ecosystem services supply (Burkhard et al., 2012; Chen et al., 2009; Troy and Wilson, 2006; Zheng et al., 2016), study land use change (Nguyen et al., 2015; Pilehforooshha et al., 2014) and land suitability (El Baroudy, 2016; Zolekar and Bhagat, 2015), gain knowledge on sustainable intensification practices (Navarro et al., 2016) and examine the spatial distribution of returns from agriculture (Bateman et al., 2008; Bryan et al., 2009b; Marinoni et al., 2012).

Shumway et al. (2012) conduct a spatial analysis of nitrogen management practices within agricultural production. Their methodology incorporates a GIS tool enabling the identification of hot spot areas along with the identification of practices that increase nitrogen (N) use efficiency. Results from these simulations point out the adoption of crop rotating techniques, specifically the production of soy beans and cotton, as a potential measure to decrease nitrate leaching within the study area. Similarly, Paz et al. (2009) assess the N losses to the environment from agricultural production examining the region of Valencia. The assessment develops a spatially explicit N index within the GIS environment. The findings suggest that specific N management practices can be applied in specific areas that have higher leaching potential towards water and air quality improvement.

In a similar framework, Asadi et al. (2007) attempted to evaluate the groundwater quality incorporating the methods of remote sensing and GIS. More specifically, the biochemical characteristics of water samples was determined and then imported into the GIS software to produce maps of the spatial distribution of water quality parameters. Their study examines the findings in reference to land use change due to expected associated impacts on water quality (Mehdi et al., 2015). The findings comprise of a range of areas within the case study in which water quality is poor due to presence of various factors such as decay of organic matter, solid waste dumping and agricultural practices.

Studies have considered the parameter of land use in more detail examining feasibility of agricultural production within the rural landscape. Specifically, Nguyen et al. (2015) develop a GIS-based multicriteria analysis (MCA) of land suitability, taking into consideration the major components of agro-ecological principles, environmental impacts and socio-economic feasibility. Their method points out the potential expansion zones for the cultivation of rubber within the studied province considering social, economic and environmental feasibility. In a similar context, Feizizadeh and Blaschke (2013) study the optimal land use allocation for agricultural production within the Tabriz County in Iran. Through a similar methodology, they develop land suitability maps indicating the appropriate agricultural land use according to a range of factors relating to soil characteristics, climate and water supply. Furthermore, Peng et al. (2014), assess the suitability of spatial allocation of livestock farming employing GIS methods. Their study considers environmental and topographical limiting factors that relate to soil fertility, proximity to surface water, slope and access to transportation networks. Based on these, their findings indicate the particular types of land that are suitable for livestock farming within the area of study. In a similar context, Pilehforooshha et al. (2014) incorporate a range of methodological steps including a GIS raster analysis to investigate how environmental and economic types are allocated within the available agricultural areas. The study highlights the importance of incorporating GIS as it is able to identify areas that are more vulnerable to soil degradation which could not have been identified without the use of GIS analysis.

A part of the recent literature has attempted to examine the spatial variability of agricultural and environmental components using spatial cluster analysis. More specifically, approaches have incorporated spatial methods to investigate productivity potentials, crop disease and soil fertility (Aggelopoulou et al., 2013; Perry et al., 2010). Peeters et al. (2015), evaluated the spatial autocorrelation of orchard data employing a hot and cold spot analysis (clusters of high and low values). Their methodology uses the method of Getis-Ord Gi* statistic which analyses spatially-related trends within the features of spatial data (further discussion on this method is presented in Chapter 3). Furthermore, the study uses the non-spatial method of *k*–means clustering and combines it with the spatial clustering. Their results indicate that the non-spatial clustering methods produce more irregular zones while the proposed combination can improve the quality of the spatial clustering estimations. Ding et al. (2015), developed a similar methodology to investigate spatial and temporal aggregations of environmental pollution incidents in China. Their analysis enabled the identification of particular spatial aggregations of pollution within the river delta regions of Pan Yangtze and Pan Pearl while also their dynamic development was highlighted.

With regards to implementing economic returns from agriculture in spatial analysis, Marinoni et al. (2012), developed a methodology to map agricultural profit within the rural space of Australia. To address this, they gathered information relative to production revenue and costs for inputs, land use and remote sensing data which are then visualised with the use of GIS. Their approach suggests that the proposed system may contribute significantly to the design of future land management and economic scenarios towards the assessment of agricultural profitability. Similarly, Bryan et al. (2009b), mapped the spatial distribution of economic returns from agriculture with respect to the use of land and water resources. The method incorporates a profit function which is flexible to examine the implications of several scenarios such as resource degradation, price and availability of production inputs. Findings from this analysis demonstrate that there is significant variation of agricultural returns to land and water resources.

However, some inherent uncertainty and error relies within such modelling approaches (Bryan et al., 2009a; Marinoni et al., 2012). Specifically, two major limitations exist relating to mapping uncertainty and estimation uncertainty (Bryan et al., 2009b). More specifically, there are certain limitations to the spatial estimation of yields and costings due to the heterogeneity that exists within larger scale geographical areas (Bryan et al., 2009b; Hochman et al., 2012). Additionally, estimation uncertainty occurs as economic parameters such as fixed and variable costs are significantly variable across space and time while depend largely on management practices (Finneran et al., 2012; O'Rourke et al., 2016). Furthermore, it is not possible to entirely capture such variations within a large scale geographical framework that utilises several commodities.

2.6 Summary

The present chapter has presented and reviewed literature on agricultural sustainability to demonstrate the knowledge development paths and the methodological approaches that have been employed to assess and enhance sustainability within the agricultural sector. Through the literature review of this chapter it was found that studies assessing agricultural sustainability have focused in identifying the drivers of agricultural sustainability and performance, considered and studied the spatial dimensions of agriculture and examined strategies that may provide sustainable solutions for the sector.

With regards to identifying factors affecting sustainability and the performance of farming systems, recent literature has examined parameters relative to farm-level management decisions (such as labour allocation, technological adoption and the social characteristics of the farmer), as well as fixed landscape characteristics (such as topography and climate). The most common method to examine this was found to be the use of factor analysis and specifically PCA and CA (Goswami et al., 2014; Mena et al., 2017; Morgan-Davies et al., 2012). Furthermore, regression analysis modelling has been frequently used in the examined literature as a tool to investigate the explanatory power of considered parameters in variations of performance (Cavicchioli et al., 2015; Glauben et al., 2009; Kazukauskas et al., 2014; Kilcline et al., 2014; McCann et al., 2010).

Even though the two aforementioned methods serve similar purposes, PCA and CA as a combined method has the capacity to firstly reduce the dimensionality of a dataset (PCA) and then group the principal components (CA) on dimensions explaining most of the variance. On the other hand, MLR is incorporated not as a clustering tool but rather as a method that explores associations between a dependent variable and some other explanatory variables. Additionally, studies have incorporated DEA techniques to identify factors affecting sustainability as well as economic and environmental efficiency of agricultural systems (Finneran E. et al., 2012; Kelly et al., 2012; Lordkipanidze and Tauer, 2000).

Concerning the examination of agricultural strategies, literature has pointed out that ICLS may provide a solution for the sustainable development of the sector (Dumont et al., 2013; Garrett et al., 2017). To examine this in more depth, studies have attempted to evaluate the effects of ICLS implementation with the use of efficiency analysis (Asante et al., 2017), while also investigated for the determinants of ICLS adoption, employing regression analysis (Asante et al., 2018; Gil et al., 2015). Furthermore, to design the structure of the farms under ICLS, research has incorporated LP modelling to optimise land use allocation considering physical endowments and production constraints (Gameiro et al., 2016; Sneessens et al., 2016).

Finally, many studies have acknowledged that spatial aspects are integral to agriculture and thus, they have been considered in a part of the research for the sustainable development of farming systems. GIS has been used frequently as a modelling tool in order to contribute to the analysis of sustainable agricultural planning and policy making. Applications for land use planning and land suitability have incorporated MCA modelling within the GIS environment to identify areas suitable for various land uses. Furthermore, spatial clustering analysis has also been developed through hot and cold spot analysis that uses the Getis-Ord Gi statistic.

In conclusion, within the research on agricultural sustainability there exist some well-established methodologies. This chapter presented and reviewed these methods that have been used to identify drivers of agricultural sustainability and performance (Chapter 4), create implications on strategies for the sustainable development of the sector (Chapter 5) and examine the spatial implications within the examination of environmental and economic performance of farming systems (Chapter 6). The central aim of this chapter was to present the development of knowledge paths of the agricultural sustainability debate along with the methods that have been used within the agricultural studies.

Chapter 3

Methodology

3.1 Introduction

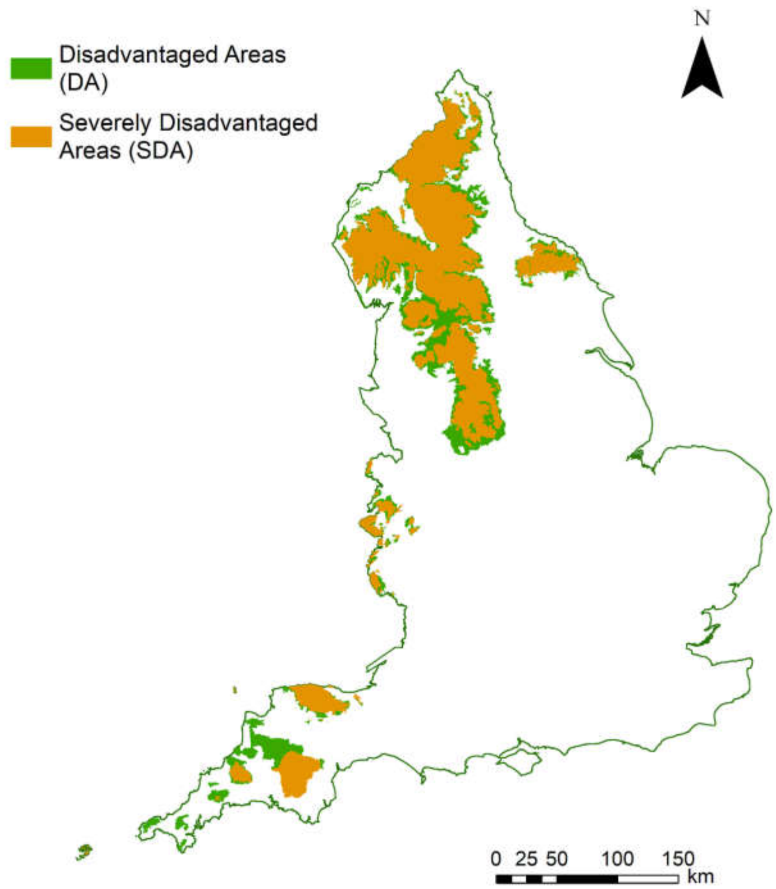
The present research consists of three main research questions and in order to address them, three core methodological steps are developed. For the first question, that regards the identification of factors triggering leading and lagging performances, a quantitative approach is developed conducting a PCA and a MLR. The second question, that examines the optimisation of ICLS incorporates a LP method. Finally, for the third question, that investigates for spatial implications, geostatistical methods through Geographic Information Systems (GIS) are used.

This chapter is organised in five sections. Section 3.2 and 3.4 present the theoretic background of the PCA and MLR respectively, in the context of using them as tools to categorise variables into major components and then evaluate their contribution to the total variation (Singh et al., 2016). In Section 3.5, the theory behind mathematical programming is discussed providing knowledge on the way that a linear function can be optimised considering a vector of constraining parameters that exist within the environment of a problem (Kaiser and Messer, 2011). Section 3.6 presents the theory behind the spatial clustering methods of Global Moran's Index and the Getis-Ord Gi statistic within the ArcGIS software. Finally, Section 3.7 presents the sources of the data that has been used in the analysis and the characteristics of the study area.

3.2 Study area and data sources

The study area of this research comprises of the Less Favoured Areas (LFAs) of England (Fig. 3.1). The English LFAs consist of an area of 2.2 million hectares which is spread across North, West and Southwest regions of England (Harvey and Scott, 2015). In terms of the landscape, the elevation ranges from 50 m to 950 m (μ = 313 m, SD = 160 m). The LFAs are classified further into two distinct categories that of Severely Disadvantaged Areas (SDA) which are more environmentally challenging areas and Disadvantaged Areas (DA) (DEFRA, 2010). The designation of areas as less favoured reflects difficulties in farming due to poor climate and terrain and lower productivity soil which lead in lower yield, higher production and transportation costs (Harvey and Scott, 2015).

Fig. 3.1 Map of the Less Favoured Areas (LFAs) of England with the categories of DA and SDA.



For the analysis of the three empirical chapters of this research (Chapter 4, 5 and 6) a range of data sources has been used in order to obtain essential information. A large part of the examined data of this research was derived from the Farm Business Survey (FBS) dataset (DEFRA 2014a, 2014b; Duchy College 2014, 2015, 2016). The FBS provides comprehensive data regarding financial, physical and environmental information for farm businesses in England. All FBS variables that have been used in the analysis are presented and discussed in the empirical chapters while also their descriptive statistics are provided. In the context of the current analysis, permission was requested and provided to use the FBS variables. More specifically, a confidentiality agreement was signed to prevent mapping techniques from revealing the identity of the farmer. Moreover, projections have been made in such way that it is not possible to link any specific individual with the results of the current approach. Although FBS provides information on farm businesses based in Wales as well, the current analysis is combining data from further sources (described below) which affected the decision on the spatial extent of the analysis. Additionally, the derived subset of farm businesses based in England regard a representative and adequate data sample that spreads across the whole study area.

Furthermore, the present analysis examined for the importance of climate conditions on the variations of agricultural performance. To account for this, data was extracted from the Met Office historic climate records datasets (Met Office, 2017). Regarding the data derived from Met Office, no special permission was required in order to use and plot the data. Definitions and descriptive statistics for the climate variables are presented in Chapter 4. Additionally, in the same chapter, data was derived from the Food Standards Agency (FSA) to account for the parameter of remoteness using the distance between farm businesses and the closest abattoir. This data was derived from the section presenting the list of the FSA approved food establishments that is available without special request or permission to get access and use.

Finally, in order to conduct the geographic analysis, geographic information data such as shapefiles and base maps were derived from a range of data sources including the

MAGIC map tool, the EDINA Digimap and the Ordnance Survey (OS) open data[4]. To obtain these datasets registration is required whereas data is available upon request to obtain access.

3.3 Principal Component Analysis

The purpose of Principal Component Analysis (PCA) is to reduce the dimensionality of a large data set constructing a smaller set of variables (Jolliffe, 2002; Linting et al., 2007). This reduction is achieved through the identification of core underlying factors, in which the variation of the data sample is maximum (Ringnér, 2008). PCA creates a new set of independent not correlated variables (principal components) that are a linear combination of the initial variables (Abdul-Wahab et al., 2005).

PCA can be defined as a process of rotating the axes of the original variables into new orthogonal axes, the principal components, which correspond to the direction of the maximum variation of the original features. In Fig. 3.2 a diagram of the two variables x_1 and x_2 is presented, demonstrating their means ($\bar{x}_1$, $\bar{x}_2$), the 95% concentration ellipse[5] and the principal axes Y_1 and Y_2.

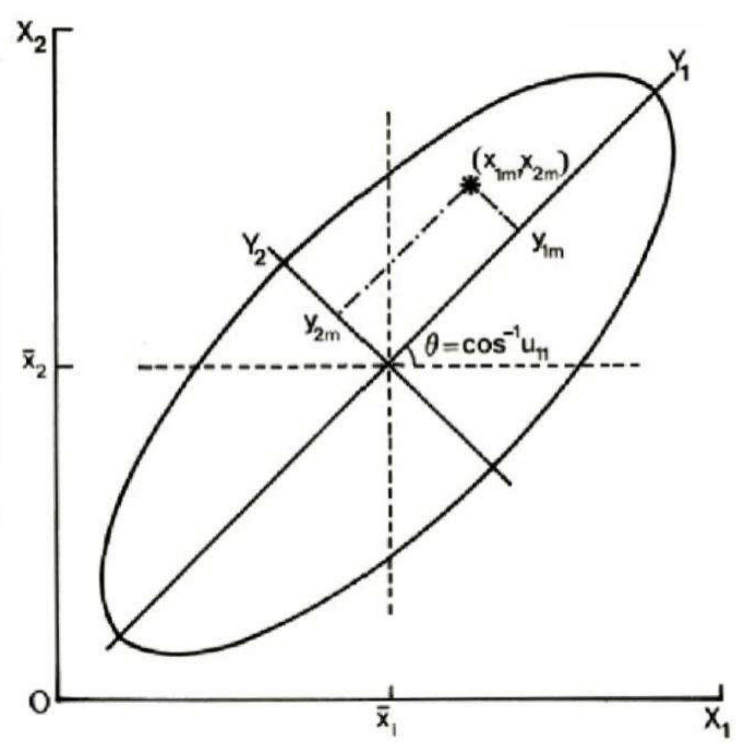
The first principal axis (Y_1) is the line crossing the mean of the data in a way that minimises the variance of each observation (squared distance between observation and the line). The second principal axis (Y_2), has the same characteristics but its direction needs to be orthogonal to the first principal axis (Y_1). As a result, the two new axes that minimise the variance formulate the Principal Components.

[4] Further information on data collection, datasets and geographic information can be found in:

- MAGIC: http://www.magic.gov.uk/
- EDINA Digimap: https://digimap.edina.ac.uk/
- Ordnance Survey open data: https://www.ordnancesurvey.co.uk/business-and-government/products/opendata.html

[5] A concentration ellipse in a PCA indicates the region that contains a percentage of the population (here 95%).

Fig. 3.2 Geometry of the Principal Component Analysis



The linear combination of the initial variables for the observation x_1 = (x_{1m}, x_{2m}) are derived from the calculation of y_{1m} and y_{2m} (equations (1) and (2)) which give the principal component scores for this observation:

$$y_{1m} = cos\theta \times x_{1m} + sin\theta \times x_{2m} \quad (1)$$

$$y_{2m} = -sin\theta \times x_{1m} + cos\theta \times x_{2m} \quad (2)$$

Although the distribution of the observations and the total variance is the same between the original and the estimated axes, the variance of y_{1m} and y_{2m} are different than the variance of x_{1m} and x_{2m}. More specifically, a larger percentage of variation is explained from y_{1m} in comparison to the initial variable. Furthermore, y_{2m} explains the remaining percentage of variance that is not explained by y_{1m}. Therefore, y_{1m} and y_{2m} as a combination explain the total variation of the original data.

The PCA algebraic background of obtaining the principal components for a given dataset with k variables is based on the solution of the following sequence of equations (3):

$$\begin{cases} Y_1 = \alpha_{1,1}x_1 + \alpha_{1,2}x_2 + \alpha_{1,3}x_3 + \alpha_{1,4}x_4 + \cdots + \alpha_{1,k}x_k \\ \vdots \\ Y_k = \alpha_{k,1}x_1 + \alpha_{k,2}x_2 + \alpha_{k,3}x_3 + \alpha_{k,4}x_4 + \cdots + \alpha_{k,k}x_k \end{cases} \quad (3)$$

Where $Y_1, Y_2, Y_3, \ldots, Y_k$ are the principal components, $x_1, x_2, x_3, \ldots, x_k$ are the variables and $a_{k,1}, a_{k,2}, a_{k,3}, \ldots, a_{k,4}$ are their correlation coefficients. In the context of PCA, these correlation coefficients between the principal components and the variables are called factor loadings. Furthermore, the squares of the factor loadings correspond to the percentage of variance that each component explains. Thus, the sum of the squared loadings represents the total variance of each variable which is equal to 1.

The specific percentages of explained variance in the variables are named eigenvalues which as a total sum estimate the total variance of the whole dataset. Mathematically, the eigenvalue (δ_i) is calculated as shown below (4):

$$\delta_i = \sum_{i=1}^{j} \left(a_{ji}^2 \right) = a_{1,j}^2 + a_{2,j}^2 + a_{3,j}^2 + \cdots + a_{n,j}^2 \qquad j = 1,2,3,\ldots,n \quad (4)$$

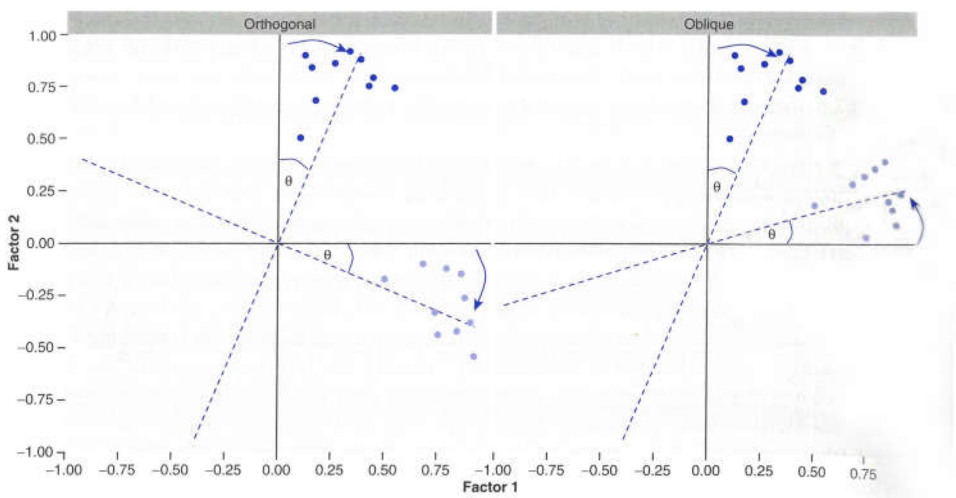
Furthermore, in the mathematical form, the components are a linear combination of all variables x_k.

$$Y_i = \sum_{j=1}^{i} \left(\frac{a_{ij}}{\delta_i} \right) \quad (5)$$

The associated eigenvalues indicate the considerable importance of each factor. Higher eigenvalues indicate higher percentage of variance of the variables explained by each factor and vice versa. Thus, it is essential that only factors with large eigenvalues are retained. Cattell (1966), suggested the scree plot technique in which all eigenvalues are plotted against the component that they correspond to. According to this method, a point of inflexion in the curve should emerge indicating the cut-off point for extracting the principal components. However, scree plots are often vague in terms of indicating graphically the cut-off point. Hence, they are used in combination to Kaiser's criterion which implies that only components with eigenvalues greater than one should be extracted (Kaiser, 1960).

Generally, variables tend to load highly on the most important principal component (component explaining most of the variation among the others) and less in all other. This makes interpretation of the PCA difficult hence the procedure of factor rotation is employed. By schematic means, when plotting variables using principal components as classification axes, rotation of factors rotates these axes in a way that the variables are loaded maximally on one particular factor (Fig. 3.3). There are two methods for rotating the factor, namely orthogonal and oblique. In orthogonal rotation, there is the assumption that the principal components are uncorrelated whereas in oblique factors may be related with each other. It is suggested that for naturalistic datasets the former does not have reasonable grounds as there should be interactions between the various principal components (Field et al., 2012).

Fig. 3.3. Orthogonal and oblique factor rotation (Field et al., 2012, p. 941)



3.3.1 Validity of results

Prior to the PCA, a number of validation processes were applied to the initial dataset in order to ensure the suitability of variables for conducting the present analysis. Specifically, the statistical significance of the data sample was checked with one-sample t-test. Additionally, to check for multicollinearity issues, correlation matrices were employed. Variables with high correlation coefficients (>0.9) were considered as multicollinear and thus had to be excluded from the sample. Furthermore, the adequacy of the correlations within the matrix is tested with Bartlett's sphericity test which examines whether the correlations within the data sample are too small (correlation coefficients close to zero). Thus, a significant output resulting from Bartlett's sphericity test indicates that the variables that are going to be used in the analysis are appropriate in terms of correlations (the significance value is smaller than 0.05).

The accuracy of the PCA estimations depends on sample size and thus, testing the sampling adequacy is of essential importance. The Kaiser-Meyer-Olkin (KMO) ratio is employed to test the sampling adequacy (Kaiser, 1970). This can be calculated both partially for a single variable as well as overall for a data sample. KMO represents the ratio of the squared correlation between the variables to the individual correlation between variables. Values close to 1 indicate appropriateness of the sample while it is suggested that only values greater than 0.5 should be accepted both for the partial as well as the overall KMO (Kaiser, 1974). Specifically, Hutcheson and Sofroniou (1999) suggest the interpretation of KMO ratio scores as presented in Table 3.1.

Table 3.1 KMO scores interpretation (Hutcheson and Sofroniou, 1999, p.225)

KMO score	Categorisation
0.9	Marvellous
0.8	Meritorious
0.7	Middling
0.6	Mediocre

0.5	Miserable
<0.5	Unacceptable

Furthermore, the residuals of the correlations provide information for the validity of the model based on the selection of extracted components. More specifically, in well fitted estimations there will be small differences between the observed correlations and the correlations based on the model. Thus, one approach to account for this is to calculate the sum of the large residuals (residuals greater than 0.05) and check whether their proportion lies within acceptable bounds (less than 50%). Furthermore, the distribution of the residuals will be checked as it is expected to be approximately normal with no presence of outliers. In fact, the process of extracting the principal components is repeated until the above criteria are simultaneously satisfied.

3.4 The Multiple Linear Regression model

Multiple Linear Regression (MLR) is a method that has widely been used for explaining the variance of a dependent parameter that is caused by a series of other independent variables. The results of this procedure point out statistically significant correlations between the principal components and the dependent variable. The latter will allow for the identification of the particular factors that trigger disparities in productivity and/or profitability of beef and sheep farms.

MLR is employed to test the explanatory power of several independent variables (x_1, x_2, …, x_k) on variations of the dependent variable (y). The MLR model with k variables and *n* observations is formally expressed in the following form:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon \qquad (6)$$

where *y* is the dependent variable, β_0, β_1, β_2, … , β_k are the coefficients of the regression, x_1, x_2, …, x_k are the independent variables and ε is the unobservable random error. The regression coefficient of explanatory variables in MLR are calculated with the least squares principle which minimises the residual of sum squares. It is assumed that the errors are normally distributed, have the same variance given any value of the explanatory variables, and are mutually independent (Plant, 2012). Due to the multiple variables that can be accommodated within the MLR model, it is hoped that causality may be inferred (Wooldridge, 2009).

In the context of the present analysis, factor scores corresponding to the principal components from the PCA will be used as explanatory variables in the MLR (Aristya et al., 2017; Huat et al., 2013; Micha et al., 2015; Tariq et al., 2012). Furthermore, the model will use productivity related variables as dependent variables.

The elements associated with the vector of explanatory variables $X = \{x_1, x_2, \ldots, x_k\}$ are tested for statistical significance through one sample t-test. In addition, considering multicollinearity issues, correlation matrices are employed. Finally, with regards to the validity of the MLR model estimations, the coefficient of determination (R squared) is used.

3.4.1 Limitations of PCA and MLR

Limitations emerge within the steps of this multivariate statistical analysis. Specifically, an important parameter relates to the identification of orthogonal projections of the dataset in which the variance is maximum. The variables within the examined dataset may be not linearly correlated and, in these occasions PCA is not able to estimate meaningful results. The latter, relates to another issue, that of obtaining principal components comprising of many different variables and as a result they are difficult to be interpreted (Chatfield and Collins, 1980). Furthermore, it has been noted that in the PCA there is no statistical model on the background while there is no information about variance components due to error. This highlights that the sampling behaviour of the eigenvalues remains unknown and thus there is no standard way to decide how many of the eigenvalues of the analysis should be considered as large (scree plots and Kaiser's criterion are used as a way of overcoming this limitation) (Chatfield and Collins, 1980).

Concerning MLR, a limitation emerges in the process of selecting predictors for the modelling. Specifically, using many predictors in the regression analysis may cause overfitting which leads in poorer estimations due to existence of unnecessary data noise in the analysis. On the other hand, omitting important predictors leads in underfitting and biased estimations of relationships for the included variables (Chatterjee and Simonoff, 2013). Furthermore, the validity of the estimations depends on whether the linear regression assumptions are met.

3.5 Linear Programming

Linear programming (LP) has been used in agricultural studies as a planning and decision-making tool. The main purpose of linear programming is to optimise (minimise or maximise) a linear function (7), which represents the objectives of a problem. The optimisation is conducted subject to a vector of constraining factors (8), which represent the limits of the environment in which the problem exists (Kaiser and Messer, 2011).

While there exist various ways to present a linear programming model, the general form of a generic model for n activities and m structural constraints is:

Min or Max:
$$Z = c_1x_1 + c_2x_2 + \cdots + c_nx_n \tag{7}$$

Subject to:
$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \; &\{\leq, =, \geq\} \; b_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \; &\{\leq, =, \geq\} \; b_2 \\ \vdots \qquad \vdots \qquad \vdots \qquad \vdots \quad &\quad \vdots \qquad \vdots \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \; &\{\leq, =, \geq\} \; b_m \\ x_1, \quad x_2, \quad \ldots \quad x_n \; &\geq \; 0 \end{aligned} \tag{8}$$

The objective function (7) represents a mathematical formulation of the objective that the decision maker wants to fulfil (this can be either maximised or minimised). This objective consists of a range of activities (x_i) that are determined by the decision maker and are expressed as $Z = f(x_1, x_2, \ldots, x_n)$. The results of the solved objective function (Z) estimate the optimised solutions for the examined problem that may regard profits, costs, sales or production outputs. Furthermore, the value of the objective function is determined by the volume of each activity x and the corresponding coefficient c. The technical coefficients $a_{i,j}$, indicate the amount of resource i that is required to produce a unit of the activity j. The resource endowment value b_i demonstrate either the maximum amount of resource i that is available (then the symbol in the constraint is, $\leq$) or the minimum condition that needs to be met ($\geq$).

The graphical representation of solving a LP maximisation problem with two activities is presented in Fig. 3.4 and the objective function is given by equation (11). In the present illustration, there are four structural constraints within the modelling (inequality 12 to (15). The first three indicate the endowments in the activities x and y. The fourth, although not presented in the same form, requires all activities (here x and y) to be greater than zero, which constrains them to be in the first quadrant of the cartesian coordinate system. The lines passing through the endowment values of y and x represent the constraining lines. Taking as an example the first constraint the constraint line is estimated as follows:

Rewriting the weak inequality 12 as an equation:

$$x + y = 600 \tag{9}$$

Equation (9) provides all the values for x and y that lie on the frontier of this constraint. To estimate the feasibility region, using basic algebra, this equation is solved for x providing the x intercept:

$$1x + 1(0) = 600, \text{ or}$$
$$x = 600 \tag{10}$$

Similarly, the y intercept can be estimated and used to graphically draw the constraint line (Constraint 1, Fig. 3.4). The same methodology can be used to estimate the constraint lines for the rest of the constraints. Their graphical combination formulates the region for all feasible solutions along with the frontier, on which the optimal solution will be located. The solution of a minimisation problem with two activities (Fig. 3.5) is similar to the solution of the maximisation problem.

Although the graphical method of solving LP models demonstrates the logic behind LP, it can only be employed for very small problems with two or three activities. For the solution of larger scale problems with many activities the simplex method is used. The simplex method is an algebraic method which finds the optimal solution for a problem using iterative procedures. Through the iterative procedures, in a problem with n variables and m constraints, the method assigns zeros to $n-1$ variables of the model solving for the remaining one resulting in the estimation of the solution. Generally, the $n-m$ variables that are assigned to zeros are the non-basic variables while the nonzero variables are the basic variables. Furthermore, in this type of models the slack variables are introduced, representing an amount of unutilised resource (the slack) of the endowment. This enables the method to transform the constraint inequalities to equations which allows substituting different equalities and thus, the identification of the final solution for all variables. As the slack variables do not affect the objective function value they are included in it with zero objective function coefficients (an example of such a model is presented and discussed below).

$$Max: \quad Z = 40x + 45y \tag{11}$$

$s.t.$:

$$x + y \leq 600 \tag{12}$$

$$x + 1.5y \leq 750 \tag{13}$$

$$x \leq 400 \tag{14}$$

$$x, \quad y \geq 0 \tag{15}$$

Fig. 3.4 Graphical solution of a LP maximisation problem (Kaiser and Messer, 2011, p. 16)

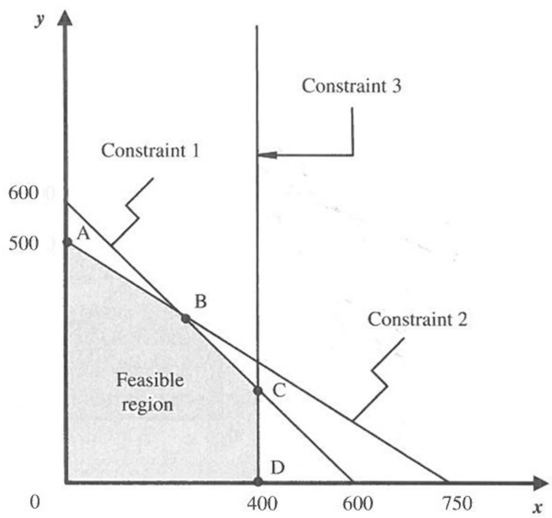
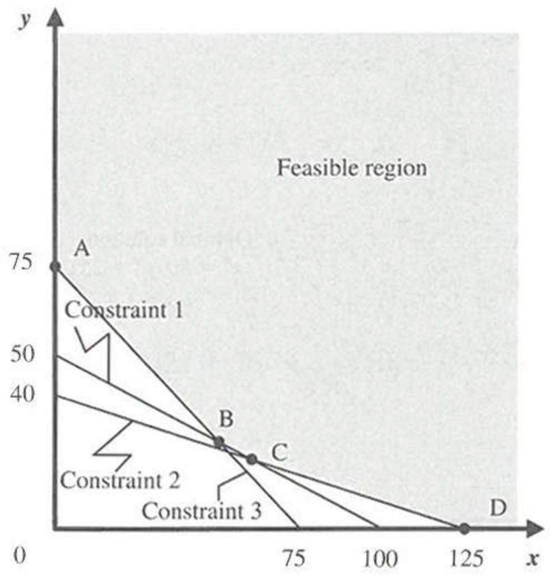


Fig. 3.5 Graphical solution of a LP minimisation problem (Kaiser and Messer, 2011, p. 29)



An illustrative example of solving a simple maximisation problem using the simplex method is presented below, considering the objective function (16) and constraints (17) to (20).

$$Max: \quad Z = 35x_1 + 50x_2 + 0s_1 + 0s_2 + 0s_3 \tag{16}$$

$s.t.$:

$$x_1 + x_2 + s_1 = 1000 \tag{17}$$

$$2.5x_1 + 0.75x_2 + s_2 = 1500 \tag{18}$$

$$1.5x_2 + s_3 \leq 400 \tag{19}$$

$$x_1, x_2, s_1, s_2, s_3 \geq 0 \tag{20}$$

The solution using the method described above (assigns zeros to $n - m$ variables) is called the basic solution. For example, if we assume $x_1 = 0$ and $s_1 = 0$ then the above problem becomes:

$$x_2 = 1000 \tag{21}$$

$$0.75x_2 + s_2 = 1500 \tag{22}$$

$$1.5x_2 + s_3 = 800 \tag{23}$$

Then, knowing that $x_2 = 1000$ (from Equation (21)) we solve for s_2 in Equation (22):

$$0.75(1000) + s_2 = 1500, \quad \text{or} \tag{24}$$

$$s_2 = 750 \tag{25}$$

Similarly for s_3:

$$1.5(1000) + s_3 = 800, \quad \text{or} \tag{26}$$

$$s_3 = -700 \tag{27}$$

Therefore, the basic solution when $x_1 = 0$ and $s_1 = 0$ is:

$$x_1 = 0, x_2 = 1000, s_1 = 0, s_2 = 750, s_3 = -700$$

The $n - m$ variables assigned with zeros are called nonbasic variables (in this example x_1 and s_1) whereas the m variables (nonzero) are called basic variables (x_1, s_2 and s_3). A basic feasible solution satisfies all constraints including the non-negativity while a basic infeasible solution violates at least one of the constraints. The LP model can also be expressed in a tableau form (Table 3.2).

The columns of the tableau are organised as follows:

- The Basis column contains all basic variables which in the first iteration represent the slack variables (s_1, s_2, s_3) while the activities of the model are $x_1 = x_2 = 0$.
- The next column, demonstrates the contribution of the current basis (CB) and includes the objective function coefficients of the basic variables which are $c_1 = c_2 = 0$ (as in the first iteration the basic variables are the slack variables).
- The columns of x_1, x_2, s_1, s_2, s_3 are the activities and slack variables of the model and they regard the basic and nonbasic variables.
- Column b presents the resource endowments
- The final column of the tableau is used for the estimation of the pivot row.

Regarding the rows, the first row of the table presents the objective function coefficients (c) while the three following rows contain the constraints of the problem. The last two rows z_j and $c_j - z_j$ provide a rationale for selecting the non-basic variable that should be used in the next solution to increase the value of the objective function.

Table 3.2 The simplex tableau

		x_1	x_2	s_1	s_2	s_3		
Basis	CB	35	50	0	0	0	b	b_i/a_{ij}
S1	0	1	1	1	0	0	1000	
S2	0	2.5	0.75	0	1	0	1500	
S3	0	0	1.5	0	0	1	800	
	z_j							
Net Eval	$(c_j - z_j)$							

3.5.1 Sensitivity Analysis

Concerning the validation of the estimations, LP allows for the validation process of sensitivity analysis in which the results of the optimisation are examined in relation to their potential implementation in the real world to help the decision maker handle the outputs (Kaiser and Messer, 2011). Specifically, this analysis examines the extent to which the solution of the objective function is sensitive to changes in model parameters. In this way the method is enabled to answer questions related to changes in supply of production inputs (such as labour) and quantify their effects on the solution (such as profits). Furthermore, sensitivity analysis can be conducted for the objective function coefficients and the resource endowments. The former, uses the algebraic method of parametric programming to calculate the supply function by holding the coefficients of $n - 1$ variables fixed and altering values of the remaining coefficient. The latter, estimates the shadow prices which provide the value of each resource to the estimation of the objective function.

3.5.2 Limitations of the LP method

Specific limitations occur from the use of LP models for optimisation. One of the issues is related to the exogeneity of prices for inputs and outputs (Acs et al., 2010). The latter indicates that the variables are not affected by the constructed modelling but rather are constant and independent of other factors that exist within the model. Additionally, the methodology of LP has limitations due to the assumed linearity of constraints as well as risk neutrality (Hanley et al., 1998).

In a similar context, it has been suggested that the variables in LP models are measured and applied mathematically (Memmah et al., 2015) which does not permit capturing qualitative information such as the farmer's goal orientation and vision for the future of the farm. Furthermore, there exist significant variables affecting agricultural performance such as weather conditions and performance of labour that cannot be incorporated in such modelling.

The latter is linked to the objective function which expresses a single objective, that of maximising or minimising a particular parameter (for example profit). Therefore, the LP method cannot account for multiple goals that a farmer would have set for his farm business further to profit maximisation such as environmental objectives. In this context, multiple criteria analysis could better address the many objectives that the decision makers have within the agricultural decision making.

3.5.3 Assumptions made in the LP model

In the context of the current examination, a LP method would indeed solve a single objective maximisation function that regard farm-level profitability. However, in this particular application, profit maximisation is estimated through optimisation of ICLS which is highlighted as a strategy enhancing agricultural sustainability (Martin et al., 2016). In this way, although the modelling solves an economic objective function, a series of further criteria is fulfilled including enhanced delivery of ecosystem services (Sanderson et al., 2013), reduced environmental impacts and enhanced biodiversity (Soussana and Lemaire, 2014), benefits for productivity (Bell et al., 2014), farm-level self-sufficiency (Peyraud et al., 2014), soil quality and social benefits (Martin et al., 2016).

In that sense, this optimisation method will provide information to farmers and policy makers on a preferable agricultural strategy that delivers economic, environmental and social benefits. Therefore, in the context of the present analysis, LP can be incorporated effectively as a tool for the decision making process and fulfil the task of evaluating ICLS. Furthermore, the LP modelling allows for the examination of different dynamics across various agricultural production strategies through simulations of different scenarios (Gameiro et al., 2016; Olaizola et al., 2015; Sneessens et al., 2016). Finally, the latter enables the representation of the flexibility that farming systems have in designing their production plans as well as of the marginal value product within optimised utilisation of available resources.

3.6 Geostatistical analysis

3.6.1 Outline of the employed geostatistical tools

The objective of the geographic analysis was to create spatial implications through the examination of spatial distribution and commonality of drivers of performance, production constraints and profitability. For this reason, the spatial statistics and mapping clusters toolsets from the ArcGIS software are employed. As an initial step, the method needs to assess whether the observed spatial patterns are clustered, dispersed or random. For this examination, the Spatial Autocorrelation (Global Moran's Index) tool was used. Following, once spatial patterns found to be statistically significant clustered, Hot Spot Analysis is carried out. This analysis identifies statistically significant spatial aggregations of higher (hot spots) or lower values (cold spots). A discussion of the processes carried out within each geostatistical tool is presented below.

3.6.2 Spatial Autocorrelation – Global Moran's I index

Spatial autocorrelation refers to a measure of the extent to which a set of spatial observations and their corresponding data values tend to be spatially clustered (positive spatial autocorrelation) or dispersed (negative spatial autocorrelation) (Peeters et al., 2015). To geographers, the most common tool to assess spatial autocorrelation is the Moran's Index and to a smaller extent Geary's *c* (Cliff and Ord, 1973). A common feature among these methods is that they examine for spatial autocorrelations globally which means that the whole region of the analysis is studied (Getis and Ord, 1992). Within the GIS software, the spatial autocorrelation (Global Moran's I) calculates the Moran's I Index value (28), a $z-score$ (30) and a $p-value$ to evaluate the statistical significance of the estimated index.

The Moran's I statistic for spatial autocorrelation is estimated as:

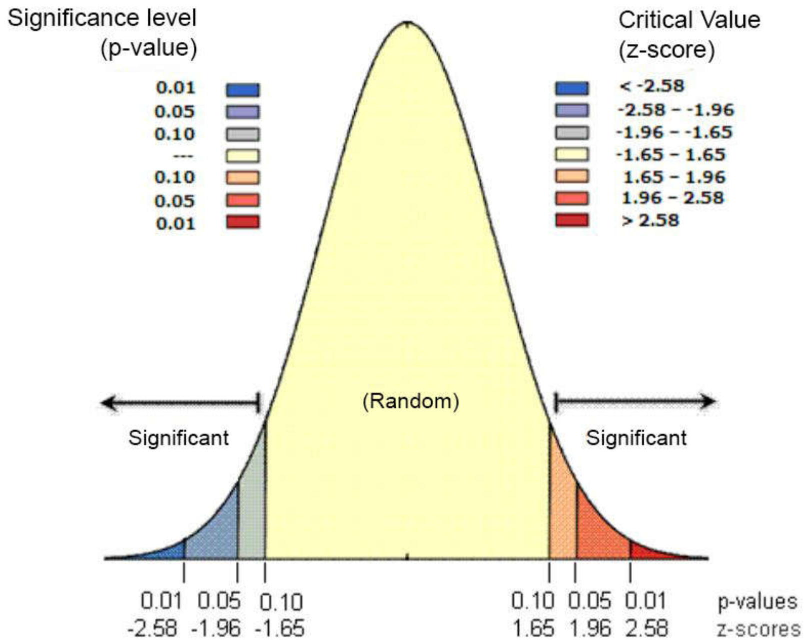
$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \quad (28)$$

Where z_i is the deviation of an observation for feature i from its mean (x_i – $\overline{\mathrm{X}}$), $w_{i,j}$ is the spatial weight between feature i and j, n represents the total number of features and S_0 is the sum of all the spatial weights:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \quad (29)$$

The Global Moran's I tool is an inferential statistic and as such, the estimations of the analysis are interpreted within the framework of the established null hypothesis. For this particular statistical test, the null hypothesis is that the examined variable is spatially allocated randomly. The latter would indicate that the spatial underlying factors triggering the identified spatial pattern of values is a result of random factors. The calculated $z-score$ is provided as tool to assist in deciding whether to reject the null hypothesis or not. More specifically, the $z-scores$ are standard deviations and are associated with the $p-values$ and the normal distribution as shown in Fig. 3.6. Very high or very low $z-scores$ (values close to 2.58 or -2.58 respectively) are associated with very small $p-values$ and thus, the null hypothesis can be rejected.

Fig. 3.6 Z-scores and p-values corresponding to the normal distribution (ESRI, n.d.)



The z_I-$score$ for the statistic is calculated as:

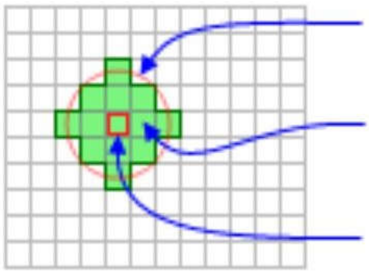
$$z_I = \frac{I - E[I]}{SE[I]} \quad (30)$$

Where $SE[I]$ is the standard error and $E[I]$ is the expected value of Moran's I under the null hypothesis that the spatial pattern is a result of random conditions and is calculated by:

$$E[I] = \frac{-1}{n-1} \quad (31)$$

The accuracy and validity of estimations depends greatly on selecting the appropriate conceptualisation of spatial relationships. Specifically, the ArcGIS software provides the option of fixed distance band which is the most appropriate when using point data (which is the type of the data that the present analysis uses). The fixed distance band applies a constant radius establishing a sphere of influence of spatial interactions among the data features (Fig. 3.7). Each feature is examined within the context of its neighbouring features that are located within the selected distance within which all datapoints should have at least one neighbour. Neighbours within this distance are weighted equally while features beyond this radius do not affect the calculations (their weight is set to zero). The distance band is calculated in a way that it reflects maximum clustering under which the spatial processes triggering the clusters are most distinct (ESRI, 2017).

Fig. 3.7 Illustrative example of the current spatial relationships conceptualisation (ESRI, n.d.)



For this reason, the Incremental Spatial Autocorrelation tool is employed to measure the spatial autocorrelation for a range of different distances. This tool calculates the corresponding $z-scores$ for each iteration indicating the intensity of spatial clustering. Peaks in z-scores signify distances in which the processes triggering spatial clustering are most pronounced. Peak values of $z-score$ resulting from large distance bands indicate phenomena of wider spatial scale (such as climate that formulates north-south wide trends) while small distance bands correspond with smaller scale phenomena (such as topography). Thus, depending on the nature of the examined variable the selected fixed distance bands range from smaller to larger distances among the $z-score$ peaks.

3.6.3 Hot Spot Analysis

The Hot Spot Analysis tool identifies statistically significant spatial clusters using the Getis-Ord Gi* statistic. This tool estimates $z-scores$ and $p-values$ as measures of statistical significance which are used in the same way as in the Spatial Autocorrelation method (discussed in Section 3.6.2). The hot spot analysis examines feature values in the context of their neighbouring features. This indicates that the local sum of a feature and its neighbours is examined proportionally to the sum of all features of the dataset. In turn, when the local sum differs substantially from the expected local sum, a statistically significant z-score occurs. Thus, a statistically significant cluster is estimated when neighbouring features have similar values (either high or low) with each other formulating the hot and cold spots respectively.

The estimation of the Getis-Ord local statistic is estimated as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \tag{32}$$

Where x_j is the attribute value for the feature j, $w_{i,j}$ is the spatial weight between feature i and j and n represents the total number of features and S is the standard deviation of the sample.

The estimated Gi* statistic for each feature of the dataset corresponds to a $z - score$. In the cases that a $z - score$ is statistically significant, it demonstrates the intensity of spatial clustering. Higher positive $z - score$ indicates more intense clustering of high values while smaller negative $z - scores$ indicate more intense clustering of low values.

Similarly, to the Spatial Autocorrelation method, it is essential to consider the conceptualisation of spatial relationships when conducting the Hot Spot analysis. As discussed before, for point data the fixed distance band is the most appropriate method. Furthermore, this conceptualisation is considered the most appropriate in the context of the Hot Spot analysis method and thus its use recommended by the ArcGIS software.

3.6.4 Limitations of the spatial clustering methods

Although the aforementioned discussed spatial statistics tools can provide essential insights for the analysis of spatial phenomena, a few issues need to be considered when conducting such geographical approaches.

The examination for existence of spatial autocorrelation within the ArcGIS environment uses a method in which peak values of $z - scores$ and their corresponding distance band play a fundamental role. However, multiple peaks in $z\ scores$ may occur and thus the selection of a specific distance band sometimes may be more a complicated process. In these instances, the researcher needs to have an in-depth understanding of the examined dataset in order to be able to identify the distance band in which the underlying processes are most pronounced. This should reflect the spatial scale of the processes triggering spatial clustering. For instance, the examination of phenomena such as climate calls for larger distances as the spatial scale of poor or fair climate may reflect a regional or even national level.

The estimation of the spatial clustering is significantly affected by the context of the approach in considering features as neighbours. More specifically, the estimation of the Getis-Ord statistic is determined by the number of features considered as neighbours and their spatial interactions which are in turn used for assigning the spatial weights. The latter indicates that this parameter should be of significant consideration and can be enhanced by employing the Spatial Autocorrelation tool to assist in the process of selecting the neighbouring specifications. Additionally, as a general rule, each feature should have at least one neighbour and features should have about eight neighbours (ESRI, 1984).

Furthermore, the Hot Spot Analysis requires sufficient sampling in order to provide reliable estimations. Specifically, as a general rule, the examined dataset should consist of at least thirty observations (ESRI, 1984). The latter, mainly relates to issues that would result from the existence of spatial outliers that would have fewer or even no neighbours within such small datasets (Peeters et al., 2015).

3.7 Conclusions

To conclude, through the sections discussed above, this chapter has provided knowledge on the theory behind the statistical (PCA, MLR), mathematical (Linear Programming) and geographical methods of the present analysis. Specifically, the combination of PCA and MLR is a multivariate statistical analysis used in agricultural sustainability studies for the examination of the explanatory power that several variables have in variations of a particular variable of interest. Moreover, LP is a mathematical modelling tool that has been incorporated in the agricultural research to optimise resource and land use allocation as well as farm production plans. Finally, geographical methods have provided the research with valuable geostatistical processes that provide essential spatial insights with regards to the sustainable development of the agricultural sector (Bateman et al., 2008; Navarro et al., 2016; Nguyen et al., 2015; Pilehforooshha et al., 2014; Zheng et al., 2016).

However, in each of the methods of the present analysis, several limitations exist and have been discussed in the sections above. Specifically, the PCA methodology highlights principal components by identifying orthogonal projections which assumes that the examined variables are linearly related. Furthermore, in several instances the estimated principal components consist of several variables and their interpretation is difficult. In addition, as the sampling behaviour of the eigenvalues is unknown it is difficult to characterise eigenvalues as large and thus to select the principal components that are important for the analysis. An appropriate tool to overcome this and improve the estimations is the scree plot in combination to Kaiser’s criterion.

Another limitation of the present analysis relates to the Linear Programming method in which the solution of the problem reflects fulfilling a single objective. However, in real life situations, the solution of a problem may include multiple goals that need to be met. Further to that, the variables used in such models are measured and applied in a mathematical form which does not allow the representation of qualitative information. Although these reflect drawbacks for the method, the LP modelling remains an effective method as it is able to represent the adaptability of farming systems in developing new production plans.

Finally, this chapter demonstrated a comprehensive discussion on the methods that the present research uses. Furthermore, the statistical background of each methodological step was explained in detail. The main objective of this chapter was to provide essential knowledge on the statistical, mathematical and geographical methods that are further developed and applied in the three empirical chapters (Chapter 4, 5 and 6).

PART II

Chapter 4

Identification of drivers of performance in hill farming systems

4.1 Introduction

Farm businesses in the Less Favoured Areas (LFAs) face particular difficulties due to a range of disadvantages (Harvey and Scott, 2015). The LFAs are defined by these environmental constraints that make agricultural practices more difficult and limit productivity (European Commission, 2005a). The rationale behind the classification of rural areas as less favoured was to provide a framework for policy interventions and financial support for farmers to maintain their production capacity and economic profitability (European Commission, 2005b). However, the classification criteria do not reflect farm business objectives alone. Lower profitability in the LFAs could lead to reduction or cessation of farming activities and consequently land abandonment and a sequence of social and environmental risks related to change in land cover, depopulation and impacts on rural communities (European Commission, 2010, 2005a). The LFA designation considers classification criteria related to climatic conditions (slow growing season due to low temperatures), lower soil productivity (poorly drained, shallow or stony soils) or steep slopes (slopes greater than 15%) (European Commission, 2005a). Initially, socio-economic characteristics were included as well but were omitted from the criteria for designating areas as less favoured in order to focus further on the physical factors (Parliament. House of Lords, 2009). In addition, the LFAs are nationally and internationally important areas for their biodiversity, cultural and natural resource value (DEFRA, 2010).

In England a total of 2.2 million hectares or 17% of the total farmed area is classified as LFAs (DEFRA, 2010), which are further classified into two distinct categories Disadvantaged Areas (DAs) and Severely Disadvantaged Areas (SDAs) (DEFRA, 2005a). The upland land classification, conducted by DEFRA (2005a), defines DA and SDA as land inherently suitable for extensive livestock production where crop production is not greater in quantity than that required to feed the livestock. SDA land differs from DA in that agricultural production is severely restricted by a combination of soil, relief and climate.

In 2014 an average LFA farm in England had an annual output of approximately £ 60,000 derived from livestock enterprises and an output of approximately £ 3,000 derived from crop enterprises (Harvey and Scott, 2015). The average diversified output (off farm activities) was a little bit lower than £ 4,000. In addition, on average there are 27 beef cattle and 363 breeding ewes per LFA farm (Harvey and Scott, 2015). The distribution of outputs between livestock and crop enterprises output is indicative of the farming systems in the LFAs which are based predominantly on livestock production (beef cattle and/or breeding ewes) (DEFRA, 2010).

Use of appropriate stocking rates that prevent over-grazing are essential for managing England's important wildlife habitats. Consequently, sustainable farming practices are vital for the conservation of the upland landscapes (English Nature, 2005). Between 1945 and 2000, technological advances and policy mechanisms caused pressures leading to an increased number of livestock and over-grazing of upland habitats (English Nature, 2005). The Common Agricultural Policy (CAP) has been the main policy intervention in the EU, providing support to hill farmers through production-based payments (headage payments) until 2005 (Acs et al., 2010). However, the latter provided motive for the farmers to increase livestock numbers which in some instances damaged vegetation and biodiversity through overgrazing. This lead to the de-coupling of support in 2005 when the Single Farm Payment (SFP) was introduced replacing headage payments by area-based payments with the objective of addressing environmental outcomes (DEFRA, 2005b). Furthermore, the introduction of Upland Entry Level Stewardship (UELS) in 2010 signified a focus on the maintenance and improvement of landscapes and the environment which differentiated from the compensating nature that the previous support tools had (Barclay, 2011). The uplands policy review conducted by DEFRA (2013), concluded that farmers should combine more efficient agricultural practices, to make a greater proportion of their income through their produce, with delivery of broader ecosystem services in support of sustainable development.

Hill farming holds a fundamental role in maintaining the cultural character of the uplands and can be seen as a stimulator of the local economy that contributes to the maintenance of the rural societies (Acs et al., 2010; DEFRA, 2004; Harvey and Scott, 2015). However, areas under threat of possible land abandonment are typically agricultural marginal areas (land at the edge of economic viability) (Strijker, 2005). Thus, many argue that it is crucial from the social and cultural perspective that the economic viability of farming in the LFAs is maintained. However, recent studies have questioned whether support for maintaining agricultural activity within the LFAs makes financial sense within the UK (Helm, 2017). Hence, it is necessary that farming systems adapt to a more sustainable approach to production that supports environmental conservation, economic viability and social integrity. Sustainable agricultural practice delivers both environmental quality and economic value which in turn stimulates social robustness (Velten et al., 2015).

The objective of this study is to analyse variation in the performances of beef and sheep farming in the English LFAs, as well as to identify the impact that support payments have on agricultural systems. There are two core dimensions, the first regards farm-level management decisions that either enhance or hinder agricultural performance; the second corresponds to the identification of broad spatial patterns in in the profitability of beef and sheep farming due to inherent spatially-fixed natural handicaps. Consideration of both of these two aspects will deliver information regarding enhancing sustainable livestock production in the LFAs. The identification of efficient practices delivers transferable knowledge on farm-level decision making that may be mirrored across the upland production systems to sustain production performance and profitability. Furthermore, this analysis creates insights for the development of policy support for hill farms highlighting the landscapes that should be targeted along with the corresponding support tools.

4.1.1 Background to the determinants of production performance of livestock production systems in the LFAs

In an analysis of the factors that cause heterogeneity in the performance of farms, Goswami et al. (2014) highlighted a large group of social (farmers' characteristics and objectives), managerial (allocation of labour, adaptation of technology) and physical (climate, accessibility and remoteness) parameters that are considered to lead to differentiation in performance. Their methodology used Principal Component Analysis (PCA) and cluster analysis to create farm typologies based on the importance of the above parameters for the studied agricultural systems.

Battaglini et al. (2014) investigated the development of livestock systems in the alpine LFAs in terms of technical and economic factors (management practices, level of intensification, grassland self-sufficiency), social characteristics of the farmer and environmental characteristics (landscape, biodiversity etc.). Through a qualitative analysis, this study identified factors that affect the environmental sustainability and development of alpine grazing livestock systems. In a similar context, Bernués et al. (2011) through a qualitative approach, discussed the limiting factors for the sustainability of livestock farming systems. They concluded that environmental aspects, technical and economic characteristics, labour and household characteristics, as well as policies, have determined the development of these systems.

Concerning weather characteristics, it is likely that climatic factors such as rainfall intensity, extreme temperatures and ground frost impact on the growing of pasture as well as the fattening process of the animals. McCann et al. (2010) investigated factors related to the mortality and morbidity of dairy cattle in England and Wales and concluded that rainfall and temperature are considerably important within this context.

Self-sufficiency in forage production and dependency on external inputs for feeding stuffs are considered as parameters that affect the financial performance of farms. There is a substitutable relationship between grass and concentrates which can be cost effective when the supply of the former is increased and the demand for the latter is decreased (Dillon, 2007; Kilcline et al., 2014). Furthermore, Finneran and Crosson (2013) analysed the effects of higher levels of concentrate feeding stuffs on financial performance, concluding that they are a significant barrier for farm income.

Technological adoption on farms is a factor that may largely affect production and financial performance. In particular, according to English Nature (2006), technological development has changed the feeding and delivering methods, affecting the wintering practices in hill farming. Furthermore, higher adoption of technology results in higher profitability by means of general inputs allocation (labour, capital) (Hansson, 2007).

From the social perspective, the age of the farmer is a factor that has been considered in research on the determinants of agricultural performance (Finneran and Crosson, 2013; Kelly et al., 2012; Lordkipanidze and Tauer, 2000). Although results are controversial, age correlates with experience to an extent (Ondersteijn et al., 2003), hence differences in age may explain variations in agricultural performance. In addition, the level of education of the farmers is found to be positively correlated to the performance of farms (Hansson, 2008; Morgan-Davies et al., 2012).

The economic viability of grazing livestock systems in the LFAs depends largely on public payments. Studies have examined the implications of financial support, particularly for the outputs of the farm enterprises suggesting contrasting results (Gelan and Schwarz, 2008; Karlsson and Nilsson, 2014; Morgan-Davies et al., 2012). Morgan-Davies et al. (2012) and Acs et al. (2010) found that replacement of production-based financial support with area-based payments led to declining numbers of livestock and reductions in productivity in general. On the other hand, Kazukauskas et al. (2014) suggested that decoupling policies have positive effects on productivity. In 2014, the Single Farm Payment, in combination with agri-environment payments, accounted for more than 30% of the total revenue (output) of the farm businesses in the uplands of England (Harvey and Scott, 2015).

Many studies have identified a range of variables impacting on the financial and production performance of upland farms, where they examine the relative importance of a range of factors that relate to environmental constraints and management decisions (Battaglini et al., 2014; Bernués et al., 2011). The present study accounts for these factors while also employing the additional parameter of remoteness as a potential driver of performance into an integrated approach. This enables the present study to incorporate the spatial dimension in the analysis to examine for its relative importance in variations of farm performance. A combination of variables relating to farm and farmer characteristics (geographical location and production levels and profitability) is employed to determine the direction and the magnitude of the relationships and to provide understanding of variations in performance. Understanding the drivers of productivity and profitability, along with the role of support payments, is essential for the future design of agricultural policies and rural development strategies.

Different assumptions regarding the performance of farming systems are made based on the two LFA land classes; that of Disadvantaged Area (DA) and Severely Disadvantaged Area (SDA). Farms with a greater proportion of land within the SDA (against DA) will be facing proportionally more natural barriers than the ones with smaller proportions within the SDA. Thus, there is a hypothesis that higher proportions of SDA are associated with lagging performances. Even though this assumption may stand by definition, it is important to examine and quantify the ways physical disadvantage affect performance, particularly in the context of policy revision. In addition, due to this disadvantage, when standardised for livestock numbers, farms with higher proportions of SDA are likely to require more land for forage in comparison to their counterparts with less land within SDA (DEFRA, 2018b). Hence, it is expected that higher forage area per LU will be associated with more disadvantaged and remote farms hence lower performances per LU. Furthermore, it is expected that negative correlations between poor weather and production performance of farm businesses will be found. Higher levels of technological adoption are expected to be associated with higher levels of productivity. Finally, lower external inputs of labour with higher percentages of family labour involved in the agricultural activities are expected to reveal higher levels of performance. These hypotheses are tested in this study using data from the Farm Business Survey for upland farms in England.

4.2 Material and methods

4.2.1 Dataset, variables and general approach

A set of variables to explain variations in profitability and production performance of livestock systems was selected as the most appropriate set based on Battaglini et al. (2014), Bernués et al. (2011), Finneran and Crosson (2013), Goswami et al. (2014), Karlsson and Nilsson (2014), Kilcline et al. (2014), McCann et al. (2010) and Morgan-Davies et al. (2012). Data on management and production performance characteristics for the 2013-2014 accounting year was obtained from the Farm Business Survey (FBS), which is a comprehensive dataset providing information relative to the financial and physical performances of farm businesses in the UK[6] and is on contractual agreement with the Farm Accountancy Data Network (FADN). This accounting year was selected as the most recent complete dataset. Weather data was derived from the UK Meteorological Office climate monitoring datasets which provide gridded observation data[7]. For the purposes of this analysis monthly averaged weather data has been used. The selection of weather data instead of climate characteristics was made due to the financial data that regarded a particular year and not timeseries. The examination of factors such as temperature or precipitation in variations of performance should be in reference to the corresponding weather characteristics that contributed in the examined farm performances (either lower or higher). Long term climatic averages may lack detail on extreme instances (such as a low rainfall summer, or a cold winter) which will fail to provide explanation on variations on performance triggered by such events. Finally, the location of the approved meat establishments, derived from the Food Standards Agency, was used to consider for the effects of geographical isolation on performance.

Flaten (2017) used an average of two accounting years in order to eliminate variations in performance caused by uncontrolled factors such as weather. However, this study

[6] Further information regarding the FBS dataset, methods of data collection or getting access can be found in the following link: https://www.gov.uk/government/collections/farm-business-survey

[7] For further information regarding Met Office long term average data please use the following link: http://www.metoffice.gov.uk/research/climate/climate-monitoring

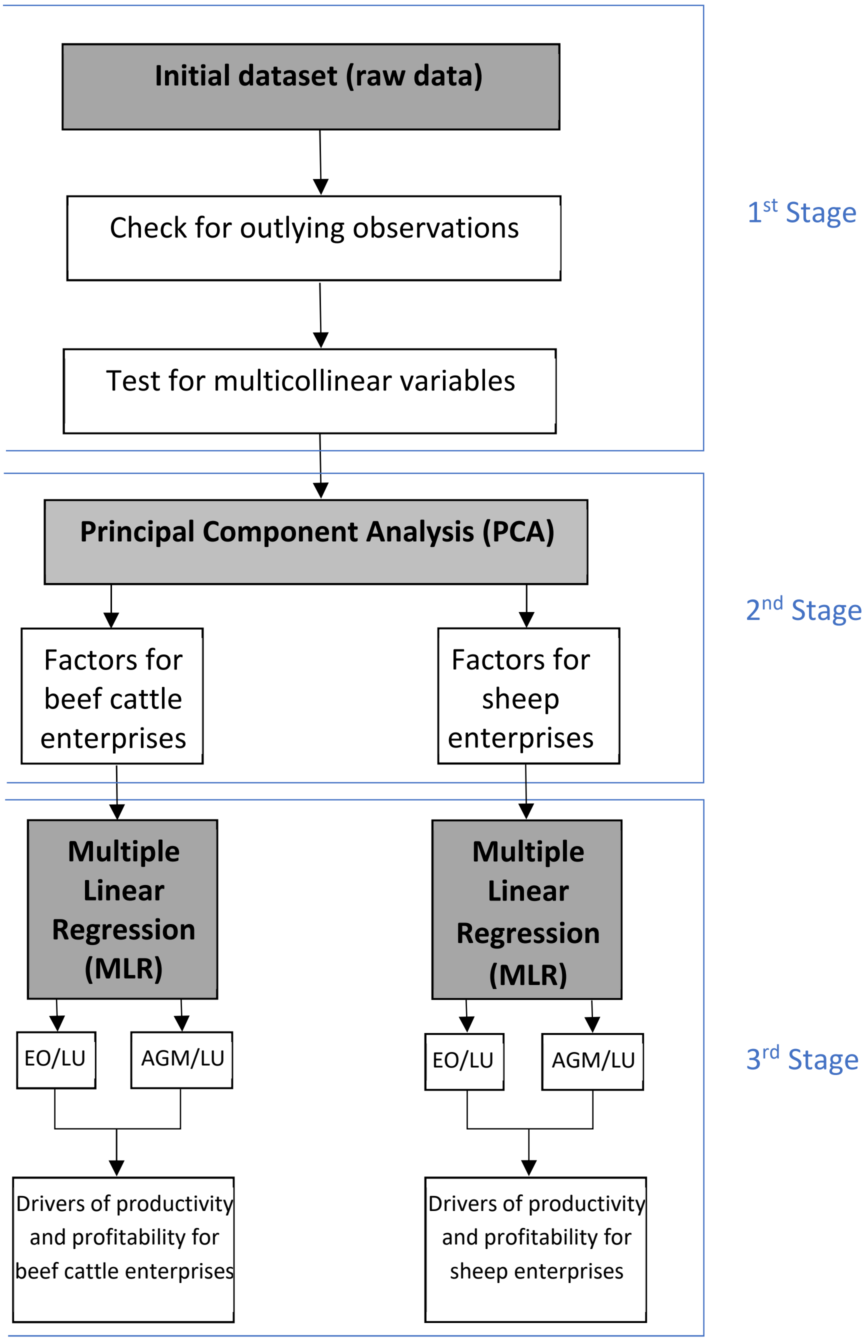
acknowledges weather conditions as a possible underlying factor that triggers differentiation in agricultural performance (Bett et al., 2017; McCann et al., 2010; Nardone et al., 2010; Morris, 2009), and uses weather and financial data for the same time period. Weather data were reordered in order to be in line with the months of the accounting year rather than the calendar year in which they were originally collected. More specifically, the weather data after being reordered, include monthly average values for April to December of 2013 and January to March of 2014. In this way, the weather data overlaps with the FBS dataset by means of months that correspond to the accounting year (starting on April and finishing on March of the following year).

The three data sets were merged geographically using Geographic Information Systems (GIS) through spatial overlap and network analysis. Specifically, to link farm business data and weather data, the datasets were imported in GIS and were spatially joined. This process joined attribute values from one feature to another (farm business to weather data) based on their spatial relationship (here overlap). To maintain confidentiality, the farm businesses are geographically referenced on the 10x10 km grid square while the weather data is presented on a 5x5 km grid. Hence, weather data was averaged in order to correspond with the 10x10 km grid square of the farm locations. Additionally, the distance to abattoir was calculated through a network analysis as the shortest route between the centre of the grid square in which the farm business is referenced and the closest approved meat establishment (derived from the Food Standards Agency). The estimated distances were then linked to the combined data set using the unique farm identifier. This resulted in a combined dataset which includes data for farm businesses and their corresponding weather characteristics and distance to closest abattoir.

Initially, 215 farm businesses were extracted from the FBS dataset for sheep enterprises and 227 for beef cattle enterprises. Production of these two enterprises is not exclusive, with some farm businesses having both enterprises, hence some of the farms occur in both samples. Specifically, there are 168 farm businesses that produce both beef cattle and sheep. This implies that in the beef cattle enterprises sample the overlapping percentage is 74% whereas in the sheep enterprises is 77.5%. Eight farm observations were dropped from the sheep sample and eight from the beef cattle sample due to missing data.

A flow chart presenting the methodological steps of this study is shown in Fig. 4.1. Initially, the raw data were examined for multicollinearity and existence of outlying observations. In a second stage the raw data is simplified using PCA. The grouped variables (principal components) derived from the PCA were then incorporated in a MLR model to analyse variations in financial and production performance (Areal et al., 2012; Aristya et al., 2017; Micha et al., 2015). In each step of the statistical analysis two distinct models are estimated regarding a) beef and b) sheep enterprises. Distinct models were constructed as the production plans of two enterprises differ to a substantial extend (requirements for housing, feeding stuffs ect.) and thus, the various factors should affect performance in different ways between sheep and beef cattle enterprises. Hence, the analysis is conducted on enterprise level to enable the identification of the drivers of performance among these two types of livestock production. The following subsections analyse in more detail the dataset, study area as well as the statistical analysis.

Fig. 4.1 Outline of the methodological stages



Our analysis incorporates a number of ordinal variables derived from the FBS. These are presented as percentages per class in Table 4.2 and Table 4.3 for the beef cattle and sheep enterprises respectively. Education Level of farmer has six classes ranging from 0 (school only) to 5 (postgraduate qualification). Altitude has three classes corresponding to altitude of holding below 300 m, between 300 m and 600m and higher than 600m. As FBS records information on altitude using the aforementioned classes and not the actual altitude of the farm in meters, in the present analysis altitude classes are used. The variable of SDA Class represents the percentage of the total farm area that is designated as SDA, expressed in quartiles. Rurality Class ranges from 1 (urban) to 4 (deep rural). Finally, ’Beef only’ is a dummy variable that takes the value of 1 if there is only beef (and no sheep) produced within the farm and 0 otherwise. The same applies for the ’Sheep only’ variable. Descriptive statistics for the continuous and ordinal variables are presented in Table 4.1, Table 4.2 and Table 4.3.

Table 4.1 Descriptive statistics for continuous variables of the beef and sheep enterprises

Variable	μ	S.D.	μ	S.D.
	Beef		Sheep	
Farm business variables (from FBS)				
Age of farmer	56	10	55	10
Machinery equipment valuation (£/LU)	118.30	101.06	100.57	87.57
Forage area (Ha/LU) (common land included)	1.74	1.61	2.34	4.82
Liabilities (£/LU)	8,642.83	29,170.73	1,968.58	3,800.33
Paid labour (£/LU)	25.04	37.43	53.78	81.26
Unpaid labour (£/LU)	32.92	63.00	54.70	87.91
Concentrates (£/LU)	261.02	272.52	187.74	131.67
Coarse fodder (£/LU)	27.55	41.34	4.78	7.09
EO (£/LU)	804.42	476.02	72.51	62.67
AGM (£/LU)	303.23	434.76	645.72	255.71
LU	38.65	38.18	231.09	277.00
Single Farm Payment (SFP) (£/LU)	1,561.86	2,288.37	532.47	390.34
Weather variables (from the Met Office)				
Ground frost (count of days per month)	7.18	1.65	7.21	1.45
Mean max temp (°C)	12.09	0.99	11.93	0.90
Mean min temp (°C)	5.13	0.70	5.04	0.66
Rainfall (mm per month)	79.45	32.26	83.41	32.05
Snowfall (count of days per month)	6.10	1.54	6.11	1.37
Sunshine (hours per month)	120.13	12.75	118.26	12.24
Isolation variable (from the FSA)				
Distance to closest abattoir (km)	24.08	14.09	24.4	14.18

Table 4.2 Descriptive statistics for ordinal variables of the beef cattle enterprises (as percentages)

FBS variables	**Class**					
	School only	**GCSE (age 16) or equivalent**	**A level (age 18) or equivalent**	**College / National Diploma/ Certificate**	**Degree**	**Postgraduate qualification**
Education of farmer	41.4	12.7	6.4	29.5	9	1
	Holding < 300 m	**300 m < Holding < 600 m**	**Holding > 600 m**			
Altitude	57.3	37.7	5			
	SDA/ UAA < 25%	**25% < SDA/UAA < 50%**	**50% < SDA/UAA < 75%**	**SDA/UAA > 75%**		
SDA class	27.4	5.6	7.4	59.6		
	Urban	**Town and fringe**	**Village**	**Hamlet and isolated dwellings**		
Rurality class	2.8	2.3	29.7	65.2		
	No	**Yes**				
Beef only	74	26				

Table 4.3 Descriptive statistics for ordinal variables of the sheep enterprises (as percentages)

FBS variables	**Class**					
	School only	**GCSE (age 16) or equivalent**	**A level (age 16) or equivalent**	**College / National Diploma/ Certificate**	**Degree**	**Postgraduate qualification**
Education of farmer	39.6	13	6.3	30.4	9.2	1.5
	Holding < 300 m	**300 m < Holding < 600 m**	**Holding > 600 m**			
Altitude	50.7	43.5	5.8			
	SDA/UAA < 25%	**25% < SDA/UAA < 50%**	**50% < SDA/UAA < 75%**	**SDA/UAA > 75%**		
SDA class	16	5.3	10.6	68.1		
	Urban	**Town and fringe**	**Village**	**Hamlet and isolated dwellings**		
Rurality class	1.9	3.8	28.1	66.2		
	No	**Yes**				
Sheep only	78.7	21.3				

4.2.2 Study area

The sample farms were distributed throughout the LFAs in England. The elevation ranges from 50 m to 950 m (μ = 313 m, SD = 160 m). The predominant agricultural activity within the area is grazing livestock (DEFRA, 2010). Furthermore, within the LFAs several holders (15% of beef cattle enterprises and 20% of sheep enterprises) have common grazing rights (for cattle, sheep and/or other livestock) into areas that have been classified as common land.

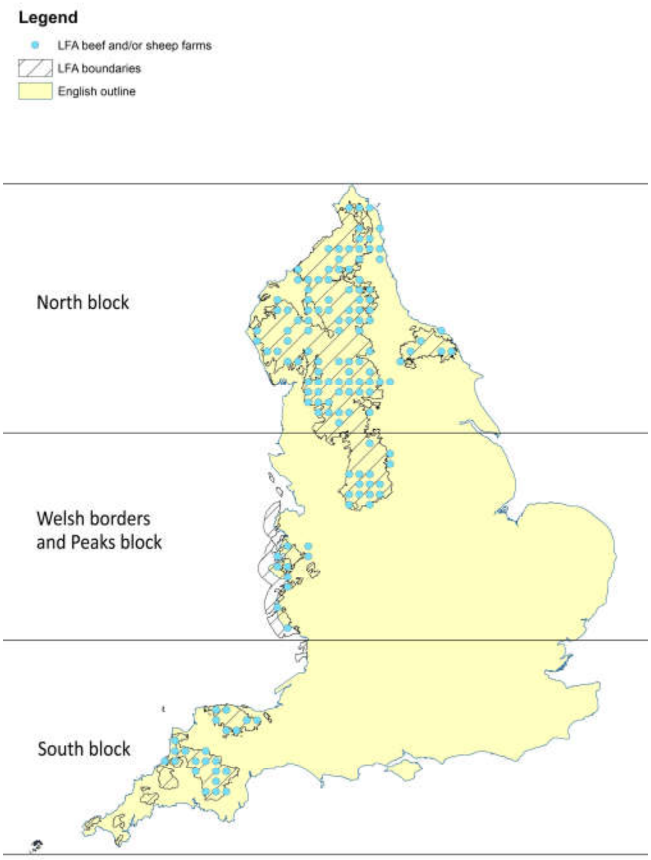
The study area was subdivided into 3 main geographic blocks namely North, South and Welsh Borders and Peaks (Fig. 4.2).

This was in order to minimise the heterogeneity of the sample and was based on the following set of factors:

a) fixed geographical characteristics: weather (differences in temperature and precipitation levels, hours of sunshine, etc.) and landscape conditions (i.e. altitude) which form gradual patterns across the country

b) regional differences in farm-level management decisions: level of specialisation (beef or sheep specialisation), size of farm and off farm activities (agri-tourism) (DEFRA, 2010).

Fig. 4.2 Map of study area



4.2.3 Variable standardisation

A standardisation process is required to reduce scale effects and express the variables into a common set of units to enable analysis. The standardisation has been made on a per Livestock Unit (LU) basis for the continuous financial variables while the ordinal variables are expressed as classes (Table 4.4). Similar methods have been used by other comparable studies (Flaten, 2017; Koknaroglu et al., 2005; Morris, 2009; Winsten et al., 2000).

Regarding management variables, paid and unpaid labour as well as concentrated feeding stuffs and coarse fodder are standardised on a 'per LU' basis. Both machinery and equipment valuation and forage area could be standardised either by the LU or by Utilised Agricultural Area (UAA). The former, is associated with processes of livestock production only. Hence it seems that a 'per LU' standardisation explains better the variation of the dependent variable which captures livestock production. The decision regarding forage area standardisation is a more complicated choice. In particular Wilson

(2011), standardised forage land by number of animals. Within the sample there exists a high level of variance in terms of size and hence a standardisation on a per UAA basis would eliminate this issue. However, the quality of forage land is not consistent in the sample and thus, farms in the more disadvantaged areas need more land to be as profitable as their less disadvantaged counterparts. This means that a standardisation per UAA can be misleading. On the other hand, the area of forage land as a proportion of the UAA mainly reflects the extent to which a farm business is focussed on grazing livestock, rather than explaining variation in terms of level of disadvantage which is one of the core factors for the purposes of this analysis.

Table 4.4 Standardised variables per category

Category	Variable	Expressed (per)
Management choices	Family or Hired Labour Self-sufficiency of forage (coarse fodder) or use of external inputs (concentrated feeding stuffs) Financial Liabilities Machinery and equipment valuation Single farm payment Beef or Sheep only	£/LU £/LU £/LU £/LU £/LU Binary
Landscape characteristics	SDA land Altitude Distance to abattoir Rurality class Forage land (common land included)	Quartile Class (1-3) Km Class (1-4) Ha/LU
Social characteristics of the farmer	Age of farmer Level of Education	- Class (1-5)
Weather	Ground frost	Number of days per month
	Snowfall	Number of days per month
	Mean maximum and minimum temperature	Average of the daily highest and lowest temperatures
	Sunshine duration	Hours per month
	Total precipitation	Mm per month
Regression dependent variables	AGM EO	£/LU £/LU

4.2.4 Principal Component Analysis

The analysis of variation in agricultural performance corresponds to the examination of several farm attributes as potential drivers. This in turn, requires investigation of large datasets that potentially include many parameters. It was important to create a subset of variables that is easy to interpret and also adequate to explain the variance of performances. For this reason the information in the dataset was simplified using PCA, which is a method that reduces dimensionality of large data sets creating smaller sets of variables (Jolliffe, 2002; Linting et al., 2007). This reduction is achieved through the identification of core underlying factors, in which the variation of the data sample is maximum (Ringnér, 2008). As a result, PCA creates a new set of independent, uncorrelated variables (principal components) that are a linear combination of the initial variables (Abdul-Wahab et al., 2005).

The PCA was applied to an initial set of variables that correspond to the categories of landscape, weather, management choices and the social characteristics of the farmer. All variables from the initial dataset were tested for statistical significance through one sample t-tests. In addition, the variables were tested for multicollinearity through correlation matrices. Specifically, the variables of snowfall and ground frost were highly correlated with each other (correlation coefficient greater than 0.9) thus, one of the two had to be excluded from the sample. According to the correlation matrix, the two variables correlated almost identically with the rest of the data. Thus, the selection was then subject to the KMO scores that are described below.

The Kaiser-Meyer-Olkin (KMO) ratio was employed to test sampling adequacy (Kaiser, 1970). KMO can be calculated both partially for a single variable as well as overall for a data sample. The overall scores for the beef cattle and sheep enterprises were 0.65 and 0.56 respectively indicating the appropriateness for conducting PCA in both datasets. Regarding the individual scores, all variables are above the bare minimum of 0.5 except for the variables of proximity to abattoir, snowfall and ground frost that scored 0.33, 0.35 and 0.33 respectively. Weather as a parameter is adequately represented by other variables thus, it was not necessary to include the last two as they would reduce the accuracy of the estimation due to their low score. However, distance to closest abattoir is a central component within this analysis as the study area comprises of generally remote areas hence, it was decided that this variable would be included in the modelling.

In addition, the Kaiser's criterion was considered, suggesting that only principal components with eigenvalues greater than one should extracted for the analysis (Kaiser, 1960). Furthermore, oblique rotation was employed as the most appropriate for the context of this analysis, rather than orthogonal, as it assumes that the principal components correlate with each other which is expected when handling naturalistic datasets (Field et al., 2012).

4.2.5 Multiple linear regression

Multiple Linear Regression (MLR) was employed for the identification of drivers (farm-level social and management parameters as well as weather and landscape characteristics) of productivity and/or profitability of beef and sheep farm businesses in the English LFAs. The MLR model with k variables and *n* observations is formally expressed in the following form

$$y_i = \beta_0 + \beta_1 x_{1n} + \beta_2 x_{2n} + \ldots + \beta_k x_{kn} + \varepsilon_i \,,$$

Factor scores corresponding to the selected principal components of the beef and sheep enterprises were used as explanatory variables (Aristya et al., 2017; Huat et al., 2013; Micha et al., 2015; Tariq et al., 2012). Productivity and profitability of the farm enterprises were used as dependent variables in the model (EO/LU and AGM/LU respectively). The data used in the MLR were tested for statistical significance through one sample t-tests. In addition, to consider multicollinearity, correlation matrices of all independent variables were examined. Finally, the validity of the MLR model estimations in explaining the variations of beef and sheep enterprise performance was checked through the coefficient of determination (R squared).

4.3 Results

4.3.1 Principal Component Analysis

4.3.1.1 Sheep model

A PCA is conducted for the sheep enterprises of LFA farms using 19 variables with oblique rotation (oblimin). The KMO criterion indicates that the sample is adequate with an overall KMO of 0.56 which is considered “mediocre” (Kaiser, 1974) among the acceptable values. The Bartlett sphericity test is significant (χ^2 (171) = 945.43, $p < 0.001$) which indicates that the correlation matrix was not an identity matrix, hence, there exist correlations between the variables in the sample. Regarding eigenvalues, seven components had an eigenvalue higher than Kaiser’s criterion (>1) and cumulatively explained 64% of the variance. The calculated proportion of this sample using eight principal components was 42.6% whereas the root mean square of the residuals is 0.072. Both these metrics are well outside the bounds that should raise concerns. Table 4.5 shows the PCA outputs after the oblique rotation. Values above 0.3 are flagged in bold indicating the loadings that will be considered for the interpretation of the underlying factors within principal components. Interpretation of the principal components is of critical value as it demonstrates the variables that load and formulate them signifying the broader aspect that they represent while providing a shorthand that describe them accurately.

Specifically, component 1 relates to favourable weather, as sunshine and mean maximum temperature load positively whereas rainfall negatively. Mean minimum temperature loads positively on the component as well, however this does not raise concern as the variable captures temperature, thus the higher it is (even among the minimum range) the more favourable are the weather conditions. Rurality class loads heavily to this component as well, however the majority of the heavily loaded variables relate to weather, hence this will not affect the interpretation of the principal component. SDA class also loads (to a lesser extent) negatively on the component validating the content of the component as more disadvantaged areas are likely to have less favourable weather.

Component 2 relates to level of physical disadvantage, as SFP per LU and forage area per LU are loaded heavily. This is mainly driven by the fact that farms with higher proportions of disadvantaged areas within their land need larger land areas to support each Livestock Unit. This in turn is indicated by receipt of SFP per LU which similarly is determined by the hectares of each farm. Therefore, the main underlying factor of this component is related to hectares per LU thus indicating level of physical disadvantage.

Component 3 corresponds to use of feed stuffs as concentrated feeding stuffs and coarse fodder both load heavily on this component. Component 4 relates to size of enterprise (LU). This is clearly indicated by the most heavily loaded variable of LU whereas it is in line with the positive loading of paid labour per LU. The latter is expected to be positively correlated with LU since larger farms will require further external labour inputs. Component 5 regards the social characteristics of the farmer. In particular, this component describes the older and less educated farmers.

Component 6 relates to remoteness as distance to closest abattoir, altitude and rurality class load on it. However, there is an interesting correlation between these variables. Altitude and distance to the closest abattoir are negatively correlated within this component. Although it would be expected that longer distance to abattoirs would indicate more remote farms, it seems that abattoirs are more likely to be found in areas of deeper rurality. In particular, there is a positive correlation between rurality class and number of abattoirs and a negative correlation between rurality class and distance to closest abattoir. Therefore, shorter distance to abattoir in combination to higher altitude of farm indicate farms in areas of deeper rurality that are remote from the larger urban centres.

Component 7 captures the financial liability of farms. In fact, larger liabilities are associated with higher proportions of SDA and lower machinery and equipment valuation, which all are reasonable correlations. The variable of liabilities relates to bank and family loans, bank overdrafts, creditors, hire purchases etc. Sunshine obtains a marginally significant negative loading (-0.3) indicating that favourable weather conditions have a negative relationship with financial liabilities. Finally, component 8 regards the labour per LU. Based on the factor loadings, the component corresponds to higher costs for family (unpaid) labour per LU and smaller for external (paid) labour inputs.

Table 4.5 Principal component analysis for sheep enterprises in LFA farms (N = 207) (continued)

Variables	**Oblimin rotated factor loadings**							
	Favourable weather	Physical disadvantage	Feeding stuffs per LU	Size of farm (LU)	Social characteristics of farmer (Older and less educated)	Remoteness	Financial dependency	Family labour
Altitude	-0.1	0.01	-0.11	0.15	-0.04	**0.77**	-0.04	-0.03
Coarse fodder per LU	0.07	0.12	**0.86**	-0.22	-0.01	-0.04	0.1	0.01
Concentrates per LU	-0.08	-0.1	**0.87**	0.16	-0.06	-0.02	-0.16	0.02
Distance to closest abattoir	**-0.33**	0.25	-0.07	**0.45**	-0.02	**-0.49**	-0.01	-0.11
Education of farmer	0.01	0.06	0.13	**0.45**	**-0.6**	0.13	0.25	-0.08
Forage area common land included per LU	-0.13	**0.83**	-0.07	0.15	-0.05	0.1	-0.09	0.05
Liabilities per LU	-0.01	0.07	-0.05	-0.03	-0.03	-0.03	**0.78**	0.17
LU	0.09	-0.14	-0.13	**0.81**	-0.03	0.02	-0.08	0.09
Machinery per LU	0.05	**0.48**	-0.18	**-0.31**	-0.27	-0.1	**-0.36**	0.11
Mean max temp	**0.79**	-0.04	0.03	0.07	-0.01	-0.16	0.14	0.01
Mean min temp	**0.76**	0.09	-0.05	0	0.11	0.08	0.18	-0.13
Paid labour per LU	0.2	0.22	0	**0.43**	**0.41**	0.09	0.02	**-0.41**
Rainfall	**-0.54**	0.21	0.02	-0.19	0.12	0.4	0.15	-0.06
Rurality class	**0.67**	0.01	-0.03	-0.16	-0.06	**0.35**	-0.11	0.1
SDA class	**-0.35**	0.1	0.23	0.15	0.11	0.22	**-0.4**	0.13
SFP per LU	0.13	**0.83**	0.13	-0.16	0.03	-0.09	0.17	0
Sunshine	**0.69**	0.04	-0.05	0.12	0.05	-0.12	-0.3	0.06
Unpaid labour per LU	0.02	0.07	0.03	0.1	0.12	0.01	0.09	**0.92**
Proportion Variance Explained	0.15	0.1	0.09	0.09	0.07	0.07	0.06	0.06
Cumulative Variance Explained	0.15	0.25	0.33	0.42	0.49	0.56	0.62	0.69

4.3.1.2 Beef model

A PCA was conducted for the beef enterprises of LFA farms using 19 variables with oblique rotation (oblimin). The overall KMO criterion for this model is 0.65 (mediocre) indicating that the sample was adequate. Bartlett's sphericity test was statistically significant (χ^2 (171) = 781.73, $p < 0.001$) indicating that there are large enough correlations for running the PCA. Eight principal components were selected for the beef enterprise model. The results of PCA after oblique rotation are shown in Table 4.7.

Aggregations of higher loadings in the principal components indicate that component 1 relates to favourable weather. Mean minimum and maximum temperature and sunshine load positively and highly on this component. Rainfall loads negatively, validating the identification of the underlying factor, however the load is lower than the rest of the weather variables. Concentrated feeding stuffs load as well but since the majority of the variables that load highly relate to weather, this variable is not considered in this principal component.

Component 2 regards level of physical disadvantage. Altitude, class of SDA and forage land per LU load positively whereas LU and specialisation on beef load negatively. These correlations indicate that the common underlying factor captures level of landscape-related disadvantage.

Component 3 captures financial dependency with high loadings from liabilities and SFP per LU. The interpretation of the fourth component is slightly ambiguous. Altitude and rainfall load positively indicating higher level of physical disadvantage. On the other hand, coarse fodder per LU loads positively and machinery and equipment valuation negatively indicating less mechanised systems which use more coarse fodder per LU. The second combination loads more heavily on the component hence it will be used to label the principal component 4.

Component 5 relates to the social characteristics of the farmer corresponding to younger and more educated farmers. Component 6 captures remoteness and component 7 size of farm (LU) and paid labour obtaining similar loadings to the sheep enterprises PCA. Finally, component 8 regards rurality class although this is formed by the rurality class variable only. Sunshine loads significantly as well, however rurality class reflects population density hence weather is not expected to have any correlation to that.

The two PCAs portray similar results in terms of number of components as well as of content of the underlying factors. In both models, the principal components were formed of significant aggregations of variables in terms of number of variables that load on them as well as of their related content. However, the last component from the beef cattle enterprises PCA was formed from a single variable only. As a result, all components are considered in the next step of the multiple regression analysis with the exception of the latter.

In conclusion, the PCA for both sheep and beef cattle enterprises obtain relatively similar results in terms of the formulated principal components which are aggregated in Table 4.6.

Table 4.6 Aggregated PCA results for beef cattle and sheep enterprises

Beef cattle enterprises	**Sheep enterprises**
Favourable weather	Favourable weather
Physical disadvantage	Physical disadvantage
Financial dependency	Financial dependency
Size of farm (LU) and paid labour	Size of farm (LU)
Social characteristics of farmer (younger and more educated)	Social characteristics of farmer (Older and less educated)
Remoteness	Remoteness
Low machinery evaluation	Feeding stuffs per LU
Rurality class	Family labour

Table 4.7 Principal component analysis for beef enterprises in LFA farms (N = 219)

Variable	Oblimin rotated factor loadings							
	Favourable weather	Physical Disadvantage	Financial dependency	Low machinery valuation	Social characteristics of farmer (younger and more educated)	Remoteness	Size of farm and paid labour	Rurality class
Altitude	0.01	**0.45**	-0.04	**0.34**	-0.03	**0.36**	0.32	0.28
Beef only	-0.04	**-0.74**	0.03	0.02	-0.18	0.02	0.03	0.15
Class SDA	-0.13	**0.75**	-0.03	-0.03	-0.08	-0.13	0.04	0.03
Coarse fodder per LU	-0.09	0.02	0	**0.68**	0.01	0.13	-0.07	-0.08
Concentrates per LU	**-0.32**	-0.03	**-0.34**	-0.18	0.1	**0.62**	0.06	0.07
Distance to closest abattoir	-0.27	0.13	-0.16	-0.11	0.1	**-0.7**	0.19	0.18
Education of farmer	-0.06	-0.1	0.16	0.14	**0.76**	0.05	0.16	-0.02
Forage area common land incl per LU	-0.22	**0.39**	0.25	0.23	-0.01	-0.31	-0.01	0.02
Liabilities per LU	-0.05	-0.24	**0.76**	-0.03	0.14	-0.03	0.1	0.08
LU	-0.1	**-0.42**	**-0.42**	0.03	0.12	-0.14	**0.4**	-0.12
Machinery equipment valuation per LU	-0.17	0.18	0.3	**-0.6**	0	0.28	-0.01	-0.02
Mean max temp	**0.79**	0.06	-0.21	-0.17	0.12	0.02	0.06	-0.06
Mean min temp	**0.86**	-0.07	0.02	0.17	0.02	0.01	0.01	-0.03
Paid labour per LU	0.08	0.03	0.1	-0.06	-0.04	-0.04	**0.89**	-0.06
Rainfall	-0.22	0.23	0.14	**0.5**	0.05	0.03	-0.22	0
Rurality class	-0.01	-0.04	0	0	0.05	-0.05	-0.07	**0.92**
SFP per LU	-0.11	0.19	**0.74**	-0.06	0.04	-0.02	0.05	-0.09
Sunshine	**0.63**	-0.07	0.09	-0.21	-0.13	0.03	0.08	**0.39**

4.3.2 Multiple Linear Regression

The principal components of the PCAs were imported in the regression analysis as explanatory variables. Model simplification was conducted by means of not including principal components formulated by only one variable (Rurality class in the beef cattle enterprise model). Further to that, PCA was primarily conducted to reduce the dimensionality of the initial dataset which resulted in a smaller subset of 8 variables (reduced from 19). Thus, no further model simplification was considered. The dependent variables relate to the performance variables of productivity (EO/LU) and profitability (AGM/LU). Four different models were conducted for each type of enterprise, distinct models examine each one of the three geographic blocks and one model tests the total study area. This allowed consideration of geographic variation in the importance of variables related to productivity and profitability. The selected geographic reference group is the North block since we assume that it is the most challenging among the geographic blocks of the study area. However, the explanatory power of the variables in each region is examined through the distinct models and not in the model that combines all regions. Aggregated results from the MLR are presented in Table 4.8. This table demonstrates the statistically significant coefficients of all the MLR models for both enterprises. More detailed presentation of the results for each regression analysis can be found in the Appendix.

Results from the regression analysis of all regions indicate that sheep enterprises in the Welsh Borders and Peaks block perform better in terms of AGM in comparison to the North. Although the current approach considers statistical significance at 5% level, this particular estimation is statistically significant at the 10% level of significance (a = 0.10) (p value = 0.08) and implies that farm enterprises in this region are more profitable by £90/LU when compared to farms of the North block. However, the coefficient of determination for this regression model is relatively low (approximately 10%) whereas the adjusted R squared is 5% indicating a big proportion of unexplained variation within the estimation. No similar findings were obtained for the equivalent model of the beef enterprises.

Regarding sheep enterprises, in the North block, favourable weather is a statistically significant positive determinant for profitability. On the other hand, physical disadvantage is negatively correlated with productivity. Both of coefficients indicate a significant effect on performance of sheep farming (£58.9/LU and - £33.6/LU per extra unit of the explanatory variable with p values of less than 0.10). Results regarding the South block show that feeding stuffs per LU are positively correlated to the performance of farms both in terms of EO as well as of AGM. Furthermore, financial dependency is a negative determinant for performance (EO and AGM). The coefficient of determination is 40% for the AGM model and 47% for the EO model. On the contrary, results from the Peaks and Welsh Borders block indicate that feeding stuffs per LU are negatively correlated to the profitability of farms (- £127.5/LU per extra unit in the feeding stuffs variable). Finally, family labour is a positive determinant of EO and AGM.

Concerning the beef enterprise models, low valuation of machinery and equipment is a highly statistically significant negative determinant of performance (AGM and EO). Furthermore, remoteness from urban centres and proximity to abattoirs is positively correlated with AGM and EO in most of the regions whereas the largest coefficients are estimated for the South block. Financial dependency correlates negatively with the EO of South and Peaks and Welsh Borders block but positively with AGM of the North. Size of enterprise (LU) is a positive determinant of performance specifically for the Peaks and Welsh Borders block. The social characteristics of farmer (younger and more educated) have a positive effect in EO within the North block. Finally, favourable weather is negatively correlated to EO in the North block. No significant effects are estimated for the level of physical disadvantage regarding the performance of beef enterprises.

Table 4.8 Aggregated statistically significant results from the MLR modelling for the beef cattle and sheep enterprises (continued)

Enterprise	**Block**	**Dependent variables**	**Explanatory variables**									
			Favourable weather	Physical disadvantage (+)	Feeding stuffs per LU	Financial dependency	Aged and less educated farmer	Size of enterprise (LU) and hired labour	Family labour	Remoteness (from urban)/Proximity to abattoir		
Sheep	North											
		AGM per LU	58.91[b]									
		EO per LU		−33.63[c]								
	South											
		AGM per LU			64.68[c]	−130.6[c]						
		EO per LU			104.16[b]	−165.9[b]				88.94[b]		
	Peaks and Welsh Borders											
		AGM per LU			−127.55[b]				79.52[b]			
		EO per LU							102.29[a]			
	All blocks										Peaks and Welsh Borders block	South block
		AGM per LU	37.45[c]	−36.95[c]							90.59[c]	
		EO per LU		−36.42[b]								

Table 4.8 Aggregated statistically significant results from the MLR modelling for the beef cattle and sheep enterprises (continued)

			Favourable weather	Physical disadvantage (+)		Financial dependency	Younger and more educated farmer	Size of enterprise (LU) and hired labour	Low machinery valuation per LU	Remoteness (from urban)/Proximity to abattoir		
Beef	North											
		AGM per LU				63.93[c]			−125.49[a]	−78.2[b]		
		EO per LU	−76.83[c]				78.43[b]		−193.68[a]	143.95[a]		
	South											
		AGM per LU								176.65[a]		
		EO per LU				−156.48[b]			−141.06[b]	310.58[a]		
	Peaks and Welsh Borders											
		AGM per LU						93.24[c]	−206.3[a]			
		EO per LU				−178.26[a]		141.46[a]	−187.2[a]	139.48[c]		
	All blocks										Peaks and Welsh Borders block	South block
		AGM per LU							−128.18[a]	−54.11[c]		
		EO per LU	−76.98[b]			−46.09[c]	69.25[b]		−180.93[a]	161.4[a]		

[a] Statistically significant coefficient at the 1% level or less

[b] Statistically significant coefficient at the 5% level or less

[c] Statistically significant coefficient at the 10% level or less

4.4 Discussion

Regional differentiation of financial performance and productivity of farm businesses has been investigated through analysis of factors such as farmer training, age and education as well as agricultural investments (Giannakis and Bruggeman, 2015). Furthermore, regional heterogeneity has been identified relating to natural and economic backgrounds that may determine management decisions as well as prices (Hanley et al., 2007; Karlsson and Nilsson, 2014). Our results show that sheep enterprises of farm businesses located in the geographic block of Welsh Borders and Peaks are statistically significant more profitable than their counterparts in the North block. This finding indicates underlying correlations within the Welsh Borders and Peaks block that make it more profitable in comparison to the North. In particular, higher levels of family labour participation occur within this block which according to Wilson (2011) indicate lower labour costs per LU thus, triggering higher financial performance. Labour use efficiency has been described as a solution for the challenges that farms in the uplands face and can be stimulated by higher technological adoption such as electronic identification tags to improve identification, handling and time spent per animal (Giannakis and Bruggeman, 2015; Morris et al., 2017; Smit et al., 2015). According to Morgan-Davies et al. (2018), precision livestock systems have the potential to reduce the on farm labour demand by 36% and hence significantly reduce labour cost and improve efficiency.

Considering the fixed characteristics of the landscape, the level of physical disadvantage, which is comprised of weather, altitude and terrain, is a negative determinant for the performance of sheep farms particularly in the North block. The latter implies that farm businesses located in more disadvantaged areas face significantly more barriers in their productivity and profitability. Kowalczyk et al. (2014) agree that altitude plays a major role in agricultural performance whereas Mena et al. (2017) point out the importance of climate for vegetation growth.

On the other hand, physical disadvantage does not appear to be a negative determinant for the performance of beef cattle enterprises. A possible interpretation is that beef cattle enterprises are less likely to be located in severely disadvantaged areas.

Specifically, the majority of the beef farms in the sample are located in altitudes bellow 300 m verifying that they are less likely to be affected by harsh conditions. The negative coefficient of the favourable weather on productivity of beef cattle is on contrary to the findings of McCann et al. (2010) who links mortality of dairy cattle to poor weather conditions. However, this negative relationship may not indicate a causality, such as that favourable weather results in reduction of productivity. Rather, it is possible that other fixed or non-fixed parameters that are related to favourable weather result in lower EO/LU. Although weather is not found to be a determinant for beef cattle production systems through this analysis, evidence of relevant literature suggest that weather conditions may affect livestock production (Gaughan, 2012; Rojas-Downing et al., 2017).

Remoteness from larger urban centres and proximity to abattoirs is a significant positive determinant for beef cattle enterprises performance in all blocks of the study area. This result is in accordance with Krishna and Veettil (2014) who reported that remoteness correlates with higher yields. It would be expected that this relationship is negative, as remote farms lack opportunities for external labour inputs (Darnhofer et al., 2010) and information (Krishna and Veettil, 2014). On the other hand, shorter distances between farms and points of interest (abattoirs) imply lower transportation costs, hence bigger margin for profits (Ojiem et al., 2006). Thus, the appropriate facilitation services need to be established to guarantee easy access and proximity to the market for the agricultural businesses. For example, this could potentially regard supporting the introduction of mobile abattoirs or the establishment of other forms of auction markets such as web based markets.

The findings of this analysis regarding management decisions of farmers suggest that financial dependency (financial liabilities, support payments) of farm businesses is a negative determinant for productivity of beef and sheep enterprises but affects positively profitability of beef cattle enterprises in the North block (Bojnec and Latruffe, 2013; Davidova and Latruffe, 2007; Fertö et al., 2017; Mugera and Nyambane, 2015). The former is in accordance with studies that examined the effects of subsidies in livestock farm businesses. Morgan-Davies et al. (2012), and Gelan and Schwarz (2008) found that the introduction of the SFP caused considerable reductions of number of breeding ewes and beef cattle in Scotland. Regarding the positive relationship with profitability, it is possible that the coefficient reflects positive externalities from the SFP. The negative relationship suggests that payments on per hectare basis failed to provide adequate support and motive for livestock farmers in the LFAs and generally lead in more extensive production systems (Acs et al., 2010).

Feeding stuffs per LU in the sheep enterprises showed contradictory results. Different relationships were found for the distinct geographic blocks. Underlying characteristics such as weather or physical disadvantage determine the dependency on external inputs for feeding stuffs as they affect the quality and yield of the forages (Flaten et al., 2015; Mena et al., 2017). Generally higher levels of purchased feeding stuffs are an essential obstacle for farm profitability as they lead to increased costs (Finneran and Crosson, 2013; Ripoll-Bosch et al., 2012). Thus, farm businesses should be encouraged to be less dependent on external inputs by production of home grown feeding stuffs when this is achievable (Mena et al., 2017). Due to the landscape characteristics of the study area, there are farm businesses located in areas with no available land for cultivation hence these farms are not able to produce homegrown feeding stuffs.

The size of the enterprise (LU) and hired labour showed significant results for the beef cattle enterprises of the Welsh Borders and Peaks block. The relationship is positive suggesting that productivity and profitability increase with the size of farms (number of beef cattle) and hired labour. Morgan-Davies et al. (2012) suggest that magnitude of production depends greatly on availability of external labour which in turn shapes management decisions in the farm. Although relevant literature suggest a range of possible solutions for decreasing the on farm labour demand, it is still important that upland farms have adequate supply of labour so that their production is not decreased due to shortages, even in the cases that the demand has decreased through technological advancement.

Machinery and equipment valuation is one of the most important determinants specifically for the beef cattle enterprises, throughout all geographic blocks of the study area. It is found that lower valuation of machinery, which suggests either equipment that is out of date or lack of machinery, is negatively correlated with productivity as well as profitability. This is in concordance to Hansson (2007) who reports that higher adoption of technology within the farm results in higher profitability. These findings highlight the importance of technological adoption for the performance of beef cattle farming systems.

Concerning the social characteristics of the farmer, lower age and higher education level of the farmer in the North block has a positive relationship with the performance of beef cattle enterprises. From the perspective of age, our findings are on contrary to Finneran and Crosson (2013), who report that the age of farmer has no significant effects on incomes. However, the present results are in concordance with the findings of Giannakis and Bruggeman (2015) who highlight the negative relationship between age and economic performance of farm businesses. Such findings call for strategies that will promote livestock farming attracting further younger farmers. As for the parameter of farmer's education level, related studies have shown contrasting results, either reporting that education is not a significant determinant for the economic results of farm businesses (Goswami et al. 2014), or that higher education level of the farmer is expected to be positively related with the performance of farms (Hansson, 2008). The role of education should be accounted for in the future strategies by means of introducing networks of transferable knowledge (Garrett et al., 2017) that will mitigate the lack of knowledge and information.

This study addresses two main aspects regarding the analysis of leading and lagging performances in beef and sheep farming in the LFAs of England in the context of identifying the parameters resulting in such differentiations. The first highlights the farm level management decisions that affect production performance and profitability. Our analysis showed that the size of enterprise (LU) and hired labour, feeding stuffs per LU and lower age and higher education level of farmer enable higher performance for farm businesses allowing them to expand and develop. Through the upland policy review, DEFRA (2011) proposes that effective management practices and knowledge that enhance agricultural performance should be mirrored across the uplands. With regards to education and knowledge of efficient practice, the Rural Development Programme for England (RDPE) (2007-2013) has highlighted the importance of this parameter proposing training for developing the hill farming skills and the establishment of broad knowledge transfer networks (DEFRA, 2007). Expansion of farm enterprises depends greatly on availability of labour that can be a significant issue in such remote areas. In relevant case studies, approaches suggest the establishment of co-operations between sectors and the identification of human capital gaps in order to construct local recruitment plans (Jungsberg et al., 2018).

The second aspect regards the identification of broad spatial patterns in the feasibility of beef and sheep farming due to fixed natural characteristics. These characteristics correspond to weather, remoteness and level of physical disadvantage. In situations where these negative drivers dominate, farming in landscapes of lower productivity becomes heavily handicaped. Thus, an efficient policy mechanism should recognise spatial variation in financial deprivation. Policy support in such situations should develop conservation strategies promoting restoration of natural ecosystem services (Hodgson et al., 2010; Strohbach et al., 2015) such as water quality, flood and climate regulation. Towards this direction, Payment for Ecosystem Services (PES) provide a range of market based schemes rewarding land owners for delivering and maintaining these services (DEFRA, 2013). According to DEFRA (2016), the Peatland Code and Visitor Giving Schemes (VGS) have proven to be essential for providing tools for restoration and enhancement in the context of environmental quality and tourism within the uplands. Such schemes market the environmental benefits resulting from restoration of peatland, improving soil conditions while increasing carbon storage capacity, and the investment in tourist infrastructure achieving local and environmental benefits (DEFRA, 2018c; Reed et al., 2013). In such way, upland rural communities will be provided with some valuable options with regards to regenerating their economy sustainably in the scenario that agricultural production ceases. On the other hand, within more productive landscapes, farming systems should be encouraged to maintain agricultural production and keep enhancing biodiversity (Strohbach et al., 2015). Furthermore, policies should target particular farming systems rather than broad spatial units, tailoring support on the specific characteristics of each system (O'Rourke et al., 2016).

Finally, with regards to both the aspects discussed above, and particularly the landscape characteristics, there exist a range of unmeasured factors that may explain differentiations in performance between different areas. Such factors may concern soil characteristics as well as the bedrock type that are to affect the quality of forage land and thus, the grass as feed intake for the livestock.

4.5 Conclusions and limitations of the approach

This study demonstrates an analysis of the parameters that cause variations in performance of beef and sheep farming in the LFAs. Factors that were examined as possible determinants for leading or lagging performances include management choices, weather, landscape characteristics and the social characteristics of the farmer. In particular, this approach decomposes the causes of variation in performance into two core dimensions. The first, narrows down certain farm-level managerial choices that benefit or hinder agricultural performance. The second regards broad spatial patterns across the country in which beef and sheep farming underperforms. The latter is expressed as a result of fixed environmental and physical parameters that impact on the farming systems.

Findings of the study suggest that financial dependency, the level of physical disadvantage and low valuation of machinery are negative drivers of performance. On the other hand, favourable weather, proximity to abattoir, size of farm (LU) and labour as well as the lower age and higher education level of the farmer are positive drivers of performance. Furthermore, geographical implications through this analysis point out that sheep enterprises based in the geographic block of Peaks and Welsh Borders, are likely to be more profitable than those based in the North block.

Limitations have emerged through this analysis due to absence of accurate geographical location of the farm businesses. The datasets (FBS, Met Office, Food Standards Agency) were linked within the GIS software. However, to maintain confidentiality, the location of the farms is geographically referenced on the 10x10 km square grid rather than by the precise location. This limited to an extent the methodological approach which would have been able to create further implications in case that the exact location of the farms was provided by the FBS dataset. The latter would also allow for further datasets to be linked such as those relating to soils and geography which may provide useful information regarding drivers of performance of the grazing livestock systems in the LFAs.

A future development of this analysis might include further investigation of the specific identified drivers among the four core categories of variables of this study. Specifically, the impacts of remoteness may be studied in more depth using relevant information regarding access to inputs and transportation costs in order to account for direct effects that remote farm businesses face. In addition, further research in machinery and equipment used on farm may reveal particular practices that enhance efficiency and performance of livestock enterprises. A potential solution may be the adoption of machinery-sharing arrangements which regard joint ownership as well as coordinated purchases of production equipment (Larsén, 2010). Furthermore, with regards to improving production of feed for developing more cost-effective practices, future work could focus on the collaboration of upland and lowland farms through cover crops grazing (Poffenbarger, 2010).

The findings of this approach suggest that there is a need for a common policy for the LFAs that will promote sustainable development implementing measures that benefit the environment allowing the achievement of agricultural produce. In particular, policy solutions need to spatially target support according to the level of disadvantage. To do so, a new classification should be designed replacing the previous broad designation criteria that were applied across the whole LFAs. Rather, these should combine altitude and weather characteristics, since they play a significant role in farm performance, considering the extent to which the landscapes are exposed to them. In heavily handicaped landscapes of poor agricultural performance, support should focus on delivering environmental benefits (ecosystem services). In more productive areas, policies should encourage maintenance of sustainable agricultural production and continue to provide effective options for delivering environmental benefits. In any case, the role of education should be accounted for by means of introducing networks of transferable knowledge to provide essential information regarding particular practices that can enhance livestock production systems within the LFAs.

Finally, it would be valuable to observe how the forthcoming policies could address these challenges and provide frameworks that would account for natural disadvantages and also exploit information on management decisions that will enhance performance of LFA livestock systems and environmental quality within the uplands. Towards this direction, our work provides a framework that is based on the use of FADN data and hence it can broadly be applied to all EU member countries to evaluate livestock systems based on the LFAs.

Chapter 5

Evaluating integration of crop and livestock production systems as an option for the sustainable development of hill farms

5.1 Introduction

The European Union (EU) has designated areas in which agricultural production is more challenging due to harsh natural conditions, the Less Favoured Areas (LFAs). To mitigate production risks, ensure continuous use of agricultural land, maintenance of the countryside and generally to improve the sustainability of farming systems, the EU provides financial support to hill farmers (European Commission, 2005a). Agricultural production in these areas across Europe is restricted by poor climate, lower soil productivity, steep slopes and harsh conditions (European Commission, 2006; Harvey and Scott, 2015). Presence of natural handicaps may lead in lower productivity within the LFAs that could result in decrease or cessation of farming activities hence in land abandonment and a series of environmental and social risks related to loss of biodiversity, depopulation or loss of agricultural land (European Commission, 2010, 2005a). Thus, there is an emerging call for strategies and policies that will enable the development of sustainable hill farming systems.

Grazing livestock production is the predominant agricultural activity within the LFAs of England (DEFRA, 2010). On average, crop production accounts for approximately 5% of the total output of farm businesses in the LFAs (Harvey and Scott, 2015). Specialisation of livestock production emerges in areas dominated by natural handicaps with smaller farm holdings, where animal production has long been established as the predominant type of agricultural activity (Martin et al., 2016; Peyraud et al., 2014). However, specialisation of production on hill farms has led to environmental degradation and reduction of biodiversity (Bonaudo et al., 2014; Peyraud et al., 2014; Tichit et al., 2011).

Integration of crop and livestock production systems (ICLS) has emerged as a strategic management approach in the sustainable planning of agricultural systems (Duru and Therond, 2015; Hendrickson et al., 2008; Sanderson et al., 2013). From the economic perspective, diversification of agricultural production enables benefits from economies of scope (Sanderson et al., 2013) which result in lower costs of production in integrated production systems when compared to specialised ones (Panzar and Willig, 1981). ICLS allow the farm businesses to be less dependent on external inputs by utilising home grown crops as feeding stuffs as well as by using animal manure as natural fertilisation for crop production (Soussana and Lemaire, 2014). Furthermore, utilisation of crops as forage at the farm level has been described as a process that enhances productivity within integrated agricultural systems (Bell et al., 2014).

From the environmental perspective, integration of agricultural production systems provides the option of reusing resources at the farm level (Schiere et al., 2002) which leads to nutrient cycle improvement (Reganold et al., 2010). In addition, ICLS provide environmental benefits through management of intractable weeds and diseases, enhanced water consumption efficiency (production of dual-purpose crops, that are foraged during vegetative phase while harvesting for grain, are sown earlier and have longer vegetative phase and thus, higher water use efficiency due to deeper rooting) and improvement of soil quality (Bell et al., 2014).

While ICLS has been described as a strategy that enhances the sustainable development of farming systems, a series of parameters discourage farmers from implementing it exist in farm business organisation. Within the economic and political context, historically, mass-production objectives promoted the development of economies of scale which resulted in specialisation of production and larger farm sizes (Ryschawy et al., 2013). Additionally, various farm structures require the relevant knowledge of the dynamics between crop and livestock production systems which emerges as another barrier as many farmers may lack the technical knowledge (Martin et al., 2016). Furthermore, the implementation of ICLS depends on the suitability of landscape and climate which implies that in areas with more harsh conditions it may be more difficult to adopt such organisation plans. More specifically, in areas with more favourable conditions, production of cash crops is preferred because of the high-yield potentials

(Gil et al., 2015), while in areas with more unfavourable environmental and physical conditions the cultivation of land is not feasible due to restrictions on mechanisation (e.g. steep slopes). The latter provides an interpretation of why ICLS is to be implemented in intermediate areas, in which crop production is feasible but on the other hand does not attain high yield productivity (Bonaudo et al., 2014). Furthermore, relevant studies suggested that the adoption of ICLS depends on labour availability (as greater workload may be required) (Lemaire et al., 2014; Poffenbarger et al., 2017), local supply chain infrastructure (storage plants, production-input suppliers) and financial capital to invest in the new production systems and technology (Garrett et al., 2017).

Studies have employed Linear Programming (LP) modelling to examine how various levels of integration between crop and livestock production affect farm level sustainability (Sneessens et al., 2016). Furthermore, this method has been employed to optimise agricultural land use allocation by proposing minimisation of costs as well as maximisation of compactness (Aerts et al., 2003; Memmah et al., 2015). Additionally, approaches have attempted to optimise the integration between the various enterprises within the farm business, aiming towards profit maximisation (Annetts and Audsley, 2002; Gameiro et al., 2016; Glen, 1986; Veysset et al., 2005).

The aim of this study was to investigate the optimisation of integrated crop and livestock production systems to increase farm business profitability, and thus ensure the future sustainability of the grazing livestock systems and maintenance of environmental quality in the LFAs of England. More specifically, we analysed differences in profitability (here Annual Gross Margin[8] and Net Farm Income[9], AGM and NFI respectively) emerging from optimised integration and utilisation of available resources, identifying the policy implications for the design of sustainable agricultural

[8] Gross Margin: Output from the enterprise less the Variable Costs, including the allocated variable costs of grass and other forage; Net Farm Income: It is equal to Gross Margin less Fixed costs that consist of Unpaid Labour, Rental Value, Imputed Rent on Tenants Improvements and adds to Ownership Charges, Net Interest Charges, and the Imputed rental value of the farmhouse.

[9] Net Farm Income: Gross Margin less fixed costs. Fixed costs include labour, machinery and general farming costs and land expenses.

systems in the LFAs. In addition, structural changes in farm businesses from optimised farm organisation were examined, along with resulting land use changes.

To explore the different strategies to promote the future sustainability of LFA farms, a LP model was constructed integrating the parameters of feed requirements, housing capacity, stocking densities, labour and land use. The LP method used distinguishes several models that represent a gradual set of production systems ranging from farm businesses that utilise poor permanent pasture only, to farms that cultivate arable land and integrate crop and livestock production. This allowed the investigation of various levels of integration between crop and livestock production systems on economic as well as environmental performance.

5.2 Methodology

5.2.1 Dataset and variables

To investigate the optimisation of the profitability of upland farms by integrating crop and livestock enterprises, the study uses data derived from the Farm Business Survey (FBS). The FBS is a comprehensive dataset that provides information regarding financial and physical performances of a sample of farm businesses across England[10]. In the present analysis data for the 2013-2014 accounting year were employed using records of 139 farm businesses. Additionally, records of the previous 4 accounting years (2009-2013) were employed to calculate the historic maximum numbers of beef cattle per farm business. In addition, financial and physical data for the crop and livestock production were obtained from the Farm Management Pocketbook by Nix and Redman (2016) and also the Farm Management Handbook provided by Scotland's Farm Advisory Service (2016).

The objective function of this method estimates the AGM which corresponds to market returns (enterprise outputs) less variable costs. Variable costs for the livestock

[10] Further information regarding the FBS dataset, methods of data collection or getting access can be found in the following link: https://www.gov.uk/government/collections/farm-business-survey

enterprises correspond to costs for concentrated and homegrown feeding stuffs, veterinary and medicines and other livestock costs (livestock haulage, packaging material, working dog expenses, bio-security costs etc.). Crop enterprise variable costs include costs for seed, fertilisers, crop protection (pesticides) and other requirements (soil analysis, soil sterilisation, marketing and haulage, packaging materials etc.). Livestock components in the modelling are expressed on a ‘per livestock unit’ basis for the beef cattle and sheep production while a ‘per hectare’ basis is used to express the crop components. Furthermore, the costs of forage land are included in the objective function as the FBS dataset does not consider them in the calculation of livestock variable costs. In this method, forage land is disaggregated into the classes of temporary grassland which consists of grass/clover mixtures less than 5 years old, permanent grassland that comprises permanent pastures over 5 years old and rough grazing. Descriptive statistics with regard to AGM, NFI, area used for crop and livestock production, labour inputs, stocking rates, maximum number of beef cattle on farm and permanent grass area used per livestock unit are presented in Table 5.1. Further description of the model inputs is available in the model activities section.

Table 5.1 Descriptive statistics of the inputs used in the linear programming models

μ / SD	AGM (£/LU or £/ha)	NFI (£/LU or £/ha)	LU or Hectares	Labour (hours/year)	Stocking rate	Max number of beef cattle	Permanent grass (ha) per LU
Livestock production	463 / 275	363 / 618	72 / 56	3288 / 2529	0.5 / 0.3	94 / 78	1.7 / 2.1
Arable land production (main crops, fodder crops, temporary grassland)	660 / 288	-41 / 166	74 / 91	714 / 1175	- / -	- / -	- / -
Permanent grass	- / -	- / -	125 / 97	388 / 301	- / -	- / -	- / -
Rough grazing	- / -	- / -	42 / 55	63 / 82	- / -	- / -	- / -

5.2.2 Linear Programming

This study constructs a deterministic, single period LP model that maximises the AGM of farm businesses in the LFAs of England (Benoit and Laignel, 2010; Hosu and Mushunje, 2013; Olaizola et al., 2015). Environmental backgrounds are incorporated in the approach by constraining the optimisation according to environmental conservation objectives (appropriate stocking densities) and physical barriers (land availability). The solution of the model provides the corresponding optimal allocation of the various production enterprises including land use, labour and fertiliser requirements along with stocking rates. To better examine the effects of integrating crop and livestock production, the modelling is segregated into four distinct scenarios (Table 5.2). These scenarios correspond to type and quality of farmed land ranging from systems that utilise poorer permanent pasture only[11], to systems that utilise higher quality of pasture (temporary grassland) in combination with arable land. Comparisons between scenarios will enable the discussion of the most feasible type of production system from the economic, social as well as the environmental perspective. In this section, the general form of the LP model along with the objective function is discussed and then the model activities along with the constraints are described.

5.2.3 Model structure

The structure of the model is based on the general form of Linear Programming models proposed by Hazell and Norton (1989):

Maximise $Z = c'x$ (33)

Subject to: $Ax <= b$ (34)

and $x >= 0$ (35)

[11] No discrete classes of quality of permanent pasture exist within the method. Permanent pasture is generally located in the areas that face the most challenging conditions and have lower productivity. On the other hand, temporary grassland (based within arable land) corresponds to fairer conditions (topography and climate) and thus is more productive. This is why we classify permanent pasture as of poorer quality.

Where Z is the AGM at farm level, c is the vector of gross margins or costs per unit of activity, x the vector of activities, A is the matrix of technical coefficients and b is the vector of resource availability and technical constraints. The maximisation of (33) is subject to a range of constraining factors that regard livestock housing capacity, stocking densities, livestock feeding requirements, labour and land use. These factors form seven constraints that are applied in the optimisation method. The production activities of the farm business are organised in 15 categories describing production of beef cattle, sheep, temporary and permanent grass, wheat (spring and winter), barley (spring and winter), triticale, oats (spring and winter), beans, peas and oilseed rape (spring and winter).

Table 5.2 Integration scenarios in the LP modelling

Optimisation Scenario	Description	Percentage of arable land in the farmed area	Number of farm businesses
PPO	Permanent grassland and rough grazing only	0	74
PPM	Mainly permanent pasture and rough grazing with some arable land	<25%	28
PPA	Permanent pasture and rough grazing integrated with arable land	25-50%	20
AMP	Mainly arable land with some permanent pasture and rough grazing	>50%	17

The modelling of the current method was implemented in the statistical software R using the package of LPsolveAPI. Individual models were constructed for each of the farm businesses and were solved through a loop in R.

5.2.4 Model activities

Livestock Housing capacity. Housing is a significant parameter for the production of grazing livestock and has been considered as a constraining factor in relevant studies

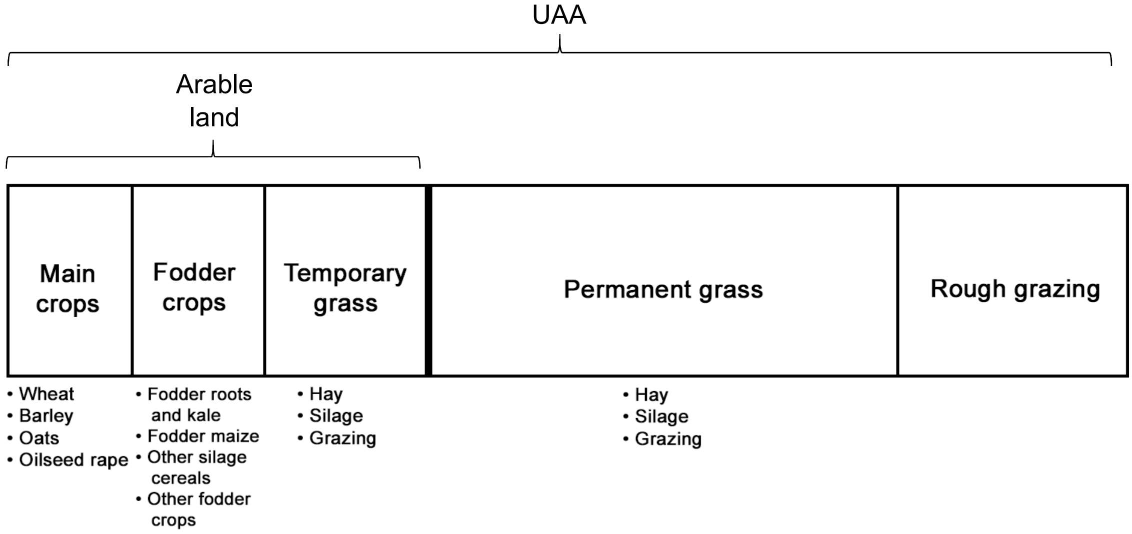
(Acs et al., 2010; Jansen and Wilton, 1984; Veysset et al., 2005). However, for the areas under consideration, housing is rarely required for sheep enterprises thus it is only applied to the beef cattle enterprises. Specifically, this parameter indicates the number of beef cattle that can be maintained on each farm. However, the FBS dataset does not provide information regarding currying capacity of buildings as such. Therefore, the maximum historic record (over the accounting years of 2009-2014) was used as an indicator for the carrying capacity of the farm. This assumes that building capacity remains the same and is available for use.

Feeding stuffs requirement. Concerning feeding requirements, farm businesses can utilise their land for cultivation of temporary or permanent grassland as well as rough grazing. This type of intake can fulfil part of the dietary requirements of livestock. Additionally, home grown forage cereals (such as wheat or barley) can be produced and used on farm as feeding stuffs and/or compound feeds can be purchased. However, in the present method, crop production and concentrates purchased are not set to contribute to the feeding requirements of livestock. This was decided as the nutritional requirements of the flocks under consideration remain unknown due to lack of information on age and liveweight of the sheep and beef cattle. The use of feeding requirements as a constraint in this study relates to land used for rough grazing, permanent pasture and the cultivation of temporary grassland. FBS data were used to calculate the current number of hectares per animal on each farm. This estimates the requirement per head in hectares which varies between the farms in the sample due to quality of pasture. Additionally, a ratio between temporary and permanent grass land was estimated. This ratio captured the balance between poorer (permanent) and higher (temporary) quality of grassland. The vast majority of the farms under consideration (66%) had a ratio of temporary and permanent grass land of 0 to 0.25. Specifically, this parameter forced the model to utilise some of the arable land for cultivation of temporary grass and forage crops. The latter was vital for the accuracy of the estimations as stocking capacity depend greatly on the quality of pasture. These are employed as fixed parameters per farm business in the LP modelling so that adequate pasture or temporary grassland is provided to the livestock.

Stocking rate. This rate indicates the number of livestock units per hectare (LU/ha) that a farm is capable of supporting, with respect to environmental conservation as well as to economic interests. No recommendations exist for a maximum stocking density in English livestock farms, thus this had to be calculated from the FBS dataset. Due to variations in quality of pasture in the study area, the forage land used for this calculation had to be adjusted on the basis of effective stocking density. This is provided only for the rough grazing areas while the permanent and temporary grassland remain unadjusted. The maximum effective stocking rate in the study area is 2.54 LU/ha (approximately 1 cow per acre) which is incorporated in the model as the upper bound. According to Scotland's Farm Advisory Service (2016), stocking rates range from 0.5 LU/ha which indicate very extensive production systems to 2.5 LU/ha which correspond to very intensive systems.

Land use. The present method allows the reallocation of crop and livestock enterprises within the farm. However, the physical characteristics of the study area call for a disaggregation of the utilised agricultural area (UAA) of each farm. Typically, in the upland farms there are some lower altitude improved areas (arable land) within their UAA in which crops can be grown (forage crops, other crops and temporary grass) and also there are areas situated at higher altitude facing harsh conditions providing only poor permanent pasture (permanent grass and rough grazing) (Acs et al., 2010) in which the steep slopes do not allow the use of machinery and equipment (Fig. 5.1). Thus, in this method, main and fodder crop enterprises and temporary grassland are allowed to be reallocated only within the arable land while land currently used for permanent grassland and rough grazing may not be converted into a different land use.

Fig. 5.1 Land use organisation plan of a typical LFA livestock farm



Labour requirements. Labour is incorporated in the model as a constraining factor, as the supply of external labour inputs is limited in such remote agricultural areas (Darnhofer et al., 2010). Each enterprise requires a certain amount of labour in and this is derived in the form of Standard Labour Requirement (SLR) from the Farm Business Survey (FBS) dataset. SLR calculates the annual number of hours that each farm enterprise requires. In the model, the sum of the labour requirements of the optimised allocation of the ICLS cannot exceed the total SLR that the farm business has during the current accounting year. This limits the optimisation process to a degree, but the approach provides a useful proxy indicator of the availability of labour as no relevant data exists for the study area.

5.2.5 Calibration of modelling

The models used in the present methodology integrate all types of livestock and crop production that exist within LFA farms and may therefore represent several specific types of farm land organisation ranging from specialised to diversified. Within the model, farm businesses can adjust their production plan and level of integration between crop and livestock systems based on the suitability of available land for cultivation. In order to examine whether the optimisation scenarios provide a realistic optimal solution, the results of each scenario-model were compared to the actual performance of farms with equivalent production organisation (i.e. comparison of the averages of farm businesses between the current FBS data and the LP estimations). The major components of this process comprise the AGM derived from (i) livestock production and (ii) crop production. Table 5.3 presents a summary of these parameters for each type of farm organisation both for the current as well as the optimised estimations. Although LP assumes that farmers' objectives relate purely to profit maximisation (Acs et al., 2010), the models obtain rational results from production planning optimisation for all models.

Table 5.3 Comparison of current and optimised financial performance for each optimisation scenario[12].

		PPO (0% arable)		PPM (0%<arable<25%)		PPA (25%<arable<50%)		AMP (50%<arable)	
		Current	Optimised	Current	Optimised	Current	Optimised	Current	Optimised
Livestock AGM		**100%**	**100%**	**88.8%**	**90.9%**	**83.7%**	**76.9%**	**43.20%**	**2%**
(of which)	Sheep	68.7%	82.3%	55.4%	93.2%	37.5%	100%	22%	50%
	Beef cattle	31.3%	17.7%	44.6%	6.8%	62.5%	0%	78%	50%
Crops AGM		**-**	**-**	**11.2%**	**9.1%**	**16%**	**23.1%**	**56.8%**	**98%**

[12] Figures show the percentage of total farm AGM derived from livestock and crop enterprises, plus the contribution of sheep and beef enterprise AGMs to the total livestock AGM.

5.3 Results

From an economic perspective, the impacts of optimising production in the agricultural systems of the LFAs are captured by AGM and Net Farm Income (NFI) differentiation, whereas from an environmental perspective, the most significant impacts relate to changes in land use change, fertiliser application and stocking densities (Acs et al., 2010).

5.3.1 Financial Results

From the economic point of view, changes occur through increased AGM per hectare particularly in the PPA (Permanent pasture and rough grazing integrated with arable land) ($\mu = 762, s.d. = 205$) and AMP (Mainly arable land with some permanent pasture and rough grazing) ($\mu = 757, s.d. = 217$) scenario, which produces the highest average gross margins per hectare. Additionally, information on the distribution of the results in quartiles, in relation to the median of the sample are presented in Fig. 5.2. The optimised NFI obtains the highest average value under the PPA scenario ($\mu = 185, s.d. = 286$) whereas the AMP has the lowest NFI ($\mu = 1, s.d. = 212$). This implies high fixed costs for the AMP scenario that result in lower NFI. On the other hand, the AMP scenario produces the largest increase of NFI in absolute numbers (initial $\mu = -191, s.d. = 242$) after PPA, indicating that farm businesses in these scenarios have the highest potentials for improvement. The latter applies especially for the case of AMP scenario which after the optimisation becomes marginally profitable, even though it shows the lowest current NFI. Furthermore, Fig. 5.3 presents information on the distribution of the results. Structural changes are estimated through the integration scenarios, as crop production is preferred over livestock production from the economic perspective. According to Fig. 5.4, in all scenarios (except for the PPO - Permanent grassland and rough grazing only) the percentage of gross margin generated from livestock enterprises is decreased. The latter indicates that more arable land is allocated to crop production rather than temporary grassland. Furthermore, the optimal allocation of livestock within the farm business results in reduced numbers of beef cattle and increased numbers of sheep (Table 5.4). In terms of the total livestock units per farm, the PPO and PPM (Mainly permanent pasture and rough grazing with some arable land) and PPA scenarios yield increased livestock units, while in the AMP the livestock units per farm decline and livestock production is significantly reduced.

Fig. 5.2. Boxplots of AGM (£ per hectare) for the four optimisation scenarios

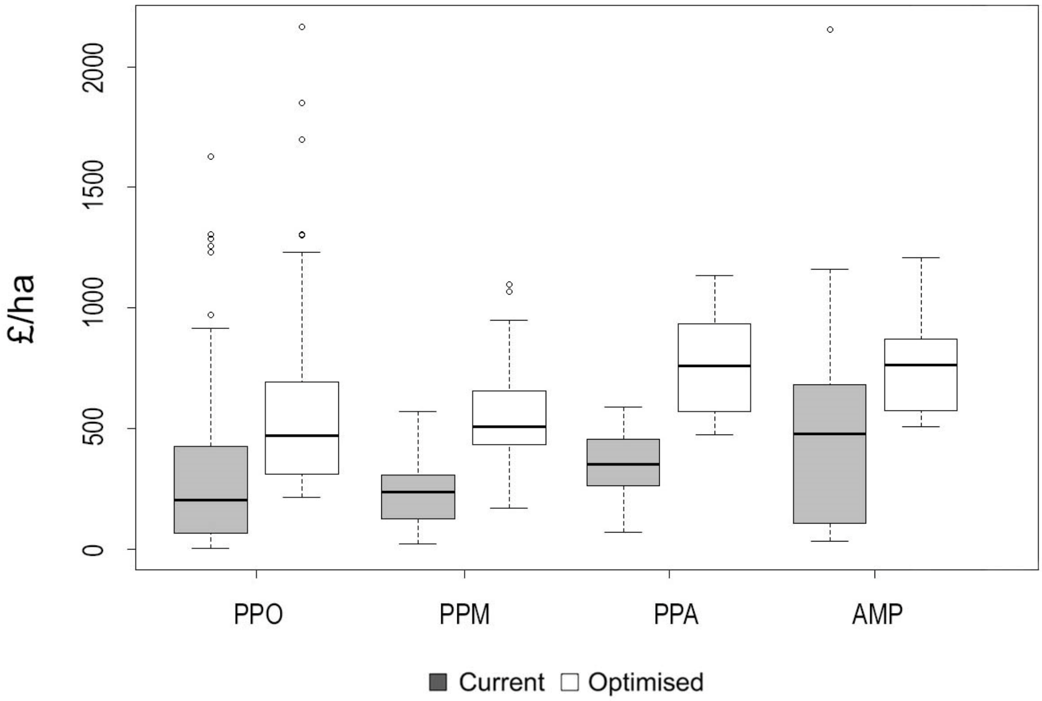


Fig. 5.3 Boxplots of NFI (£ per hectare) for the different optimisation scenarios

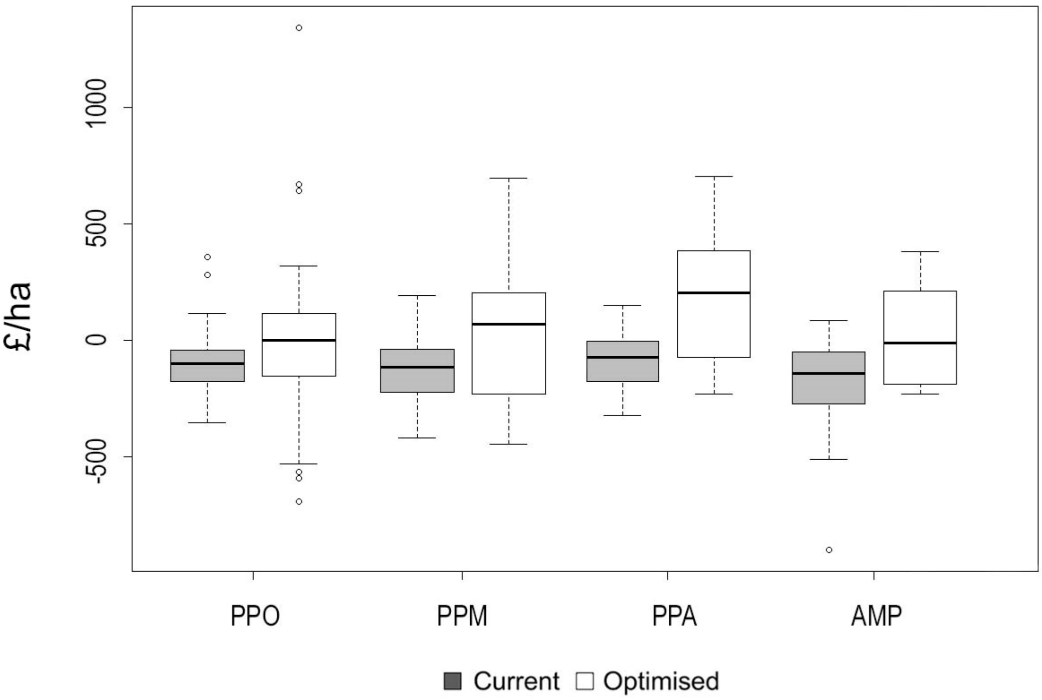


Fig. 5.4 Mean percentage of Annual Gross Margin (±SE) from livestock production in the optimisation scenarios

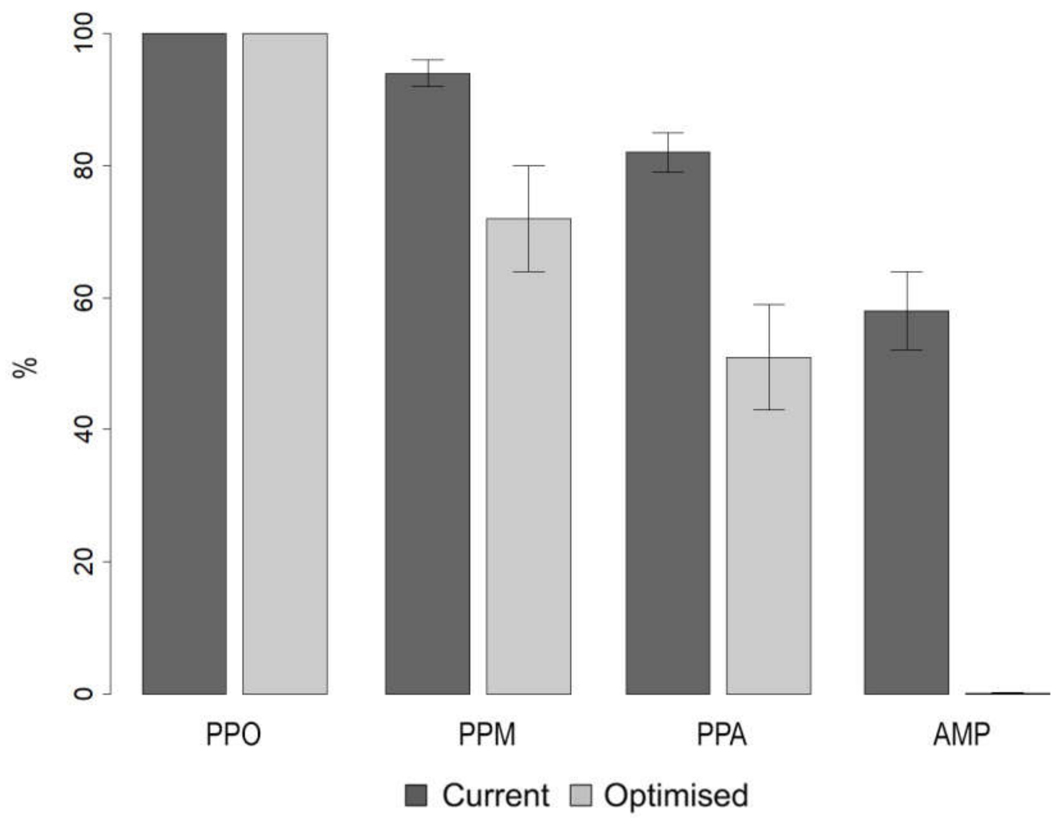


Table 5.4 Mean livestock numbers per farm for the different optimisation scenarios

	PPO	PPM	PPA	AMP
Beef cattle current	54	73	112	202
Beef cattle optimised	61	81	0	12
% of beef enterprises maintained after optimisation	20%	7%	0%	6%
Sheep current	617	606	633	787
Sheep optimised	1164	1478	1374	0
% of sheep enterprises maintained after optimisation	86%	68%	65%	0%
LU current	77	91	119	225
LU optimised	115	149	82	85

5.3.2 Environmental Results

Land use change implications for each integration scenario are presented in Table 5.5. Under the PPO scenario where land is suitable only for livestock production, a decrease is estimated for the permanent grass area (approximately 5%). In the PPM scenario all arable land is utilised while 2/3 of this area are allocated to crop production. Through the PPA scenario less permanent and temporary grass area is used for livestock production which is triggered by a significant decrease in livestock numbers. In general, within arable land, production of main crops (66.2 ha) is preferred over fodder crops and temporary grass (15.8 ha). The highest decrease of forage land is estimated under the AMP scenario (approximately 89% for permanent and 95% for temporary grass).

All optimisation models estimate that some permanent and temporary grass land will come out of production. This mainly results from reductions in beef cattle numbers within all models and declining total livestock units in PPA and AMP scenario (Table 5.4). Although surplus land emerges, the models do not propose increase of livestock as the associated costs are greater than the market returns. Thus, as most profitable option for the farm businesses emerges the abandonment of some land used for livestock production (here permanent and temporary grass land). In general, the stocking densities for all scenarios except the AMP remain relatively low and close to the current rates (ranging from 0.49 to 1.18 LU/ha). Stocking rates gradually increase from systems with higher percentages of poor permanent pasture to systems with more arable land where AMP estimates the highest optimised rate of 2 LU/ha (Table 5.6).

The land use changes estimate declining numbers of N fertiliser application for all scenarios of integration (in tonnes per hectare). The highest reduction of N fertiliser application occur in the AMP scenario ($\mu = 21, s.d. = 32$). This mainly results from reductions of temporary grass land which requires significant amounts of N fertiliser (0.25 t/ha). Furthermore, a significant increase is estimated for the PPA scenario ($\mu = 26, s.d. = 25$). Finally, Fig. 5.5 demonstrates information on the distribution of the results. In the context of investigating for environmental impacts with the use of indicators (here application of N), further indicators such as the emissions from livestock would cover also impacts from the livestock enterprises. However, the incorporated dataset does not provide enough information on livestock liveweights, age category ect. and thus, this examination considered application of N fertiliser as an environmental indicator.

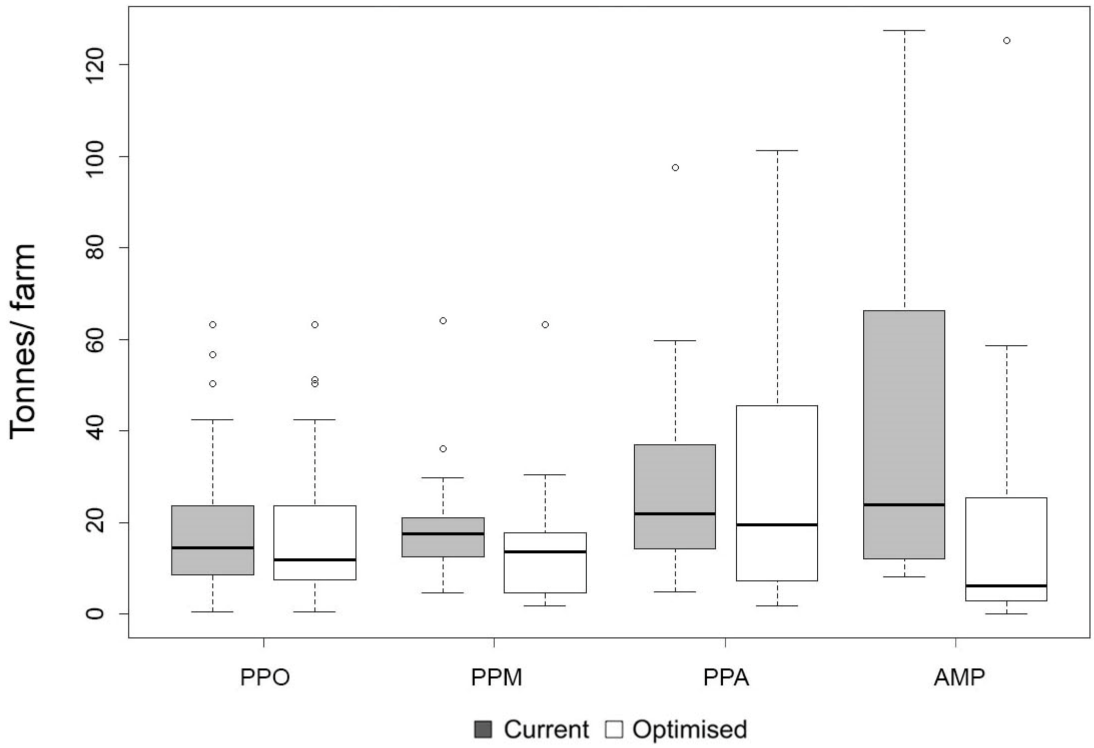
Table 5.5 Land use change for the different optimisation scenarios (average hectares per farm and percentage change)

		PPO	PPM	PPA	AMP
Current	Permanent grass	136	125.2	97.1	76
	Arable land (of which)	-	26.1	82	351.8
	Main crops	-	10.6	27.9	230
	Temporary grass	-	15.5	54.1	121.8
Optimised	Permanent grass	129	84.8	23.6	7.8
	Arable land	-	26.1	82	351.8
	(of which)				
	Main crops	-	18.3	66.2	346.2
	Temporary grass	-	7.8	15.8	5.6
% change	Permanent grass	-5.1%	-32.2%	-75.7%	-89.7%
	Arable land	-	0%	0%	0%
	Main crops	-	72.6%	137.2%	50.5%
	Temporary grass	-	-49.6%	-70.7%	-95.4%

Table 5.6 Mean stocking rates for the different optimisation scenarios

	PPO	PPM	PPA	AMP
Stocking rate current (LU/ha)	0.49	0.48	0.56	1.17
Stocking rate optimised (LU/ha)	0.64	0.73	1.18	2

Fig. 5.5 N fertiliser application (tonnes per farm) for the four optimisation scenarios



5.3.3 Sensitivity analysis

Key findings of this method were further investigated through a sensitivity analysis to examine whether the modelling produces plausible estimations, as well as to explore how sensitive the estimation of AGM is to changes in model parameters (endowments) (Kaiser and Messer, 2011). The implications on AGM were examined with reference to livestock numbers, stocking densities and land use change. Regarding the livestock housing capacity, it is estimated that in the case that further housing becomes available, space for each additional beef cattle would increase AGM on average by £ 305. Furthermore, in the cases that permanent pasture land constrained the optimisation scenarios, it is estimated that for each additional hectare, an average increase of AGM by £ 352 would result. The gross margin of models for farms with a higher percentage of arable land are more sensitive to changes in permanent grass areas. Specifically, an increase of 1 hectare in permanent grass results in an increase of £ 293, £ 466 and £ 813 for the PPO, PPM and PPA scenarios respectively. This implies that on farms with more arable land, the pasture is of higher quality thus obtaining higher gross margins per hectare. Concerning arable land, relaxing the availability by an additional hectare results in an increase of £520 in AGM on average. It is estimated that AGM is most sensitive to changes in arable land availability, as an increase of £637 is estimated for each additional hectare.

5.4 Discussion – Implications

Results indicate that there is a lot of potential for increasing the gross margin in LFA farm businesses through integration of crop and livestock production systems, however many differences arise between the four optimisation scenarios. The profitability of hill farming systems is greatly affected by the quality of forage land. In particular, higher quality forage land (here arable land used as temporary grassland) allows higher effective stocking densities which in turn trigger higher gross margins per hectare. This finding is in line with Willems et al. (2013), who found that good quality forage is a positive determinant of production performance in alpine sheep farming systems.

Moreover, our estimations point out that different levels of crop-livestock integration are related to financial performance on a per hectare basis. Studies have examined the direct effects of crop-livestock integration, highlighting that farm income increases when the level of crop production system increases within the farm business (Sneessens et al., 2016). On the other hand, Ripoll-Bosch et al. (2012), suggest that the economic performance of sheep farms in south Europe does not depend on the diversity of production itself, rather it is the lower dependency on external inputs and thus improved feed self-sufficiency that drives performance. All optimisation models in this method estimate the production of crops utilising as much of the land suitable for cultivation as is available hence, home produced feeding stuffs and feed self-sufficiency are promoted, contributing to improvements in financial performances (Bonaudo et al., 2014; Peyraud et al., 2014).

Concerning environmental performance, declining requirements for N fertiliser use are estimated. The latter is due to reductions in temporary grass which requires significant amounts of N fertiliser. However, across the models, integration with higher levels of crop production indicate higher levels of N fertiliser application. This is in accordance with the findings of Perrot et al. (2012) and Sneessens et al. (2016), who report that mixed livestock-crop production systems have worse environmental performances in comparison to specialised livestock production systems.

The effects of structural changes derived from optimal land use allocation suggest reductions in permanent pasture areas while land that is suitable for cultivation is utilised completely for crop production (that is suggested within the limits of land availability at a farm level and farm suitability). Among arable land, cereals (wheat, barley and oats) and peas production dominate while temporary grass land is also included to cover the feeding requirements of livestock within the farm business. This is a plausible result as crop enterprises obtain relatively higher gross margins than livestock (Sneessens et al., 2016) thus, they are preferred over grass financially. In an analysis of strategies for integrated crop-sheep production systems in Mediterranean mountainous areas Olaizola et al. (2015) show that land use integration provides resilience in prices fluctuation and greater financial stability for the farm business. Furthermore, studies have found that an additional positive effect emerges from land use diversification with grazing livestock, that is to support agri-tourism activities (Martin et al., 2016; Moraine et al., 2017).

In the optimisation scenarios, reduced livestock units are estimated, whereas the process prefers higher sheep numbers and fewer beef cattle from the financial perspective. On average, through all the scenarios, sheep numbers increase by 92% while beef cattle decrease by 92%. This result is in accordance to Acs et al., (2010) who note a structural change in optimised livestock production systems in which livestock numbers generally decrease while beef cattle production declines the most and sheep production is preferred especially on the areas with semi-natural flora or rock outcrops (e.g. upland moorland). One of the factors that constrained the number of livestock (for beef cattle enterprises) is the livestock housing capacity of farms. Specifically, 50% of the farm businesses that maintained beef cattle production after the optimisation method were constrained by this particular parameter. In other words, land abandonment is partially triggered due to fixed housing capacity.

5.5 Conclusions

This paper presents a method to investigate optimised integration of crop and livestock production systems (ICLS) for farm businesses in the LFAs of England examining a range of scenarios and integration options. The methodology incorporates the parameters of housing capacity, stocking densities, feed requirements, labour and land use. Through this analysis the farm organisation was reformed to maximise annual gross margin under optimised utilisation of available resources. The most significant impacts from structural changes were reflected in livestock numbers, livestock type, land use and fertiliser application.

Findings suggested that there is a lot of potential for improving the profitability of farming systems in the study area. Farm businesses with higher percentages of arable land within their farmed area have much higher gross margins than their counterparts with no arable land, as crop production is more profitable than livestock (Sneessens et al., 2016). This triggered increased levels of crop production (when arable land was available) which in terms of land use decreased areas of temporary grass and increased areas for cash crops such as cereals and beans. Concerning livestock production, in all optimisation scenarios sheep enterprises were preferred over beef cattle from the perspective of profitability while livestock units in total remained the same under the PPO and PPM and decreased under PPA and AMP scenario.

Limitations emerged through this study due to aggregated data in the FBS dataset for beef cattle and sheep enterprises. In particular, the FBS dataset disaggregates the livestock enterprises on the basis of different age groups such as store or fat cattle. However, through this classification, the live weight of the animals remains unknown. Thus, calculation of accurate feeding rations was not achievable. As a result, the study considered the feeding requirements of livestock covering only forage rather than including bought concentrates and homegrown silage cereals. Application of the latter would increase the accuracy of the estimations while assessing the cost effectiveness of crop production that contributes to the feed requirements of livestock (Dillon, 2007; Kilcline et al., 2014). In a similar context, as information on livestock age categories and liveweight was not known, the emissions derived from livestock enterprises was not assessed in examining the environmental impacts. In addition, this methodology studied the maximisation of one parameter only (gross margin) without accounting for the multiple objectives that farmers might have relating to maintenance of environmental quality and cultural values of hill farming (DEFRA, 2010).

A future step may expand this study towards a spatial analysis of these findings with the use of Geographic Information Systems (GIS). More specifically, this process may investigate the occurrence of spatial patterns or clusters of farm businesses with higher or lower potentials for profit maximisation. Furthermore, this examination may also seek spatial aggregations of the constraining factors (endowments). This will enable the identification of broad geographic blocks in which agricultural performance is more sensitive to existence of particular factors. Furthermore, a future step could potentially be the examination of multiple years using time series records for the farming systems under consideration.

The focus of future policies for the development of the LFAs could be on promoting the integration of crop and livestock production systems, providing a range of structural alternatives for farmers to adopt towards future proofing their farm businesses. This suggestion however highlights the importance of knowledge and information and thus, requires assisting farmers in getting access to such information. A potential policy tool to address this could be the establishment of knowledge transfer networks and social networks of farmers that will enable their collaboration with research institutes, scientists and advisory services (Asai et al., 2018). This will inform farmers about the positive effects of ICLS for their production systems and increase their willingness to change and adopt (Chalak et al., 2017). Furthermore training and technical assistance will be provided on agricultural production methods and farming practices that hill farmers may not have experience with (e.g. livestock farmers expanding to crop production) (Gil et al., 2016). The latter may also relate to lack of harvest equipment and high initial transaction costs (Asai et al., 2018) that can be accommodated by the implementation of machinery-sharing arrangements and joint ownership of equipment within established networks or farmer associations (Larsén, 2010). In that way, the principal factors affecting the adoption of integrated production systems will be narrowed down, thus providing solutions to encourage integration. Towards the direction of designing and evaluating scenarios that analyse the trade-offs between various integration options, simulation models can provide essential insights and point out acceptable interactions between ecosystem services and socioeconomic benefits (Martin et al., 2016; Ryschawy et al., 2017). Finally, in doing so the decision makers will be able to accommodate restrictions on productivity, emerging from natural constraints or availability of resources and thus mitigate the risks resulting from the challenges that agricultural production systems face in the LFAs.

Chapter 6

Policy implications of a spatial analysis for livestock farming systems in the Less Favoured Areas of England

6.1 Introduction

Farm businesses in the Less Favoured Areas (LFAs) face difficulties in their production performance due to existence of constraining factors (Harvey and Scott, 2015). The LFAs of England are characterised as important areas of biodiversity that in addition, maintain significant natural and cultural value (DEFRA, 2010). However, reduction or discontinuation of hill farming production and other economic activities would result in land abandonment and hence, in a range of pressures for the environment such as loss of biodiversity, land cover change and impacts on the rural populations underpinning hill farming systems (European Commission, 2010, 2005a). With regards to the environmental impacts of farming cessation, relevant studies suggest that re-wilding abandoned upland landscapes will benefit local habitats and biodiversity in general (Reed et al., 2009). However, studies have highlighted that agricultural abandonment, particularly within areas characterised by unfavourable conditions for agriculture, leads in loss of agro-biodiversity (van der Zanden et al., 2017). Furthermore, there is evidence suggesting the importance of maintaining extensive grazing regimes for environmental quality, biodiversity and preservation of historic 'cultural landscapes', i.e. the visual aesthetic value of landscapes (DEFRA, 2010, 2004) which is also enhanced through grazing management schemes such as the Moorland management (Scottish Government, 2017). Thus, there is an emerging call for sustainable agricultural practice that will preserve these values.

To address this call for sustainable development of agricultural systems, the identification of drivers of performance is of essential value in order to highlight practices and environmental characteristics enhancing or hindering performance (Finneran and Crosson, 2013; Goswami et al., 2014; McCann et al., 2010). These were in the objectives of the first empirical chapter (Chapter 4), which highlighted such parameters through the development of a multivariate statistical analysis. Specifically, this analysis included a Principal Component Analysis (PCA) and a Multiple Linear Regression (MLR) through which variations in profitability and production performance of farming systems in the LFAs were studied. The PCA was employed to identify some core underlying factors within the examined dataset which were then imported into the MLR model to examine for their explanatory power in variations of farm business performance (Micha et al., 2015). Factors related to favourable weather conditions (Mena et al., 2017), proximity to abattoir (Krishna and Veettil, 2014; Ojiem et al., 2006), lower farmer age (Giannakis and Bruggeman, 2015) and higher level of farmer education (Hanson et al., 2008) and the participation of family labour (Wilson, 2011) were identified as positive drivers of performance. Furthermore, factors related to level of physical disadvantage (Kowalczyk et al., 2014), financial dependency (Morgan-Davies et al., 2014) and low evaluation of machinery and equipment (Hansson, 2007) were found to impact negatively on the performance of farm businesses across the study area.

Furthermore, to identify factors mitigating the challenges that hill farming systems face and enabling their sustainable development, a Linear Programming (LP) method was employed in the second empirical chapter (Chapter 5) to identify ways of optimising farm organisation plans (Gameiro et al., 2016; Sneessens et al., 2016). The LP modelling attempted to maximise profitability (Annual Gross Margin) under optimised utilisation of available resources and endowments. This method allowed the examination of the integration of crop and livestock production systems (ICLS) as a potential solution for the sustainable development of farming systems (Duru and Therond, 2015; Sanderson et al., 2013). A classification was necessary to segregate farming systems utilising different levels of quality of pasture land. Across the different optimisation models, the results showed that sheep production is preferred over beef cattle production from the perspective of financial performance. In addition, for farms in the sample, within the limits of land availability and suitability, the method suggested that arable crops should be cultivated to maximise profits. The latter is in line with recent literature, highlighting that ICLS is the preferred strategy for increasing resilience and enhancing the sustainability of agricultural systems (Duru and Therond, 2015; Hendrickson et al., 2008; Sanderson et al., 2013).

Studies have incorporated Geographic Information Systems (GIS) to explore policy implications and inform the decision support considering spatial aspects in the context of examining agricultural sustainability (Kourgialas et al., 2017; O'Sullivan et al., 2015; Straume, 2013; Zolekar and Bhagat, 2015). Specifically, Asdrubali et al. (2013), developed a GIS-based tool to assess greenhouse gas emissions providing knowledge to the local decision-makers towards the mitigation of environmental pressures. Nguyen et al. (2015) and Feizizadeh and Blaschke (2013), conducted GIS-based multicriteria analysis investigating the land suitability of different land-use types. They concluded by proposing expansion of agricultural production areas considering environmental and socio-economic feasibility criteria. Furthermore, Peng et al. (2014), evaluated the suitability of spatial allocation of livestock farming with the use of GIS, considering environmental and topographical constraints that relate to soil fertility, proximity to surface water, slope and access to transportation networks. Pilehforooshha et al. (2014) incorporated a range of methodological steps including GIS raster analysis to investigate the environmental and economic factors leading to loss of arable land, while through a land suitability evaluation various crop types were allocated within the available agricultural areas. Furthermore, studies have incorporated the spatial clustering method of Getis-Ord G_i^* for the identification of spatial dependency among features and the evaluation of its statistical significance (Ding et al., 2015; Feng et al., 2017; Nie et al., 2015; Peeters et al., 2015).

The aim of the approach adopted in this thesis is to study the spatial heterogeneity of factors that enhance, hinder or constrain agricultural performance in the LFAs in order to create policy recommendations on the design of spatially targeted policy support. This is accomplished through examining, within a GIS environment, the spatial commonality between the results of the statistical analysis (Chapter 4) and mathematical programming methods (Chapter 5) that were developed in the current research. It is expected that the results derived from this analysis will enable the identification of spatial patterns of farm business performance and the associated influencing factors. Thus, information will be derived for the design of future policy support tools on specific spatial zones within the LFAs of England. Additionally, the current method can be replicated to study various farming systems and can be used as a tool contributing to the design of national agricultural policies in the context of establishing support tools for specific spatial zones.

6.2 Material and methods

Concerning the method of this chapter, results from the first two empirical approaches of the current research (Chapter 4 and 5) have a corresponding geographical reference. Using this reference the results were imported within a Geographic Information Systems (GIS) environment where the geostatistical processing was conducted. A more detailed description on the data and the geostatistical processes carried out follows in the next subsections.

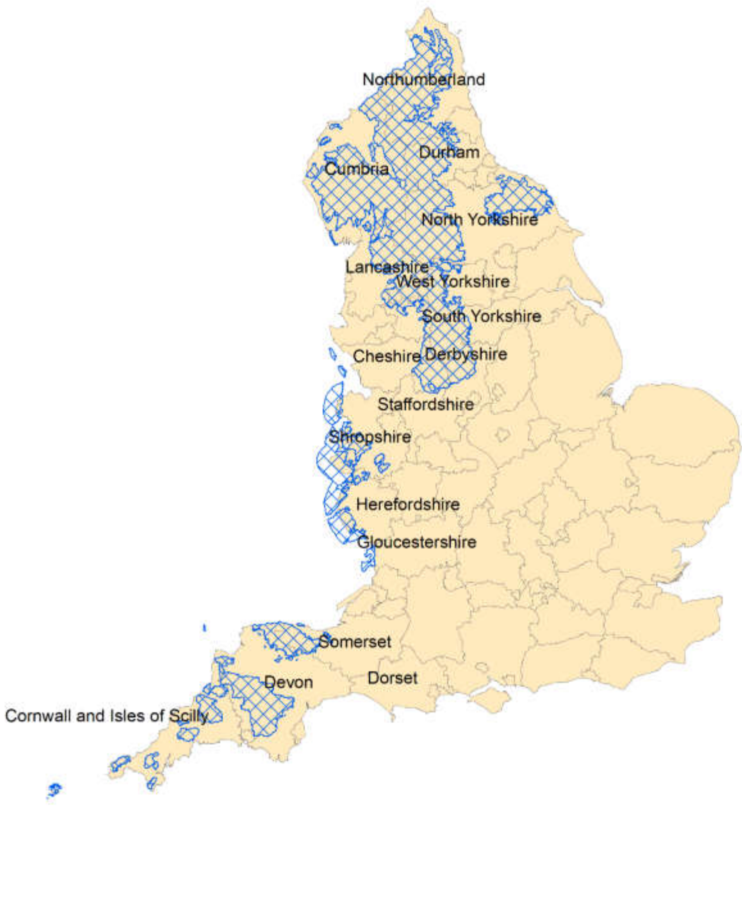
6.2.1 Dataset and variables

In order to be able to suggest specific policy recommendations for the LFAs in England it is required that the production systems operating within the designated areas are fully investigated and the production patterns are revealed. Hence, a PCA analysis was employed in Chapter 4 to identify a range of underlying factors relative to farm-level management decisions and inherent spatially-fixed characteristics were identified. The obtained Principal Components (underlying factors) that had a statistically significant effect on agricultural performance (examined through the MLR), are further investigated in the current approach through the use of hot spot analysis. In particular, as discussed in Sections 4.3.1.1 and 4.3.1.2 for the beef enterprises, the examined principal components regard favourable weather conditions, financial dependency, low evaluation of machinery and equipment and proximity to abattoir. For the sheep enterprises, these correspond to favourable weather conditions, physical disadvantage, feeding stuffs, financial dependency and family labour. Furthermore, the LP modelling that was developed in Chapter 5, allowed not only the maximisation of farm level profitability, but also the identification of factors that limit performance in the context of sustainable practice. This regarded the examination of the annual gross margin per head, increases in sheep numbers, percentage of arable land within the farmed area and shortages of labour. Finally, the secondary data used for the statistical and LP modelling are discussed in sections 4.2.1 and 5.2.1 and was derived from the Farm Business Survey (FBS)[13] for the financial year of 2013/2014. Descriptive statistics are also available in the aforementioned sections.

6.2.2 Study area

The study area of this analysis comprises the LFAs of England. The administrative boundaries of counties are incorporated here in order to segregate the study area into smaller spatial units which are easy to interpret (Fig. 6.1).

Fig. 6.1 Counties within the English LFAs



[13] FBS is a comprehensive dataset that provides financial and physical data for farm businesses based in England and Wales. Further information regarding the FBS dataset, methods of data collection or getting access are available in following link: https://www.gov.uk/government/collections/farm-business-survey

6.2.3 Geographic Information Systems (GIS)

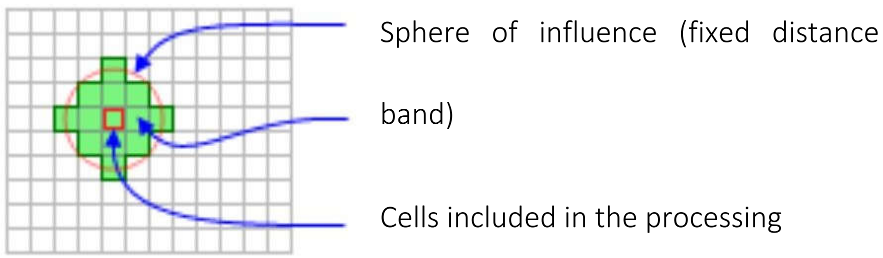
The present approach utilises GIS and specifically the ArcGIS software provided by the Environmental Sciences Research Institute (ESRI). There is a range of spatial statistics tools within ArcGIS for the analysis of spatial clusters, including hot spot analysis. This tool identifies statistically significant spatial clusters of high values (hot spots) or low values (cold spots) creating an output that contains a z-score, p-value and a confidence level rate (ESRI, n.d.). The p-values and z-scores are estimates of statistical significance. The confidence level is estimated through the Getis–Ord Gi statistic G_i^* (Eq. (36) that measures the level of commonality resulting from an aggregation of some data points and all other points considered within a radius of distance d (Getis and Ord, 1992). Scores consist of integer values from -3 to 3 while attributes with scores of -3 or 3 reflect statistical significance with 99 percent confidence level, scores of -2 or 2 reflect 95 percent confidence interval, scores of -1 and 1 reflect 90 percent confidence interval and scores of 0 are not statistically significant (ESRI, n.d.). Morans' I test is employed in this process to examine spatial autocorrelation between feature locations as well as feature values (ESRI, n.d.). The tool examines whether the spatial pattern of a data set is clustered, dispersed or random.

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - \bar{X} \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{[n \sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2]}{n-1}}} \tag{36}$$

Where x_j is the attribute value for the feature $j, w_{i,j}$ is the spatial weight between feature i and j and n represents the total number of features and S is the standard deviation of the sample.

Spatial statistical analysis requires the examination of the way that spatial relationships are approached. For hot spot analysis in ArcGIS, the method of fixed distance band is recommended as most appropriate establishing a sphere of influence among the features of the dataset (Fig. 6.2). The fixed distance defining this sphere was derived from the Incremental Spatial Autocorrelation tool. This tool searched for the distance that estimates maximum clustering under which the spatial processes triggering the clusters are most distinct (ESRI, 2017). In particular, the process generates $z-scores$ in each distance iteration indicating the spatial clustering intensity. Thus, peaks in $z-scores$ point out the appropriate fixed distance band. Peaks corresponding to larger distance bands describe phenomena of broader scale (for example climate, which has a north to south trend across England) while smaller distances are associated with phenomena of smaller scale (such as topographic trends). Therefore, depending on the variable examined, the fixed distance band varies from smaller to larger distances among the $z-score$ peaks. To select the appropriate distance bands, an incremental spatial autocorrelation analysis was conducted for all examined variables, both for the beef cattle and the sheep enterprises. Further information on the computational processes carried for the estimation of $z-scores$ is available in Section 3.6.2.

Fig. 6.2 Illustrative example of the current spatial relationships conceptualisation (ESRI, n.d.)



6.3 Results

6.3.1 PCA

6.3.1.1 Fixed distance bands

The incremental spatial autocorrelation tool as described in Section 3.6.2 was employed to identify the appropriate fixed distance bands. Each iteration initiated from a radius of 10 km (grid square size) and the increment of distance was set to 10 km (further information on the 10x10 km grid square is presented in Section 7.5). Favourable weather conditions obtained the highest values for both enterprises (190 km for beef cattle and 160 km for sheep) reflecting a broad geographical trend across the study area (north to south) (Table 6.1). The average distance bands of the remaining variables are approximately 50 km. This indicates that the phenomena triggering spatial clustering do not correspond with wide geographical distributions rather, they are of smaller spatial scale which is expected for the projected variables. More information on the statistical significance ($z - score$, $p\ value$) of the clustering of the variables is presented in Appendix A.

Table 6.1 Fixed distance bands for the beef cattle and sheep enterprises (in km)

Variable	Beef cattle	Sheep
Favourable weather conditions	190	160
Financial dependency	20	50
Proximity to abattoir	50	50
Low machinery evaluation	80	
Physical disadvantage		40
Feeding-stuffs		50

6.3.1.2 Hot spot analysis

The geographical analysis of AGM per ha estimates similar spatial patterns for both the beef cattle and sheep enterprises. More specifically, as Fig. 6.3 demonstrates, for beef cattle and sheep enterprises based within the Peak District[14] and the southwest of England, hot spots of AGM are estimated. Furthermore, sheep enterprises based in the northeast of Northumberland estimate a hot spot of AGM. On the other hand, for both types of livestock production, cold spots of AGM are estimated over the areas of Cumbria, Durham and North Yorkshire.

Hot spot analysis for favourable weather conditions for the beef cattle and sheep enterprises results in a significant geographical distinction (Fig. 6.4). A broad hot spot is estimated for the south part of the study area while an equivalent cold spot is estimated for the northern part of the English LFAs.

[14] For simplicity, the LFA area overlapping with of West Yorkshire, South Yorkshire, Derbyshire and Cheshire is referred to as the Peak district.

The spatial distribution of financial dependency for the beef cattle and sheep enterprises is presented in Fig. 6.5 estimating several clusters across the whole study area. Specifically, for the beef cattle enterprises, three clusters of hot spots (Southwest, Peak District and Cumbria and Durham) and a cluster of cold spots (northeast Northumberland) are estimated. The small distance band results in the estimation of more clusters which are of smaller size and are distributed across the whole study area. Concerning sheep enterprises, the spatial clusters obtain a wider geographical distribution indicating the areas in which factors triggering higher financial dependency are more prominent. These regard two hot spots located, one over Cumbria and one over Lancashire, West and North Yorkshire. In addition, a highly statistically significant cluster of cold spots is estimated for the farm businesses within the Peak District.

The hot spot analysis for low machinery and equipment evaluation within beef cattle enterprises is presented in Fig. 6.6. A fairly significant spatial clustering is estimated as the norther and north-western LFAs obtain a highly statistically significant cluster of low evaluation of machinery. Two cold spots of low evaluation of machinery are estimated for Northumberland and the areas around the Welsh Borders.

The analysis of proximity to abattoir estimates hot spots forming a cluster over the Peak District and Yorkshire while two cold spots are identified in the northeast and southwest (Fig. 6.7). This result indicates a spatial aggregation of abattoirs in the areas around Yorkshire and the Peak District. On the other hand, the more remote areas of the LFAs form cold spots with regards to distance to closest abattoir which implies higher transportation costs.

The geographical distribution of physical disadvantage estimates one cluster of hot spots in the north-western part of Cumbria (Fig. 6.8). The rest of the study area does not obtain significant spatial aggregations. Furthermore, the hot spot analysis of costs for feeding stuffs formulates a hot spot within the northern block and a cluster of cold spots in the Peak District (Fig. 6.9). Regarding the family labour participation, a hot spot cluster is estimated across the whole geographic block of the Peak District and Welsh Borders while a cold spot cluster is projected on the southern block (Fig. 6.10). A cold spot cluster is also estimated in the northern block.

Fig. 6.3 Hot spot analysis of annual gross margin (AGM) per hectare (ha) for beef cattle and sheep enterprises

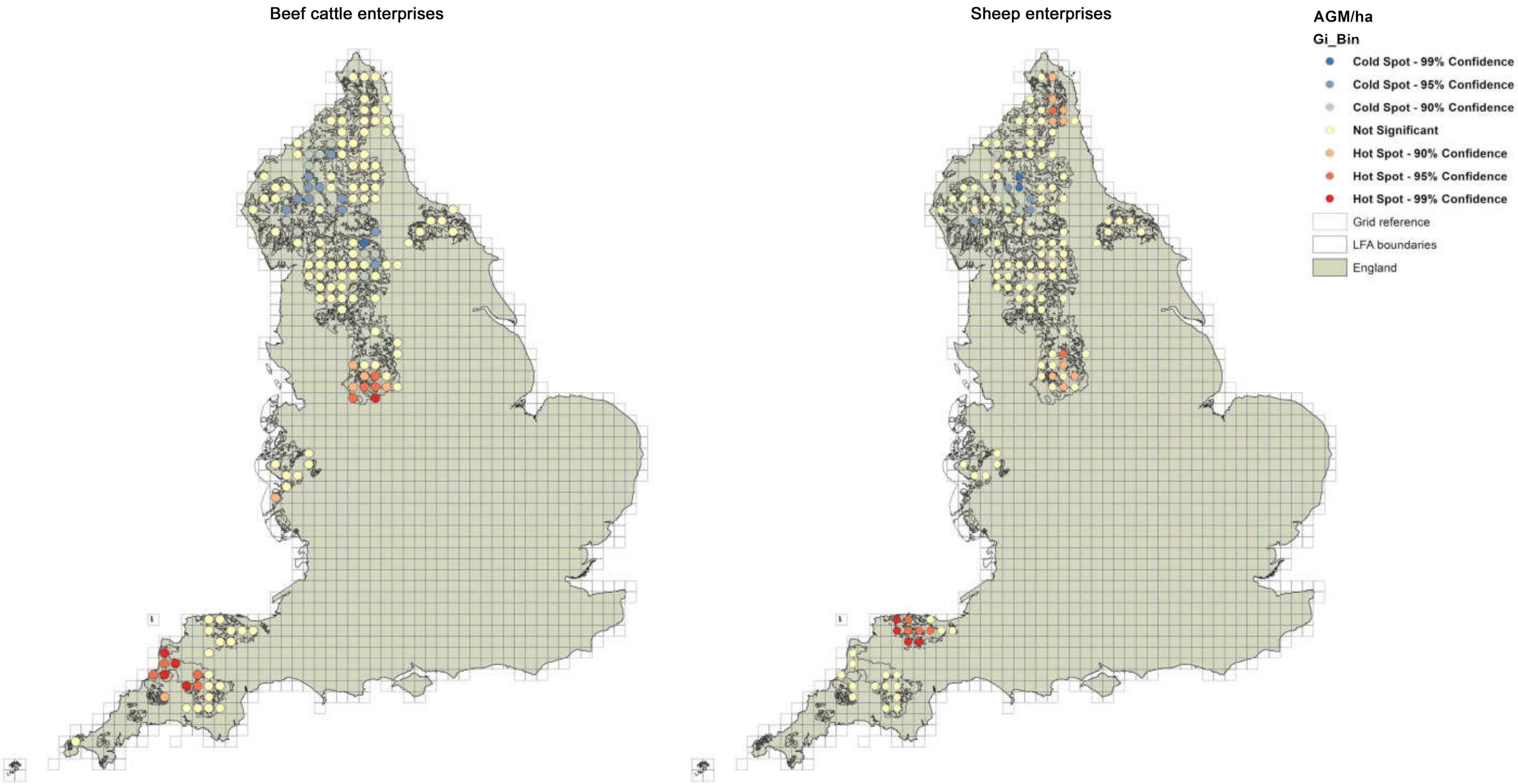


Fig. 6.4 Hot spot analysis of favourable weather conditions for beef cattle and sheep enterprises

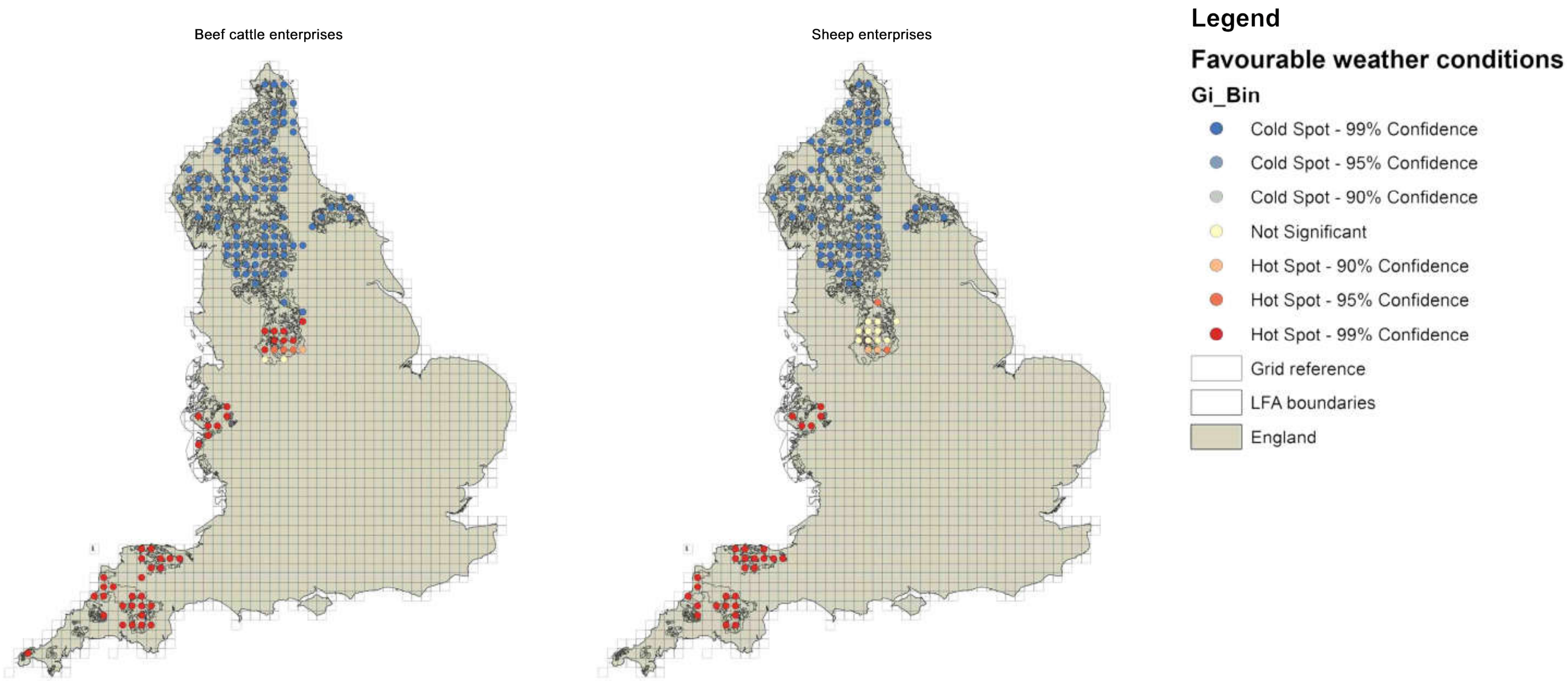


Fig. 6.5 Hot spot analysis of financial dependency for beef cattle and sheep enterprises

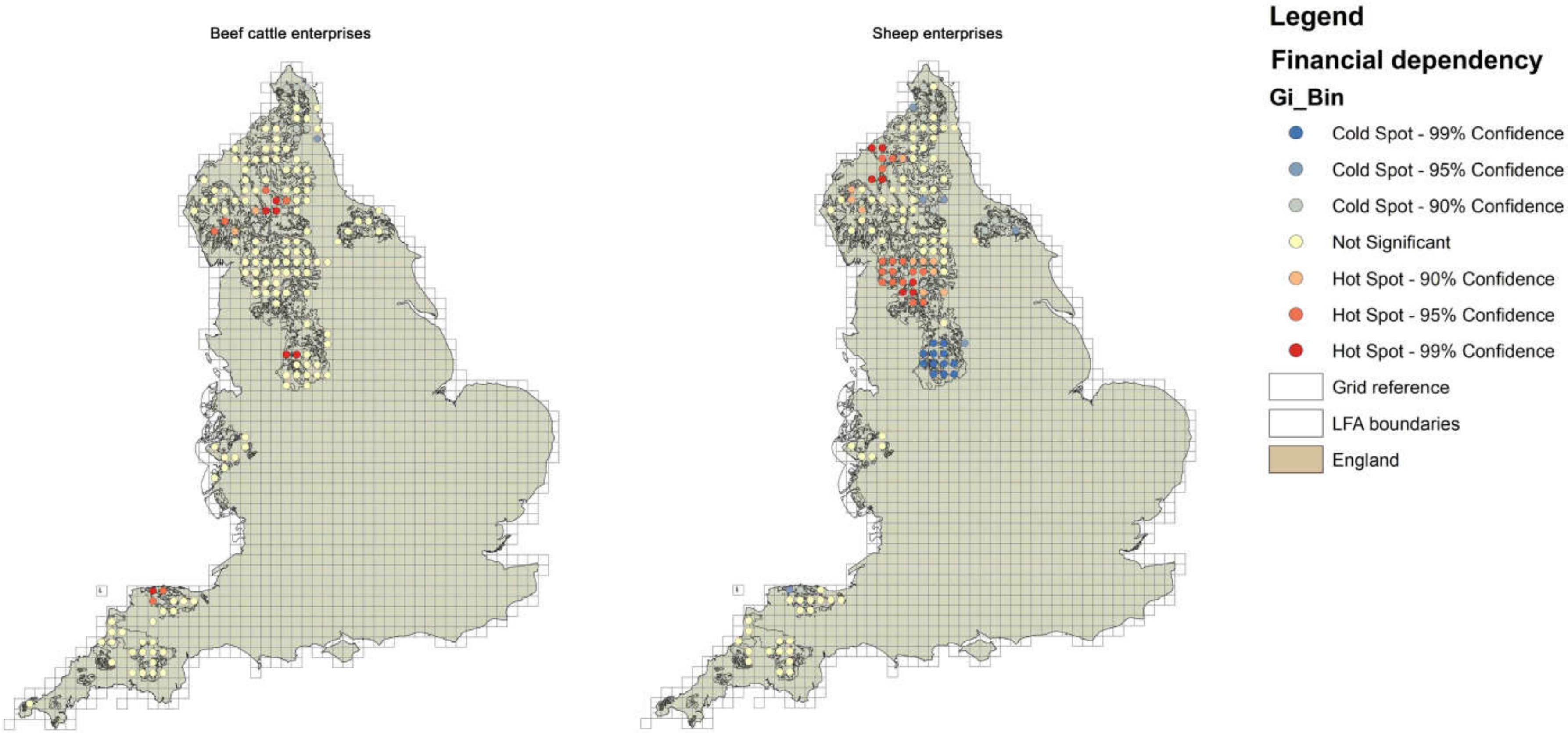


Fig. 6.6 Hot spot analysis of low machinery evaluation for beef cattle enterprises

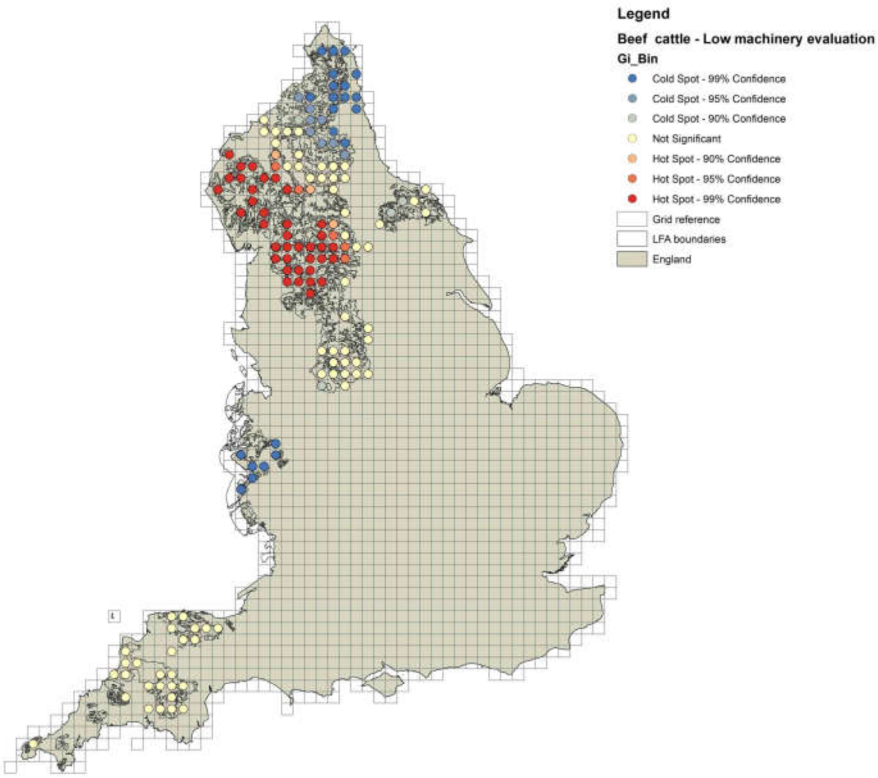


Fig. 6.7 Hot spot analysis of proximity to abattoir for beef cattle enterprises

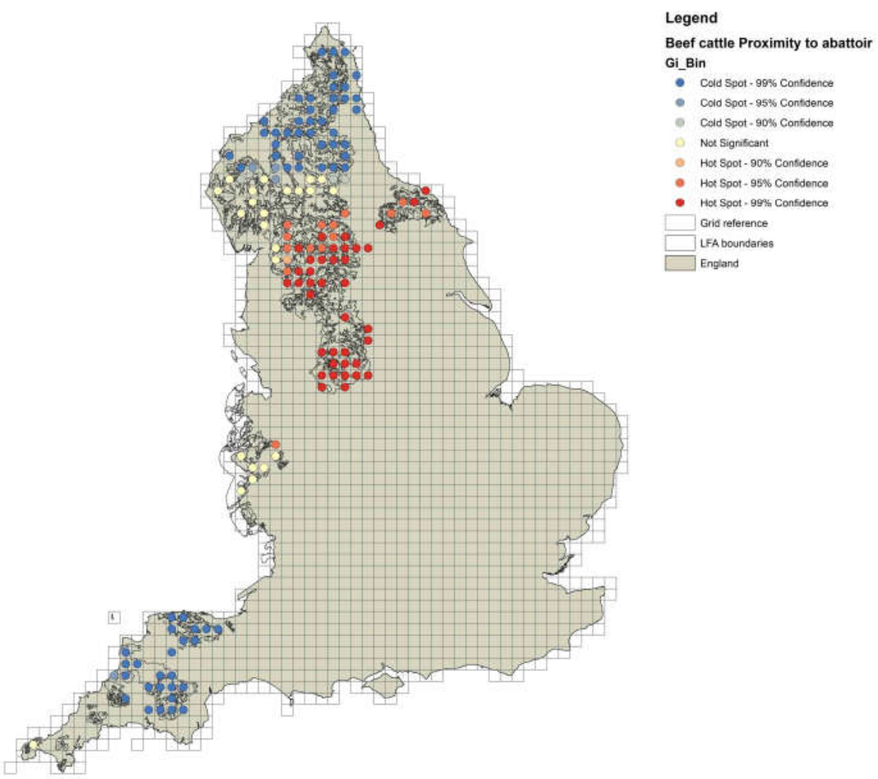


Fig. 6.8 Hot spot analysis of physical disadvantage for sheep enterprises

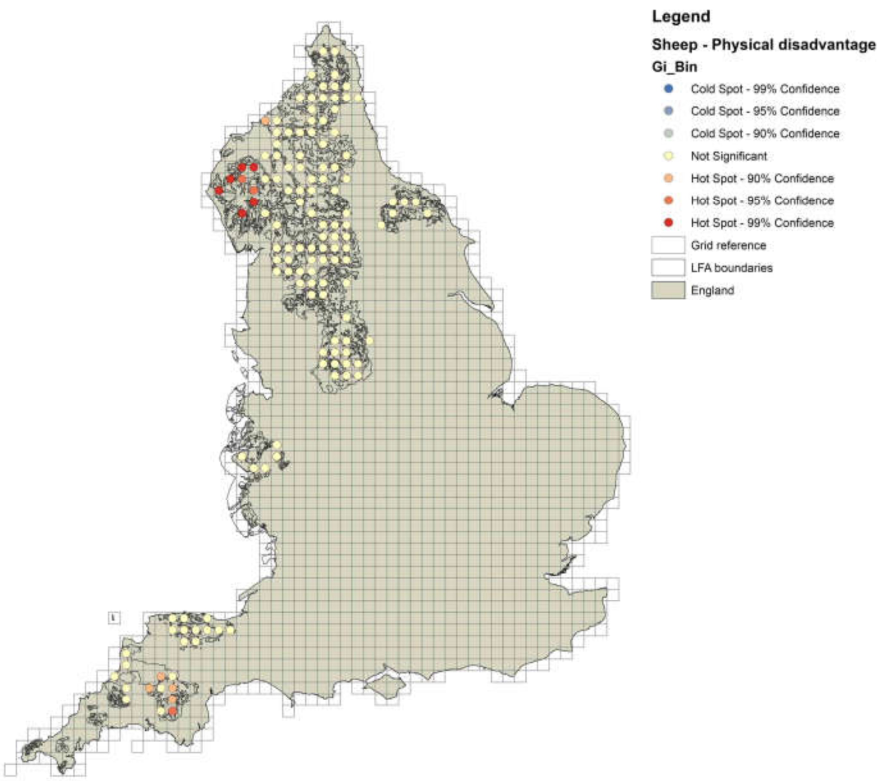


Fig. 6.9 Hot spot analysis of feeding stuffs for sheep enterprises

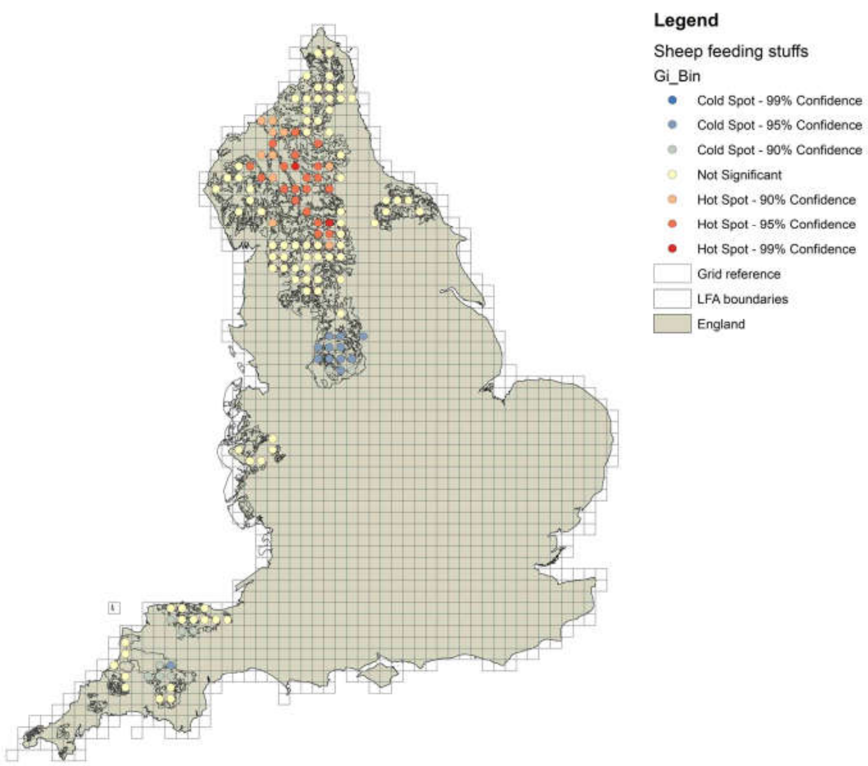
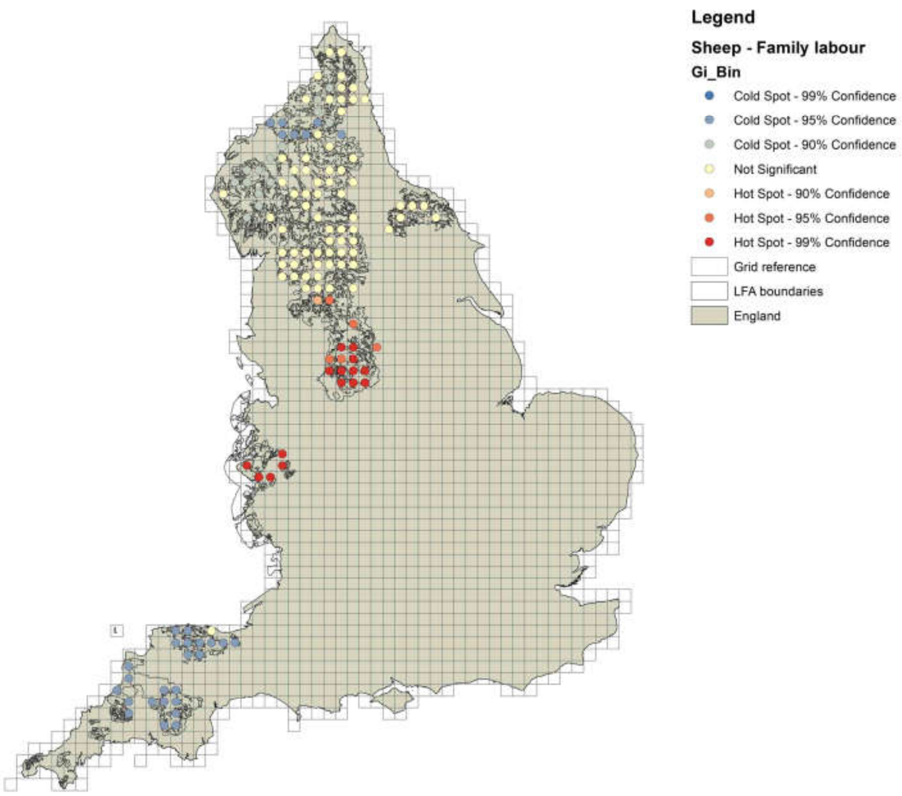


Fig. 6.10 Hot spot analysis of family labour for sheep enterprises



6.3.2 Linear Programming

6.3.2.1 Fixed distance bands

The incremental spatial autocorrelation tool is employed again at this stage to detect the appropriate fixed distance bands for the analysis. The results of this tool are presented in Table 6.2. The average fixed distance for these variables is approximately 50 km. The latter indicates that the spatial distribution of factors that trigger clustering are of lower spatial scale and do not result from phenomena that have a wide geographical distribution. The estimated distance is similar to the average fixed distance that was estimated for the previous section that examined drivers of performance.

Table 6.2 Fixed distance bands for the LP variables (in km)

Variable	Distance band
Sheep numbers change	80
Current AGM/ha	20
Optimised AGM/ha	30
Percentage of arable land	30
Beef AGM/head	100
Sheep AGM/head	50

6.3.2.2 Hot spot analysis

Hot spot analysis for current and optimised AGM per hectare is presented in Fig. 6.11. Current AGM formulates sparse clusters of smaller spatial scale across the whole study area. Clusters of higher current AGM per ha have the highest potential for profit maximisation (north-eastern Northumberland) while clusters of lower current AGM estimate areas with lower increase of profitability per ha (eastern Lancashire).

In the optimisation modelling, sheep numbers were increased significantly while numbers of beef cattle were decreased. Fig. 6.12 presents the results from the hot spot analysis investigating the variable of change in sheep numbers. A hot spot cluster is estimated for the north-eastern Northumberland while a cold spot is estimated for the west parts of West Yorkshire and north-western parts of the Peak District.

Through the optimization method that was developed in the second empirical chapter, a factor that constrained the maximisation of AGM regarded the labour availability. In the hot spot analysis, farm businesses that were constrained by this parameter formed a statistically significant hot spot on the north-eastern part of the study area while a cold spot was estimated for the Peak District and the southern part of the North block (Fig. 6.13). These cold spot clusters indicate a spatial aggregation of adequate labour availability in the southern Pennines. The latter does not imply that there is a surplus in a general context in these areas, rather it is the case that the optimisation was constrained by various factors other than labour (land availability, stocking densities) thus, there is a surplus in comparison to the current state.

Another factor that constrained profit maximisation of LFA farm businesses was the availability of arable land for cultivation. For farms for which arable land was available, the optimisation estimated that within the limits of land suitability and availability at the farm level, utilisation of the whole area for crop cultivation is appropriate to maximise profitability. Spatial aggregation of the highest percentages of arable land within the farmed area were estimated for the north-eastern parts of the study area (Fig. 6.14). On the contrary, it is estimated that the Peak District and the south-western parts of England have spatial aggregations of the lowest percentages of arable land. Both hot and cold spot clusters correspond with the equivalent aggregations of higher and lower AGM/ha respectively, indicating that a higher level of integration between crop and livestock production is linked to higher profitability.

Fig. 6.11 Hot spot analysis of current and optimised AGM per hectare

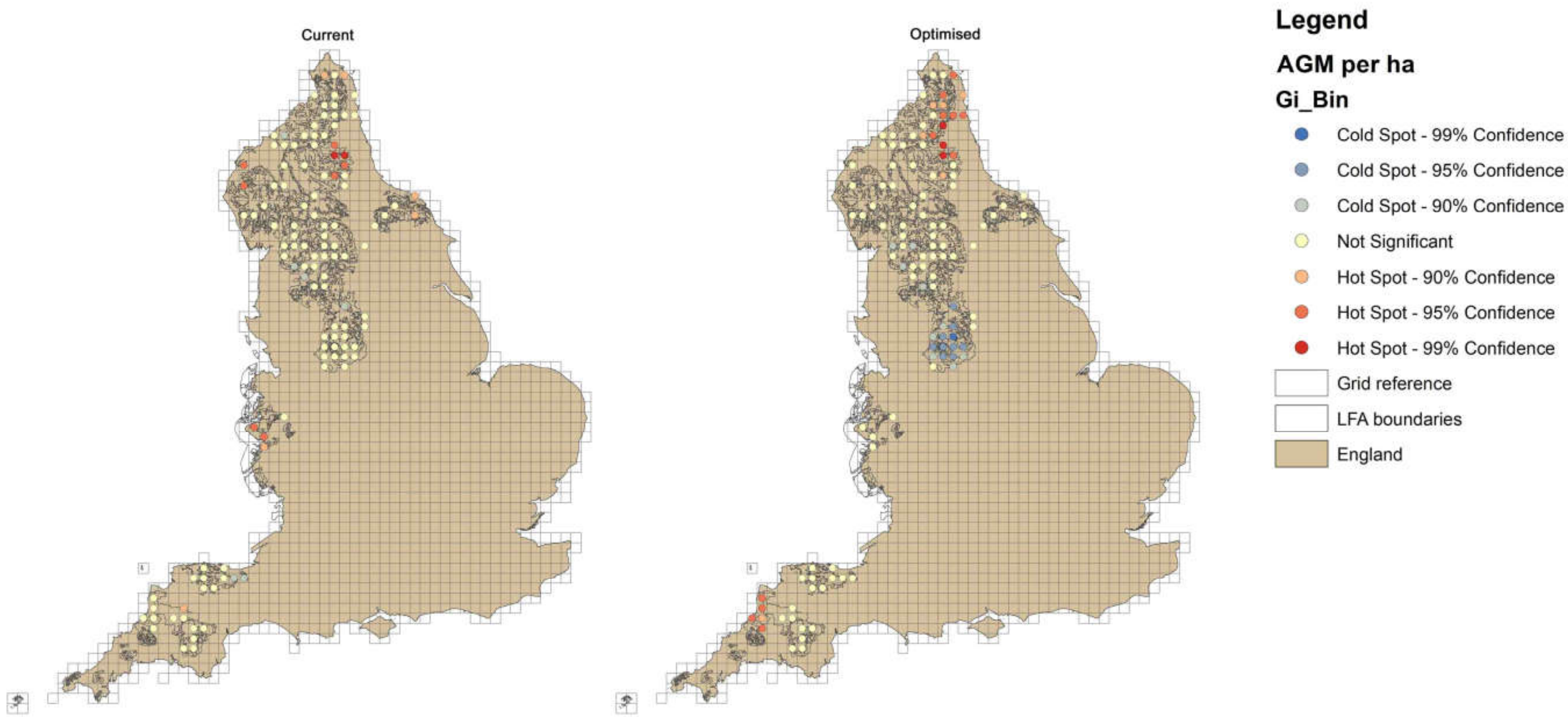


Fig. 6.12 Hot spot analysis of change in sheep

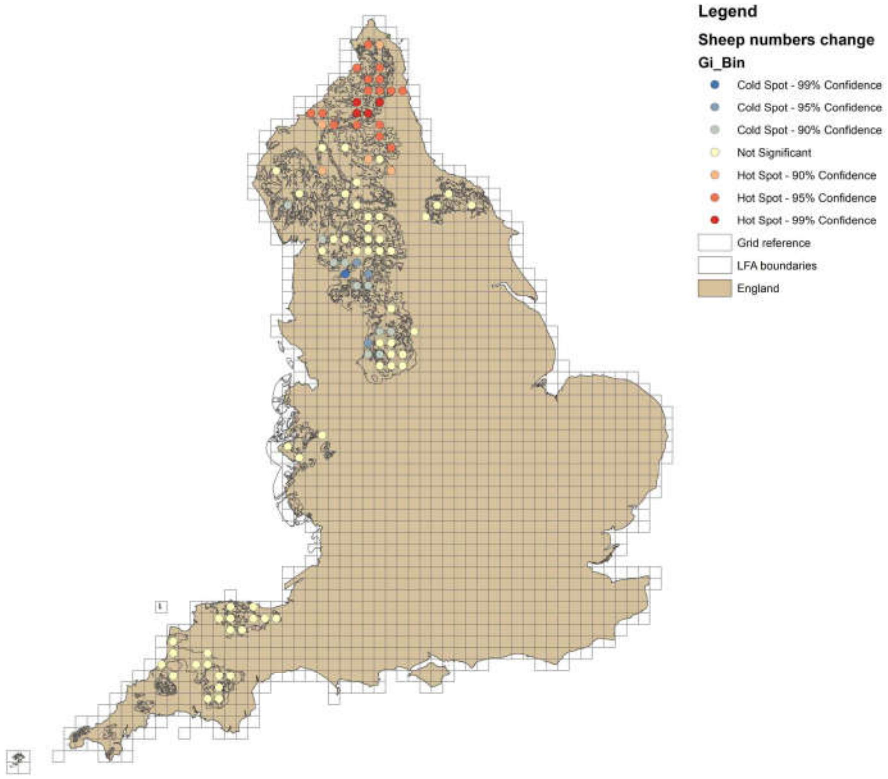


Fig. 6.13 Hot spot analysis of farms that were constrained by the availability of labour

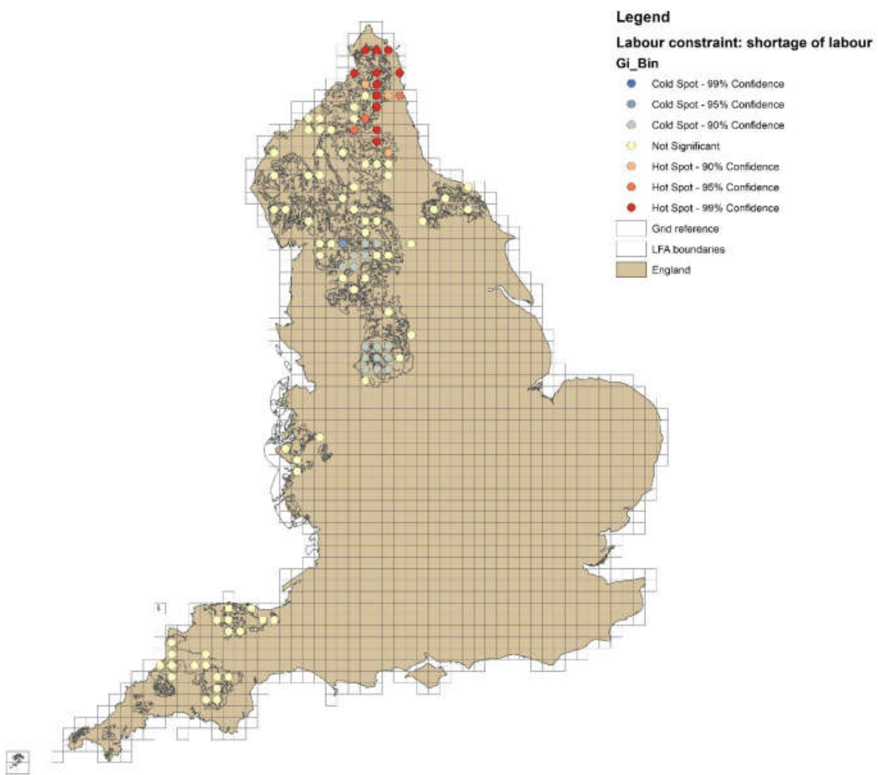
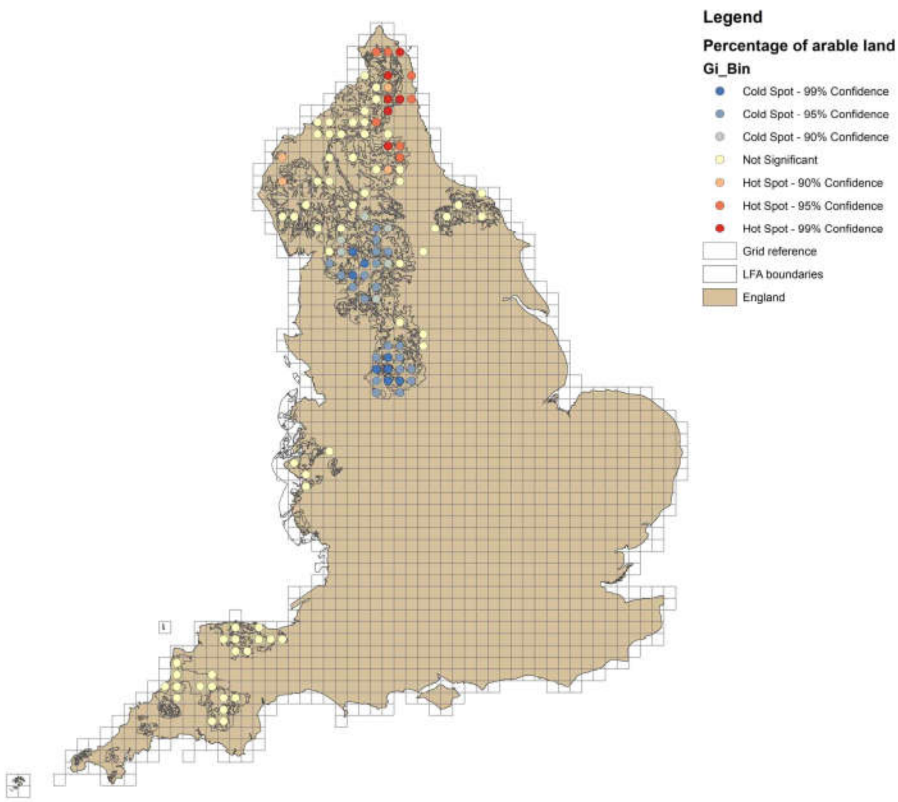


Fig. 6.14 Hot spot analysis of percentage of arable land within the farmed area



6.3.3 Aggregated results

In order to investigate correlations between the spatial clustering, the hot spot analysis outputs were plotted in several combinations using the Gi bin scores (further information available in Section 6.2.3). More specifically, the Gi bin scores from the various variables are plotted against each other in scatter plots to examine whether hot/cold spots of one variable correlate with hot/cold spots of another variable. This process allowed the identification of variables that correlate spatially using the derived the Gi bin scores that measure spatial clustering. Specifically, AGM was plotted against drivers of performance while also some of the constraining factors such as labour shortage and percentage of arable land were examined with reference to the PCA factors. The aggregated outputs from plots of AGM against the drivers are presented in Table 6.4 for beef cattle enterprises and Table 6.5 for sheep enterprises. Furthermore, Table 6.3, provides information on the codes used in the tables aggregating results from the current analysis.

Regarding beef cattle enterprises, the Peak District seems to have the most favourable conditions among the spatial units. Specifically, aggregations of high AGM per head at a 90% confidence level (column I, row C), correlate with favourable weather conditions (column II, row C, in dark red colour signifying a hot spot at a 99% confidence level) less shortage in labour (column IV, row C, in light blue colour signifying a cold spot at a 90% confidence level) and high proximity to abattoir (column VI, row C, in dark red colour signifying a hot spot at a 99% confidence level). On the other hand, northern Northumberland formulates a cold spot of AGM per head at a 90% confidence level which correlates with cold spots of favourable weather conditions and proximity to abattoir and hot spots of labour shortage. However, the same areas have lower levels of financial dependency and higher levels of percentage of arable land that have found to impact positively on performance. The areas of eastern Cumbria and western parts of North Yorkshire estimate spatial commonality between cold spots of AGM per head and hot spots of lower machinery evaluation.

Table 6.3 Confidence levels and corresponding codes

Confidence level	Codes	Type of cluster
99%	↑↑↑	Hot Spot
95%	↑↑	
90%	↑	
90%	↓	Cold Spot
95%	↓↓	
99%	↓↓↓	

Concerning sheep enterprises, for the farm businesses based in the north-eastern Northumberland a hot spot of AGM per head is estimated (column I, rows B and C at confidence levels of 90% and 95 %) that overlays with cold spots of favourable weather conditions (column II, rows B and C, in dark blue colour signifying a cold spot at a 99% confidence level) financial dependency (column III, rows B and C, in blue colour signifying cold spots at 90% and 95% confidence level) and a hot spot of percentage of arable land within the farmed area (column VI, rows B and C at 90%, 95% and 99% confidence levels). On the other hand, the areas of eastern Cumbria aggregate the least favourable conditions, as a spatial overlap is estimated between a cold spot of AGM per head overlaying with a cold spot of favourable weather conditions and family labour and a hot spot of physical disadvantage. However, with regards to sheep numbers change (Table 6.6), north-eastern parts of Cumbria estimate hot spots despite the spatial aggregation of unfavourable conditions. Thus, expansion of sheep farm enterprises to increase profitability seems to not merely be driven by presence of less favourable environmental conditions.

Table 6.4 Aggregated hot spot analysis results for the beef cattle enterprises: Profitability over drivers of performance

	Beef AGM per head	Favourable weather conditions	Financial dependency	Labour shortage	Percentage of arable land	Low machinery valuation	Proximity to abattoir
	I	II	III	IV	V	VI	VII
A	↑↑↑						
B	↑↑	Welsh Borders ↑↑↑					
C	↑	Peak District ↑↑↑	West Peak district ↑	Peak District ↓	Peak District ↓↓	north-western Northumberland ↓↓↓	Peak District ↑↑↑
D	↓	north-eastern Northumberland ↓↓↓	north-western Northumberland ↓	north-eastern Northumberland ↑↑↑	north-eastern Northumberland ↑↑, ↑↑↑	Cumbria, eastern Lancashire, western North Yorkshire ↑, ↑↑, ↑↑↑	north-eastern Northumberland ↓↓↓
E	↓↓	southwestern Northumberland, north-eastern Cumbria ↓↓↓					southern Northumberland, north-eastern Cumbria ↓↓↓
F	↓↓↓						

Table 6.5 Aggregated hot spot analysis results for the sheep enterprises: Profitability over drivers of performance

	Sheep AGM per head	Favourable weather conditions	Financial dependency	Family Labour	Physical disadvantage	Percentage of arable land
	I	II	III	IV	V	VI
A	↑↑↑					
B	↑↑	north-eastern Northumberland ↓↓↓	north-eastern Northumberland ↓, ↓↓			north-eastern Northumberland ↑, ↑↑, ↑↑↑
C	↑					
D	↓	eastern Cumbria ↓↓↓		eastern Cumbria ↓	Cumbria ↑↑↑	
E	↓↓					
F	↓↓↓					

Table 6.6 Aggregated hot spot analysis results for the sheep enterprises: increase of sheep numbers over drivers of performance

	Sheep numbers change	Favourable weather conditions	Family labour
	I	II	III
A	↑↑↑	Northumberland, Durham, north-eastern Cumbria ↓↓↓	southern Northumberland, north-western Cumbria ↓, ↓↓
B	↑↑		
C	↑		
D	↓	eastern Lancashire ↓↓↓	Peak District ↑↑↑
E	↓↓		
F	↓↓↓		

6.4 Discussion and Policy implications

The current study acknowledges the need to identify the spatial heterogeneity that exists among the various parameters enhancing, hindering or limiting financial and production performance of the upland farming systems. Furthermore, the derived knowledge from such examination should be accounted for the design of future policy tools that will spatially target policy support. Towards this direction, the current chapter synthesises the findings of the two previous empirical chapters within the framework of spatial analysis. The identified drivers of performance and the constraining factors are mapped within a GIS environment to explore spatial commonality and correlations within the farming systems of the English LFAs. Through the geostatistical analysis, the geographic areas of Peak District, Northumberland and Cumbria emerged as the most significant in terms of the various inherent barriers as well as financial performance that formulate spatial aggregations.

According to the evidence provided by the geographic analysis, it was found that within the English LFAs, spatial clusters of higher profitability for the sheep enterprises are estimated within the areas of Peak District, Welsh Borders and Northumberland (Scott and Jackson, 2016). Specifically, in Northumberland the hot spots of AGM overlap with cold spots for the variables of financial dependency and low evaluation of machinery and also with hot spots of arable land. This in turn triggered a significant increase in sheep numbers within this county in the optimisation method that was also the highest across the whole study area. With regards to the financial liabilities, farm businesses within Northumberland estimate hot spots of arable land and cold spots of low evaluation of machinery. The higher liabilities may relate to investments that result in the cold spot of low valuation of machinery. This is also in line with the hot spot of arable land that indicates a demand for production equipment.

However, spatial aggregations of negative drivers are estimated for Northumberland including poor weather conditions, higher levels of labour shortages and remoteness from abattoirs. This may provide an explanation of the spatial cluster of lower profitability for the beef cattle enterprises over northern Northumberland. For this geographic area, solutions should focus on exploiting the strengths of the farming systems that here relate to higher percentage of arable land within the farmed area. Specifically, integration of crop and livestock production systems (ICLS) should be promoted as a strategy that will increase financial resilience and sustainability of hill farming systems (Duru and Therond, 2015; Sanderson et al., 2013). More specifically, policy support should establish networks of education and transferable knowledge (Garrett et al., 2017) to train farmers on farming aspects that may not have previous experience with, such as livestock farmers expanding their operations towards arable crops. Furthermore, although such changes in farm organisation may imply high initial transaction costs, (machinery investment and buildings) machinery-sharing arrangements, can provide a solution (Larsén, 2010).

On the contrary, this analysis highlighted that Cumbria emerges as the most challenging area for livestock production. This result stems from a spatial commonality between cold spots for the variables of AGM per head, favourable weather conditions and family labour as well as hot spots of physical disadvantage, financial dependency and low machinery valuation. These spatial relationships reflect challenges emerging mainly from climate and landscape characteristics that handicap heavily these areas. Policy support in those areas should aim to enhance economic performances through the provision of vital knowledge on more efficient practices and also encourage farmers to make a greater proportion of their income through payments for the provision of public goods, such as those currently available through the Countryside Stewardship scheme and its post-BREXIT successor (DEFRA, 2011b). The latter calls for the development of a strategy that will focus on widening the provision of ecosystem services within the uplands such as production of high quality food, climate and flood regulation while enhancing financial outputs (Strohbach et al., 2015). In this context, the Payment for Ecosystem Services (PES) provides a series of market based schemes rewarding land owners for delivering and maintaining these environmental benefits (DEFRA, 2013).

Concerning production of beef cattle, spatial aggregations of higher profitability are aggregated within the Peak District. Furthermore, in the same area spatial clusters of favourable conditions are estimated including favourable weather conditions, lower labour shortage and high proximity to abattoir. However, farms located in this area have lower percentages of arable land within their farmed area. Therefore, policy support that aim to promote sustainability of farming systems through integration of crop and livestock production should account for this lack of arable land. Thus, to improve the resilience of farming systems based on the Peak District, solutions should aim to maintain the cultural value of the countryside and preserve the rural tourism potentials (DEFRA, 2010). Particular policy tools such as the Visitor Giving Schemes (VGS) provide investment options for local restoration and enhancement in the context of environmental benefits and tourist infrastructure within the uplands (DEFRA, 2016; Reed et al., 2013). Furthermore, with regards to financial dependency (receipt of financial support, bank loans and overdrafts), a hot spot is estimated for the Peak District. The latter indicates that farming systems depend on financial support to sustain economic outputs. Policy support should focus on promoting the development of diversified incomes exploiting the natural strengths of these areas which relate to proximity to abattoir, labour supply and favourable weather conditions and also the development potentials relating to diversified incomes (tourism).

6.5 Conclusions

This chapter presents a method of examining upland farming systems in a spatial context for creating policy implications on particular spatial zones within the LFAs of England. The current method incorporated the results from Chapter 4 and Chapter 5 into a Geographic Information Systems (GIS) environment to examine for spatial commonality between drivers of performance, constraining factors and profitability of hill farms in England. Through this analysis statistically significant spatial aggregations of higher and lower values were estimated within the study area. The projected factors were then plotted against each other to identify areas in which the spatial clusters overlap. This examination enabled the identification of areas in which livestock production appears to be less or more challenging and thus pointed out the need to spatially target policy support through the forthcoming strategies.

Findings suggest that the areas of Peak District, Northumberland and Cumbria aggregate the most significant spatial relationships between drivers of performance, natural barriers and profitability. Sheep production emerges as more challenging in Cumbria while Northumberland and Peak District provide more favourable conditions as farm businesses estimate hot spots of profitability and cold spots of financial dependence and have potentials for integrating crop and livestock production to further develop resilience and increase financial performance. On the other hand, production of beef cattle within the Peak District experiences the most favourable conditions while Northumberland and Cumbria have the least favourable.

Limitations emerged through this study due to the geographic reference of the farm businesses. Specifically, farms of the sample are referenced on the 10x10 km square grid as the specific location within the grid cell is not known. Therefore, for the purposes of this analysis, the location of the farms was assumed to be in the centre of the grid square in which they are referenced. However, estimations that would have used the actual location of the farms might model spatial relationships that are closer to the reality and might differ to an extend from our projections. Thus, there is the potential for improving the accuracy of the projections in the case that the precise location of the farms is incorporated into the method. Further discussion on the limitations of the current methodology is presented in Section 7.5.

To conclude, the forthcoming policy measures should be spatially targeted in order to address the challenges of different systems that vary spatially (O'Rourke et al., 2016; O'Sullivan et al., 2015) considering the heterogeneity that exists in the upland environment and the spatial variability of factors affecting or constraining agricultural performance. The focus of future policies for the development of the LFAs should be on maintaining the cultural value of the countryside, preserve the natural capital and sustain agricultural productivity. This should be accomplished by exploiting the strengths of each landscape within the study area and also by mitigating the challenges emerging from natural handicaps through the provision of options for diversification of income and the provision of public goods (ecosystem services). In addition, the policy making should take into consideration the findings of this study regarding the areas in which production of either beef cattle or sheep is estimated as less or more challenging. The latter, should deliver knowledge in the context of rethinking the criteria used for the provision of support to hill farming systems.

PART III

Chapter 7

Summary Discussion and Conclusions

7.1 Summary of the objectives of this research

Agricultural production systems operate within a continuously changing context both from the perspective of socio-economic and environmental conditions, as well as of the political context and the ways that policy making intervenes to support farm businesses. Farming in the uplands is described as more challenging due to presence of natural barriers that constrain agricultural production (Harvey and Scott, 2017). Therefore it is essential to develop strategies and effective management practices so that the future goals for production of high quality food, maintenance of environmental and cultural values and provision of ecosystem services will be met (DEFRA, 2018b, 2011b).

The present study attempts to construct a framework enabling the sustainable development of livestock farm businesses based in the English uplands. This is achieved through delivering a range of implications addressing both the requirements for effective policy design, as well as meeting the production needs of the farmers. Specifically, this research highlights factors that trigger leading or lagging financial and production performances. Furthermore, this research examined changes in profitability and environmental performance triggered by different farm organisation plans and land use. Such findings relate to farm-level management decisions, spatially inherent handicaps as well as production plans affecting sustainability and resulting in greater or lower performance. Such knowledge can be exploited for the design of forthcoming policies.

To address the main aim of the study three specific research questions were formulated and answered using a range of financial and physical data regarding livestock farming systems that are based in the Less Favoured Areas of England. To achieve that, a range of quantitative analysis methods were carried out. Specifically, to identify drivers of production performance and profitability, a multivariate statistical analysis was conducted including PCA and MLR. With the use of the former, the dimensionality of the dataset was reduced through the identification of core underlying factors (principal components) (Jolliffe, 2002; Linting et al., 2007). These were then incorporated in the linear regression analysis to examine their explanatory power in variations of agricultural performance within the study area (Aristya et al., 2017; Huat et al., 2013; Micha et al., 2015). Furthermore, for the examination of farm production plans, an LP method was developed to examine the optimisation of ICLS and the implications for environmental performance, profitability and land use change based on four different scenarios (Gameiro et al., 2016; Olaizola et al., 2015; Sneessens et al., 2016). Finally, this study aimed to reveal geographical insights including spatial distribution and commonality between factors that enhance, hinder or constrain agricultural performance in the LFAs (Bateman et al., 2008; Bryan et al., 2009b; Marinoni et al., 2012). Therefore, Geographic Information Systems (GIS) were incorporated to conduct spatial clustering analysis. The following section provides a discussion on findings from the aforementioned methodological steps and linking them to the relevant research questions.

7.2 Results from the empirical analysis and links to the research questions

Research question 1: *What are the drivers of financial and production triggering leading and lagging agricultural business performances? - Sub-question: How can such knowledge inform the policy making for developing hill livestock farming sustainably?*

Drivers of production performance and profitability triggering leading and lagging performances were identified in the work addressing this research , examining a range of variables relative to management decisions, landscape characteristics, weather conditions and the social characteristics of the farmer. The factors that affect performance were examined through the use of PCA and MLR. The findings of this empirical analysis decompose variation in performance into two core dimensions. The first relates to farm-level management decisions and the second corresponds to landscape-fixed characteristics relating to natural handicaps. The latter also allowed the identification of broad spatial patterns across the study area in which livestock farming underperforms.

Concerning the first dimension, the most significant factors affecting agricultural performance relate to financial dependency (financial liabilities, support payments) and low evaluation of machinery which are negative drivers of performance, along with size of farm (LU) and labour as well as the social characteristics of the farmer (lower age and higher education level) which are positive drivers of performance. Furthermore, with regards to the second dimension, proximity to abattoir and fair weather conditions are positive drivers of performance, whereas the level of physical disadvantage affects performance negatively. Additionally, concerning the identification of spatial patterns of performance, results demonstrate that farm businesses based in the geographic block of Peak District and Welsh Borders are likely to be more profitable than their counterparts based in the North geographic block of the Pennines.

Research question 2: *How can livestock production in the LFAs be optimised to ensure economic viability of hill farming systems? -Sub-question: What are the financial and spatial implications of integrating crop and livestock production?*

Optimisation of Integrated Crop and Livestock production systems (ICLS) was studied using an LP model that estimated increased financial outcomes for the farm businesses with increased sheep numbers and crop production and decreased numbers of beef cattle. The modelling of the upland production systems was conducted through the construction of different production organisation scenarios. These represented different levels of crop and livestock integration ranging from systems that utilise permanent grassland only (livestock production only) to systems utilising permanent and temporary grassland as well as land suitable for cultivation of crops (livestock and crop production). A range of changes is estimated for the land use, projecting a reduction of areas utilised for permanent and temporary grassland and an exploitation of all land suitable for cultivation. Concerning environmental performances, the current method considered the amount of N fertiliser applied, for which the optimisation estimated reduced amounts. However, across the scenarios, higher levels of crop production are associated with higher requirements of fertiliser and thus, they obtain a poorer performance in comparison to the specialised livestock systems in the context of applying N. With regards to the constraining factors, a significant parameter for the optimisation of livestock enterprises and specifically the beef cattle is the housing capacity. In particular, half of the farm businesses that maintained beef cattle production after the optimisation were constrained by this particular factor.

Research question 3: *What does the spatial analysis reveal that is relevant to the sustainable development of the LFA farming systems?*

The aim of this research question was to investigate the spatial distribution and commonality of factors that enhance, hinder or constrain agricultural performance in the LFAs, in order to create recommendations for the design of spatially targeted policy support. To address this, the results derived from the first two research questions were incorporated into a Geographic Information System (GIS) environment to study the spatial distribution. Findings from the spatial clustering analysis suggest that the Peak District aggregates the most favourable conditions for livestock production. This emerges from an estimated spatial commonality between the factors of proximity to abattoirs, lower levels of labour shortages and fair weather conditions. A spatial aggregation of higher profitability for the beef cattle enterprises is estimated for this area. On the contrary, northern Northumberland is found to aggregate the less favourable conditions for beef cattle enterprises where a spatial overlap is estimated for poor weather conditions, higher levels of labour shortages, lower evaluation of machinery and greater remoteness. Sheep enterprises based in these areas formulate spatial clusters of high financial performance overlapping with the aforementioned non-favourable conditions. The latter indicates presence of management practices that result in overcoming such barriers. The latter also provides an interpretation for the spatial aggregations of increased optimised sheep numbers that overlap with areas of poorer weather conditions.

7.3 Discussion and Conclusions

The current study acknowledges the significant environmental and cultural values that characterise the English uplands as well as the important role of agriculture in preserving and maintaining these values. To facilitate development of a sustainable agricultural sector within the LFAs, the present research attempts to create a framework that delivers valuable knowledge of relevance to both the decision makers and the farmers. Towards this direction, as discussed in Chapter 4, agricultural performance was studied to reveal farm management practices, as well as spatially inherent landscape characteristics, enhancing or hindering performance. This part of the empirical analysis allowed the identification of farm-level management decisions triggering leading performances that can be mirrored across the farming systems to enhance performance. Furthermore, the identification of spatially-fixed characteristics affecting agricultural performance, created implications for the revision of the LFA designation criteria and the ways that policy support should be provided. Specifically, the current research suggests that policy support should incentivise farmers to implement farm-level practices enabling greater performance. In addition, for areas highlighted as heavily handicapped, policy solutions should offer options for enhancing the provision of ecosystem services. The aforementioned strategies need to consider the spatial heterogeneity among various farming systems, and thus, spatially target support measures.

Furthermore, change in the design of structural plans within the hill farming systems was investigated to identify ways of mitigating challenges that emerge in the sector. Specifically, this regards the implementation of farm organisation scenarios integrating crop and livestock production systems (ICLS). As discussed in Chapter 5, ICLS provide an option for the sustainable development of hill farms, increasing profitability while enabling greater resilience and lower dependency on external production inputs. Furthermore, the examination of ICLS allowed the investigation of the optimised utilisation of available resources which demonstrated improved environmental performances for the farm businesses under consideration. Variations in the environmental and agricultural performance were identified across the various scenarios that had different integration options based on the land availability and suitability at the farm level.

The latter highlights the need for a new agricultural policy in the UK that considers the spatial variability of factors affecting agricultural performance as well as the spatial heterogeneity of strengths and weaknesses in the context of sustainable agricultural development. More specifically, as analysed in Chapter 6, particular areas within the LFAs of England seem to spatially aggregate further favourable or unfavourable conditions in the context of agricultural production. Policy support aiming to provide solutions in heavily disadvantaged areas, could provide options for diversifying farm income as well as the provision of public goods (through Stewardship or other payments for ecosystem services - PES). More specifically, in the context of upland farming systems, the Peatland Code and Visitor Giving Schemes (VGS) have shown to be vital measures through providing options for restoration and enhancement of environmental quality and tourism (DEFRA, 2016). Particularly, in such schemes, payments are given for benefits derived from restoration of peatland, improved soil conditions through increased carbon storage capacity and investment in tourist infrastructure resulting in local and environmental benefits. Thus, the rural communities underpinning the upland systems are provided with a range of options towards the regeneration of the local economy while enhancing environmental quality. Furthermore, strategies should exploit the opportunities for sustainable development that here relate to land suitable for production of arable crops and integration with livestock production systems. Strategies should incentivise farmers to adopt ICLS while also provide technical knowledge and advice for farmers. The main pillars of intervention should include the establishment of networks of transferrable knowledge as well as the promotion of solutions for potential barriers in the implementation. Through networks of information, farmers will be able to get access to information on the positive impacts of ICLS on sustainability and thus increase willingness to change. Additionally, through the networks technical knowledge will be provided to farmers on areas of production for which they may not have had previous experience. Finally, potential challenges in implementing ICLS, such as high initial costs, should be encountered through coordinated purchases and machinery sharing arrangements.

7.4 Policy Implications

Sustainable agricultural activity within the English uplands plays a fundamental role not only for the financial viability of the hill farming systems, but also for environmental quality, biodiversity and upland cultural values (DEFRA, 2010) as well as on the provision of a wide range of public goods such as drinking water and climate regulation (English Nature, 2013a). Regardless of the natural barriers that exist in the LFAs, upland farms can benefit from opportunities to maximise the provision of environmental benefits (ecosystem services) and diversification (tourism, energy generation) given the nature of their landscapes (DEFRA, 2018b). In that context, of essential importance was the identification of practices, landscape characteristics and organisation plans affecting performances and the sustainable development of hill farms.

In an attempt to identify drivers of performance within the upland farming systems (Chapter 4), the current analysis focused on the LFAs of England evaluating the impact of several of factors on production and financial performance. Results from the current approach demonstrate a range of farm-level management decisions as well as landscape characteristics that either enhance or hinder agricultural performance. Furthermore, this analysis examined the optimised integration of crop and livestock production systems suggesting that this can be an option for the sustainable development of upland farms (Chapter 5). Finally, results concerning the geographical analysis point out the areas in the North West of England as the most heavily handicapped, while areas in the North East and the Peak District are shown to have the highest potentials in terms of profitability, options for diversification of income and integration of crop production as well as of proximity to abattoirs (Chapter 6).

With regards to farm-level practices, findings indicate that financial dependency, and low evaluation of machinery are negative drivers of performance while size of farm (LU) and labour, as well as the lower age and higher education level of the farmer, are positive drivers of performance. Therefore future policies could focus on providing education and training opportunities to farmers in order for them to gain technical knowledge on efficient production practices that enable enhanced agricultural performance (Angón et al., 2015; Darnhofer et al., 2010; Guesmi and Serra, 2015).

Further to that, policy support should provide knowledge and solutions to barriers that may occur when adopting such practices. A potential barrier may relate to high initial costs in the context of updating technological production units that can be accommodated through the use of machinery-sharing arrangements as well as joint coordinated purchases of production equipment (Artz and Naeve, 2016; Larsén, 2010).

Concerning landscapes that are identified as heavily handicapped (as discussed in Chapter 4 and Chapter 6) the current research suggests that new strategies should incentivise farmers to focus more on the provision of public goods and ecosystem services such as water quality and flood regulation (water catchment schemes), carbon storage (peatland restoration) as well as agri-tourism options (visitor giving schemes) (DEFRA, 2013; Hodgson et al., 2010; Strohbach et al., 2015). More specifically, such options could provide a vital option for farm businesses based in areas such as Cumbria (concerning beef cattle and sheep enterprises) and northern Northumberland (concerning beef cattle enterprises) which have been identified as heavily handicapped and underperforming in the context of livestock production.

Policy making needs to exploit the environmental and economic benefits that emerge from the integration of crop and livestock production systems (discussed in Chapter 5) though designing and evaluating a range of integration scenarios and trade-offs introducing collaborations between scientists and advisory services (Asai et al., 2018; Martin et al., 2016). Furthermore, the implementation of such changes depends greatly on the provision of technical knowledge and advice provided (Garrett et al., 2017) and thus, policy support should promote the implementation and development of such relevant knowledge.

Findings of this approach suggest that there is a need for a strategy within the LFAs that promotes sustainable development through measures that aim to maintain the cultural and environmental values of the uplands allowing the achievement of sustainable agricultural produce and income. Furthermore, policy solutions need to spatially target support to address the various strengths, weaknesses and constraints on agricultural performance emerging from the distinct characteristics of each landscape within the English LFAs.

7.5 Limitations and further research

The current research incorporates farm-level data derived from the FBS dataset which provides detailed financial, physical and environmental information on farm businesses in England. All available relevant variables from the FBS dataset were employed to examine agricultural production and evaluate the options enabling sustainable development of the farming systems within the LFAs of England. The comprehensive and detailed information that the FBS provides allows the use of such data in various methods that could be applied to several farm systems further to the hill livestock farms.

One of the main limitations emerging for the current study regards the geographical reference of the farm businesses that the FBS provides. More specifically, the geographic location of the farms is referenced on the 10x10 km grid square indicating the square within each farm is located rather than demonstrating the precise location. This issue was of vital importance within the context of the current research that conducts a geographical analysis. In particular, the various datasets incorporated (FBS, Meteorological Office, Food Standards Agency) were linked by geographical overlap and it was essential to use a particular location for the farms. Therefore, the location of the farms was assumed to be at the centre of the grid square. Additionally, the Meteorological Office data are referenced on the 5x5 km grid square and thus they had to be averaged so that they correspond to the same spatial unit with the FBS data (10x10 km). Furthermore, the distance to closest abattoir was then limited to capture the distance between the abattoir and the centre of the grid square in which the farm is geographically referenced. These steps provided solutions to the initial problem that enabled the study to conduct a geographical analysis regardless of the limitations. However, the linked information was either averaged (weather data) or calculated approximately (distance to closest abattoir). Therefore, it is expected that some of the information within the dataset is lost and results of higher accuracy would have been estimated in case that the exact location of the farms was known.

The latter would also allow for further datasets to be linked and examined in reference to studying the upland farming systems such as the geological classification available from the British Geological Survey as well as other types of environmental classifications (agricultural land classification, nitrate vulnerable zones and ITE land classification) available from the Centre of Ecology and Hydrology, the Environment Agency and the MAGIC map tool.

Furthermore, future applications aiming to evaluate the performance of various agricultural systems can potentially incorporate the methodology that was developed in the current research using up to date secondary farm business data. As discussed in Chapter 4, through a multivariate statistical analysis including a PCA and an MLR, agricultural systems can be studied to enable the identification of drivers of agricultural performance. Such applications can create valuable implications for the sustainable development not only of the hill farming systems but agricultural systems in a broader context addressing both the farmers as well as the policy makers. Additionally, further research could focus on the drivers of performance and specifically examine the parameter of geographical isolation to analyse how accessibility to production inputs and transportation costs affect agricultural performance in remote and marginal agricultural areas.

The LP model, that was developed in Chapter 5 to optimise the ICLS, has the potential to also be used to study a range of applications of decision analysis for the agricultural sector. This could include the determination of minimal costs for reducing carbon emissions as well as the identification of efficient ways to allocate limited production resources and capital (financial, production units). Additionally, this model can be further developed to not only consider a single objective but incorporate multiple goals that the farmers may have further to achieving profits, such as production of food and diversification of income and also to maximise a range of tasks including environmental quality objectives (DEFRA, 2018b). Although hill farmers have environmental preservation interests (DEFRA, 2010), such information is not available through the FBS data and thus, it was not possible to model such objectives across the farming systems under consideration. However, this knowledge would enable the construction of a mathematical programming model that will be able to a) create simulations and evaluate the impacts of various scenarios and b) deliver recommendations on achieving multiple farm-level objectives to enable the sustainable development of farming systems. Finally, even though the current method can be further developed to be applied in similar approaches, the objective of exploiting the strengths of each region that here relate to integration of crop and livestock production systems and provision of ecosystem services remains subject to the unique characteristics of each region.

Despite the limitations that occurred, the present research demonstrates that the investigation of drivers and constraints of agricultural performance, their spatial distribution and changes in farm structural plans within hill farming systems can help to understand how such systems respond in productivity challenges and thus inform policy support on how to enable sustainable development in the LFAs.

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Appendix

Appendix A Detailed results from MLR, incorporating PCA factor scores as explanatory variables

Sheep Enterprises

Table A. 1

Geographic region: All regions, North block as reference group

Dependent variable: AGM per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	208.672	22.6078	9.2301	<0.0001	***
Fair climate	37.4597	19.4927	1.9217	0.0561	*
Physical disadvantage	−36.9578	19.1852	−1.9264	0.0555	*
Feeding stuffs per LU	14.7372	19.32	0.7628	0.4465	
Size of farm LU	26.1945	19.5102	1.3426	0.1810	
Social characteristics of farmer	16.1996	19.2574	0.8412	0.4013	
Remoteness	−29.7508	19.0224	−1.5640	0.1194	
Liabilities	−23.0915	19.2583	−1.1990	0.2320	
Family labour	−0.414022	19.2164	−0.0215	0.9828	
South block	54.4227	57.5549	0.9456	0.3455	
Peaks and Welsh borders block	90.5978	51.9237	1.7448	0.0826	*

Mean dependent var	231.0896		S.D. dependent var	276.9952
Sum squared resid	14328189		S.E. of regression	270.3757
R-squared	0.093476		Adjusted R-squared	0.047224
F(10, 196)	2.021039		P-value(F)	0.033035

Log-likelihood	−1447.230		Akaike criterion	2916.460
Schwarz criterion	2953.120		Hannan-Quinn	2931.285

Table A. 2

Geographic region: All regions, North block as reference group

Dependent variable: EO per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	653.705	21.3043	30.6843	<0.0001	***
Fair climate	1.93746	18.3687	0.1055	0.9161	
Physical disadvantage	−36.4282	18.079	−2.0149	0.0453	**
Feeding stuffs per LU	17.8673	18.2061	0.9814	0.3276	
Size of farm LU	17.0667	18.3853	0.9283	0.3544	
Social characteristics of farmer	13.1883	18.147	0.7267	0.4682	
Remoteness	−19.1803	17.9256	−1.0700	0.2859	
Liabilities	−26.5728	18.1479	−1.4642	0.1447	
Family labour	1.79175	18.1084	0.0989	0.9213	
South block	−59.1642	54.2363	−1.0909	0.2767	
Peaks and Welsh borders block	−1.56915	48.9298	−0.0321	0.9744	

Mean dependent var	645.7229		S.D. dependent var	255.7135
Sum squared resid	12723514		S.E. of regression	254.7860
R-squared	0.055434		Adjusted R-squared	0.007241
F(10, 196)	1.150260		P-value(F)	0.326949
Log-likelihood	−1434.936		Akaike criterion	2891.873
Schwarz criterion	2928.533		Hannan-Quinn	2906.698

Table A. 3

Geographic region: North block

Dependent variable: AGM per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	211.294	24.5128	8.6198	<0.0001	***
Fair climate	58.9106	24.2829	2.4260	0.0166	**
Physical disadvantage	−31.9392	21.9185	−1.4572	0.1474	
Feeding stuffs per LU	20.6135	24.9119	0.8275	0.4094	
Size of farm LU	26.4062	23.1398	1.1412	0.2558	
Social characteristics of farmer	25.6174	24.293	1.0545	0.2935	
Remoteness	−38.6656	25.2313	−1.5324	0.1277	
Liabilities	−25.8296	23.4572	−1.1011	0.2728	
Family labour	−16.5923	25.4627	−0.6516	0.5157	

Mean dependent var	205.5971		S.D. dependent var	301.3589
Sum squared resid	11642678		S.E. of regression	292.5883
R-squared	0.109729		Adjusted R-squared	0.057360
F(8, 136)	2.095302		P-value(F)	0.040278
Log-likelihood	−1024.522		Akaike criterion	2067.043
Schwarz criterion	2093.834		Hannan-Quinn	2077.929

Table A. 4

Geographic region: North block

Dependent variable: EO per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	655.407	22.5306	29.0897	<0.0001	***
Fair climate	9.41031	22.3192	0.4216	0.6740	
Physical disadvantage	−33.6344	20.1461	−1.6695	0.0973	*
Feeding stuffs per LU	14.8007	22.8974	0.6464	0.5191	
Size of farm LU	14.4152	21.2686	0.6778	0.4991	
Social characteristics of farmer	21.9615	22.3285	0.9836	0.3271	
Remoteness	−37.5893	23.191	−1.6209	0.1074	
Liabilities	−34.4644	21.5604	−1.5985	0.1123	
Family labour	−13.2453	23.4036	−0.5660	0.5724	

Mean dependent var	653.2177		S.D. dependent var	271.5574
Sum squared resid	9835847		S.E. of regression	268.9283
R-squared	0.073755		Adjusted R-squared	0.019270
F(8, 136)	1.353675		P-value(F)	0.222523
Log-likelihood	−1012.295		Akaike criterion	2042.590
Schwarz criterion	2069.380		Hannan-Quinn	2053.476

Table A. 5

Geographic region: South block

Dependent variable: AGM per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	283.841	40.1929	7.0620	<0.0001	***
Fair climate	8.51676	49.473	0.1721	0.8652	
Physical disadvantage	−12.2262	62.8625	−0.1945	0.8480	
Feeding stuffs per LU	64.68	33.8825	1.9090	0.0723	*
Size of farm LU	−55.4372	49.0044	−1.1313	0.2728	
Social characteristics of farmer	−57.6773	47.3849	−1.2172	0.2392	
Remoteness	26.1072	32.7486	0.7972	0.4357	
Liabilities	−130.6	63.5469	−2.0552	0.0547	*
Family labour	−36.1078	36.4932	−0.9894	0.3356	

Mean dependent var	276.8675		S.D. dependent var	191.6007
Sum squared resid	572342.9		S.E. of regression	178.3167
R-squared	0.400362		Adjusted R-squared	0.133857
F(8, 18)	1.502266		P-value(F)	0.224567
Log-likelihood	−172.7937		Akaike criterion	363.5874
Schwarz criterion	375.2499		Hannan-Quinn	367.0553

Table A. 6

Geographic region: South block

Dependent variable: EO per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	602.041	48.9293	12.3043	<0.0001	***
Fair climate	24.8769	60.2265	0.4131	0.6844	
Physical disadvantage	14.9346	76.5264	0.1952	0.8475	
Feeding stuffs per LU	104.161	41.2472	2.5253	0.0212	**
Size of farm LU	−52.0708	59.6561	−0.8728	0.3942	
Social characteristics of farmer	−79.7411	57.6846	−1.3824	0.1838	
Remoteness	88.9491	39.8668	2.2312	0.0386	**
Liabilities	−165.901	77.3596	−2.1445	0.0459	**
Family labour	−23.1025	44.4254	−0.5200	0.6094	

Mean dependent var	597.1651		S.D. dependent var	248.5653
Sum squared resid	848194.3		S.E. of regression	217.0758
R-squared	0.471991		Adjusted R-squared	0.237321
F(8, 18)	2.011294		P-value(F)	0.104060
Log-likelihood	−178.1042		Akaike criterion	374.2084
Schwarz criterion	385.8710		Hannan-Quinn	377.6763

Table A. 7

Geographic region: Welsh borders and Peaks block

Dependent variable: AGM per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	313.988	39.256	7.9985	<0.0001	***
Fair climate	−49.5152	40.4669	−1.2236	0.2321	
Physical disadvantage	11.6116	77.6565	0.1495	0.8823	
Feeding stuffs per LU	−127.553	47.756	−2.6709	0.0129	**
Size of farm LU	29.42	50.8409	0.5787	0.5678	
Social characteristics of farmer	30.2661	36.3706	0.8322	0.4129	
Remoteness	−9.04354	41.3164	−0.2189	0.8284	
Liabilities	−28.4606	40.0034	−0.7115	0.4831	
Family labour	79.5276	34.3551	2.3149	0.0288	**

Mean dependent var	301.3867		S.D. dependent var	206.4905
Sum squared resid	828979.4		S.E. of regression	178.5604
R-squared	0.428173		Adjusted R-squared	0.252226
F(8, 26)	2.433537		P-value(F)	0.041214
Log-likelihood	−225.9334		Akaike criterion	469.8668
Schwarz criterion	483.8649		Hannan-Quinn	474.6989

Table A. 8

Geographic region: Welsh borders and Peaks block

Dependent variable: EO per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	632.708	34.036	18.5894	<0.0001	***
Fair climate	−6.0821	35.0859	−0.1733	0.8637	
Physical disadvantage	−82.793	67.3302	−1.2297	0.2298	
Feeding stuffs per LU	−43.8803	41.4057	−1.0598	0.2990	
Size of farm LU	6.38907	44.0804	0.1449	0.8859	
Social characteristics of farmer	33.701	31.5343	1.0687	0.2950	
Remoteness	−27.9841	35.8224	−0.7812	0.4417	
Liabilities	48.1343	34.684	1.3878	0.1770	
Family labour	102.297	29.7868	3.4343	0.0020	***

Mean dependent var	652.1321		S.D. dependent var	185.6239
Sum squared resid	623172.2		S.E. of regression	154.8165
R-squared	0.468062		Adjusted R-squared	0.304388
F(8, 26)	2.859731		P-value(F)	0.020116
Log-likelihood	−220.9394		Akaike criterion	459.8788
Schwarz criterion	473.8769		Hannan-Quinn	464.7109

Beef cattle Enterprises

Table A. 9

Geographic region: All regions, North block as reference group

Dependent variable: AGM per LU

	Coefficient	Std. Error	t-ratio	p-value	
constant	289.153	37.2162	7.7696	<0.0001	***
Fair Climate	46.0766	35.8975	1.2836	0.2007	
Physical Disadvantage	16.8159	28.5578	0.5888	0.5566	
Financial dependency	40.7622	27.9988	1.4559	0.1469	
Low machinery evaluation	−128.184	28.1753	−4.5495	<0.0001	***
Social characteristics of farmer	40.2559	28.3509	1.4199	0.1571	
Remoteness	−54.1171	29.764	−1.8182	0.0705	*
Size of farm and paid labour	20.4614	27.8048	0.7359	0.4626	
Peaks and Welsh borders	55.2441	83.5906	0.6609	0.5094	
South	−73.346	99.1576	−0.7397	0.4603	

Mean dependent var	288.3611		S.D. dependent var	424.4733
Sum squared resid	33708688		S.E. of regression	401.6038
R-squared	0.141808		Adjusted R-squared	0.104852
F(9, 209)	3.837243		P-value(F)	0.000164
Log-likelihood	−1618.637		Akaike criterion	3257.274
Schwarz criterion	3291.164		Hannan-Quinn	3270.961

Table A. 10

Geographic region: All regions, North block as reference group

Dependent variable: EO per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	787.279	36.2229	21.7343	<0.0001	***
Fair Climate	−76.9846	34.9394	−2.2034	0.0287	**
Physical Disadvantage	12.6817	27.7956	0.4562	0.6487	
Financial dependency	−46.0958	27.2515	−1.6915	0.0922	*
Low machinery evaluation	−180.936	27.4233	−6.5979	<0.0001	***
Social characteristics of farmer	69.2567	27.5942	2.5098	0.0128	**
Remoteness	161.402	28.9696	5.5714	<0.0001	***
Size of farm and paid labour	33.9655	27.0626	1.2551	0.2109	
Peaks and Welsh borders	−40.1676	81.3596	−0.4937	0.6220	
South	20.7689	96.5111	0.2152	0.8298	

Mean dependent var	782.7997		S.D. dependent var	462.1310
Sum squared resid	31933327		S.E. of regression	390.8849
R-squared	0.314105		Adjusted R-squared	0.284569
F(9, 209)	10.63460		P-value(F)	1.56e-13
Log-likelihood	−1612.712		Akaike criterion	3245.425
Schwarz criterion	3279.315		Hannan-Quinn	3259.112

Table A. 11

Geographic region: North block

Dependent variable: AGM per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	292.515	43.4359	6.7344	<0.0001	***
Fair Climate	62.6115	47.3192	1.3232	0.1880	
Physical Disadvantage	20.3847	39.0338	0.5222	0.6024	
Financial dependency	63.9301	37.6481	1.6981	0.0918	*
Low machinery evaluation	−125.493	37.3032	−3.3641	0.0010	***
Social characteristics of farmer	35.8604	40.7633	0.8797	0.3806	
Remoteness	−78.2094	37.7949	−2.0693	0.0404	**
Size of farm and paid labour	0.418461	42.4043	0.0099	0.9921	

Mean dependent var	269.1700		S.D. dependent var	478.4001
Sum squared resid	27592373		S.E. of regression	452.0929
R-squared	0.150980		Adjusted R-squared	0.106956
F(7, 135)	3.429540		P-value(F)	0.002084
Log-likelihood	−1073.078		Akaike criterion	2162.156
Schwarz criterion	2185.859		Hannan-Quinn	2171.787

Table A. 12

Geographic region: North block

Dependent variable: EO per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	782.936	41.766	18.7458	<0.0001	***
Fair Climate	−76.8363	45.5	−1.6887	0.0936	*
Physical Disadvantage	34.6346	37.5331	0.9228	0.3578	
Financial dependency	−26.9857	36.2007	−0.7454	0.4573	
Low machinery evaluation	−193.681	35.8691	−5.3997	<0.0001	***
Social characteristics of farmer	78.4357	39.1961	2.0011	0.0474	**
Remoteness	143.951	36.3418	3.9610	0.0001	***
Size of farm and paid labour	17.052	40.7741	0.4182	0.6765	

Mean dependent var	794.5799		S.D. dependent var	494.7690
Sum squared resid	25511544		S.E. of regression	434.7119
R-squared	0.266089		Adjusted R-squared	0.228034
F(7, 135)	6.992283		P-value(F)	4.14e-07
Log-likelihood	−1067.472		Akaike criterion	2150.943
Schwarz criterion	2174.646		Hannan-Quinn	2160.575

Table A. 13

Geographic region: South block

Dependent variable: AGM per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	332.38	72.9474	4.5564	0.0001	***
Fair Climate	36.0671	46.1872	0.7809	0.4419	
Physical Disadvantage	26.0418	41.1353	0.6331	0.5322	
Financial dependency	−84.684	50.3871	−1.6807	0.1048	
Low machinery evaluation	−82.835	49.7108	−1.6663	0.1076	
Social characteristics of farmer	7.62986	35.5375	0.2147	0.8317	
Remoteness	176.658	52.0091	3.3967	0.0022	***
Size of farm and paid labour	30.7124	29.2796	1.0489	0.3039	

Mean dependent var	281.6442		S.D. dependent var	205.8237
Sum squared resid	785106.3		S.E. of regression	173.7711
R-squared	0.438404		Adjusted R-squared	0.287206
F(7, 26)	2.899523		P-value(F)	0.022212
Log-likelihood	−219.0465		Akaike criterion	454.0931
Schwarz criterion	466.3040		Hannan-Quinn	458.2574

Table A. 14

Geographic region: South block

Dependent variable: EO per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	828.063	85.1033	9.7301	<0.0001	***
Fair Climate	−50.3642	53.8839	−0.9347	0.3586	
Physical Disadvantage	−54.4316	47.99	−1.1342	0.2670	
Financial dependency	−156.483	58.7837	−2.6620	0.0131	**
Low machinery evaluation	−141.068	57.9946	−2.4324	0.0222	**
Social characteristics of farmer	26.2421	41.4594	0.6330	0.5323	
Remoteness	310.588	60.6759	5.1188	<0.0001	***
Size of farm and paid labour	18.4852	34.1587	0.5412	0.5930	

Mean dependent var	607.5552		S.D. dependent var	300.1333
Sum squared resid	1068568		S.E. of regression	202.7283
R-squared	0.640532		Adjusted R-squared	0.543752
F(7, 26)	6.618449		P-value(F)	0.000152
Log-likelihood	−224.2869		Akaike criterion	464.5738
Schwarz criterion	476.7847		Hannan-Quinn	468.7381

Table A. 15

Geographic region: Welsh borders and Peaks block

Dependent variable: AGM per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	309.669	88.855	3.4851	0.0014	***
Fair Climate	15.4904	87.3532	0.1773	0.8603	
Physical Disadvantage	−34.5905	59.8112	−0.5783	0.5669	
Financial dependency	−72.4189	59.3123	−1.2210	0.2305	
Low machinery evaluation	−206.37	53.7079	−3.8425	0.0005	***
Social characteristics of farmer	−25.7786	53.6591	−0.4804	0.6340	
Remoteness	−88.5784	76.1498	−1.1632	0.2528	
Size of farm and paid labour	93.242	46.1418	2.0208	0.0512	*

Mean dependent var	359.1398		S.D. dependent var	353.2791
Sum squared resid	3296079		S.E. of regression	311.3575
R-squared	0.355863		Adjusted R-squared	0.223247
F(7, 34)	2.683406		P-value(F)	0.025194
Log-likelihood	−296.2775		Akaike criterion	608.5550
Schwarz criterion	622.4563		Hannan-Quinn	613.6504

Table A. 16

Geographic region: Welsh borders and Peaks block

Dependent variable: EO per LU

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
constant	711.537	84.8158	8.3892	<0.0001	***
Fair Climate	−118.43	83.3823	−1.4203	0.1646	
Physical Disadvantage	−45.6267	57.0923	−0.7992	0.4297	
Financial dependency	−178.262	56.6161	−3.1486	0.0034	***
Low machinery evaluation	−187.209	51.2664	−3.6517	0.0009	***
Social characteristics of farmer	−40.7235	51.2199	−0.7951	0.4321	
Remoteness	139.487	72.6882	1.9190	0.0634	*
Size of farm and paid labour	141.467	44.0443	3.2119	0.0029	***

Mean dependent var	884.5553		S.D. dependent var	422.6678
Sum squared resid	3003224		S.E. of regression	297.2039
R-squared	0.589980		Adjusted R-squared	0.505564
F(7, 34)	6.988956		P-value(F)	0.000035
Log-likelihood	−294.3235		Akaike criterion	604.6470
Schwarz criterion	618.5483		Hannan-Quinn	609.7424