Evaluating provisioning ecosystem service values: a scenario analysis for the United Kingdom

Report to the Economics Team of the UK National Ecosystem Assessment

Authors

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Abstract

This report seeks to provide an estimate of the contribution of the ecosystem to the value of provisioning services from agriculture by the change in value generated by a marginal alteration in ecosystem inputs. It is composed by two sections. In the first section, as an example, we consider recent UKCIP climate change scenarios to examine the impact which changes in temperature and rainfall will introduce on UK farm incomes. The analysis develops an econometric spatially explicit model for estimating changes in agricultural land use and livestock numbers based on the methodology introduced by Fezzi and Bateman (2011). Land use hectares and livestock stocking rates are in turn employed to calculate farm gross margin estimates of the value of changes in provisioning ecosystem services. Findings suggest that changes in ecosystem inputs induced by climate change will have a substantial influence upon the gross margins generated by farm food production. Interestingly climate change seems to generate mainly positive effects, but losses can take place in localized areas in the South of England, due to an increase in heat-stress. In the second section we present changes in agricultural values arising in each of the UK National Ecosystem Assessment scenarios.

SECTION 1

- Evaluating provisioning services for the United Kingdom via climate change scenarios -

1. Introduction

Agriculture is the major source of provisioning ecosystem services. In conducting an economic analysis for ecosystem service assessment, a focus upon the total value for farm food production can be misleading, as such total values reflects both ecosystem inputs and man-made capital, labour and expertise inputs (Bateman et al., 2011). A cleaner estimate of the contribution of the ecosystem to the value of provisioning services is provided by the change in value generated by a marginal (unit) alteration in ecosystem inputs. For example, in climate change scenarios it is of interest to examine the impact which one degree increase in temperature is likely to induce.

In order to address this challenge, a novel, spatially explicit and theoretically consistent land use model is here developed based on the methodology introduced in Fezzi and Bateman (2011). This draws upon newly compiled, highly spatially disaggregated datasets embracing temporal variation across long time series. Economic theory is used to construct behavioural models of land use decision making. These predict how farmers respond to changes in agricultural policy, prices and the wider natural environment, of which climate change is the focal interest. The model is validated through standard comparisons of actual versus predicted values.

Given our interest upon the role of ecosystem services in farm activities we do not focus upon the status-quo value of agricultural output. This is well documented elsewhere and does not reveal the role of ecosystems within that output. Rather we reveal that role by varying ecosystem inputs and examining consequences for the agricultural sector. This is achieved by examining the climate change scenarios provided by the United Kingdom Climate Impacts Programme (UKCIP, 2009).

We adopt a modelling technique which is most suited to the predicting spatially heterogeneous impact of shifts in policy, prices and (of particular importance in this context) the natural environment upon farm land use. A key advantage of this approach is that predictions can then be linked to other ecosystem services which are determined by the prevalent mix of agricultural land use, such as farmland biodiversity and carbon storage. A drawback of this focus upon land use is that it does not allow us to obtain a direct estimate of farm net income measures such as profits or land values. While the authors are examining this issue using an alternative methodology (Fezzi et al., 2010a), in this paper we proxy the provisioning values of the EFH by relating farm land use to the Farm Gross Margin (FGM) measure focussed upon in much agricultural economic and official analyses (National Statistics, 2010). While this is a commonly applied approach, we stress that it is not a theoretically ideal measure of net economic value and should be treated with caution as being as indicative only. That said the trends in relative values provide some useful information regarding the likely impacts of changes in climate over the assessment period.

The model is developed using data on England, Wales and Scotland. This is subsequently extended to include Northern Ireland, thus providing a UK wide analysis. Results from the UK wide analysis show that climate change is likely to have a negative impact upon (FGM) in parts of southern England where draughtiness problems may arise particularly within the dairying sector. However, effects upon FGM in Northern England, Wales and Scotland will generally be positive as warmer temperatures will boost crops yield.

2. The Econometric Land Use Model

Below we briefly overview the model specification; the data used for estimation and summarize the main results. For a more detailed discussion of the methodology see Fezzi and Bateman (2011).

Theoretical model

This section illustrates the economic theory which underpins our empirical model of agricultural land use. Following and Chambers and Just (1989) we specify the farm profit function as:

$$(1)\ \pi(\mathbf{p},\mathbf{w},\mathbf{z},l_1,...,l_h) = \max\{\mathbf{p'}\,\mathbf{y} - \mathbf{w'}\,\mathbf{r} : \mathbf{y} \in Y(\mathbf{r},\mathbf{z},l_1,...,l_h)\},$$

where $\mathbf{y}$ is the vector of m outputs, with $\mathbf{r}$ the vector of n inputs, $\mathbf{p}$ the vector of strictly positive output prices, $\mathbf{w}$ the vector of strictly positive input prices, $\mathbf{l}$ the vector of h land use allocations, L the total land available and $\mathbf{z}$ the vector of k other fixed factors (which may include physical and environmental characteristics, policy incentives and constraints, etc.). The farm profit maximization problem can be expressed, without any loss of generality, in terms of profit maximization per unit of land. Indicating with

s the h land use shares corresponding to the land use allocations l, and with $\pi^L(.)$ the profits per unit of land, the optimal land use allocation problem can then be written as:

(2) $$\pi^L(\mathbf{p},\mathbf{w},\mathbf{z},L) = \max_{s_1,\ldots,s_h}\{\pi^L(\mathbf{p},\mathbf{w},\mathbf{z},L,s_1,\ldots,s_h) : \sum_{i=1}^{h} s_h = 1\}\,.$$

Since the profit per area function is positively linearly homogenous and strictly convex in input and output prices, using the Hotelling's lemma one can derive the output supply (y^L) and input demand (r^L) per area (hereafter we will refer to these quantities as input and output *intensities*) as:

(3.a) $$y_i^{\,L}(\mathbf{p},\mathbf{w},\mathbf{z},L) = \frac{\partial\pi^L(\mathbf{p},\mathbf{w},\mathbf{z},L)}{\partial p_i} = \frac{\pi^L(\mathbf{p},\mathbf{w},\mathbf{z},L,\bar{s}_1,\ldots,\bar{s}_h)}{\partial p_i}\text{, and}$$

(3.b) $$r_j^{\,L}(\mathbf{p},\mathbf{w},\mathbf{z},L) = \frac{\partial\pi^L(\mathbf{p},\mathbf{w},\mathbf{z},L)}{\partial w_j} = \frac{\pi^L(\mathbf{p},\mathbf{w},\mathbf{z},L,\bar{s}_1,\ldots,\bar{s}_h)}{\partial w_j}\,,$$

where the superscript on s indicates the optimal shares, i.e. the shares that satisfy (3). The equations describing the optimal land allocations can be derived by recognizing that land is allocated to the different uses in order to equalize their marginal rent or shadow price. In terms of optimal land use shares this can be written as:

(4) $$\frac{\partial\pi^L(\mathbf{p},\mathbf{w},\mathbf{z},L,\bar{s}_1,\ldots,\bar{s}_h)}{\partial s_i} = 0\text{, for } i = 1,\ldots, h.$$

When these equations are linear in the optimal land allocations, including the constraint that the sum of the shares needs to be equal to one leads to a linear system of h equations in h unknowns which can be solved to obtain the optimal land allocation as a function of **p**, **w**, **z** and L. For more details see Fezzi and Bateman (2010).

For empirical estimation, we specify the empirical profit function per hectare as a Normalized Quadratic (NQ) function. Defining with w_n the numeraire good, indicating with $\mathbf{x} = (\mathbf{p}/w_n, \mathbf{w}/w_n)$ the vector of normalized input and output (netput) prices and with $\mathbf{z}^*=(\mathbf{z}, L)$ the vector of fixed factors including policy and environmental drivers and also the total land available L, the NQ profit function can be written as:

(5) $$\bar{\pi}^L = \alpha_0 + \sum_{i=1}^{m+n-1} \alpha_i x_i + \frac{1}{2}\sum_{i=1}^{m+n-1}\sum_{j=1}^{m+n-1} \alpha_{ij} x_i x_j + \sum_{i=1}^{h-1} \beta_i s_i + \frac{1}{2}\sum_{i=1}^{h-1}\sum_{j=1}^{h-1} \beta_{ij} s_i s_j + \sum_{i=1}^{k+1} \gamma_i z_i^* +$$
$$+ \frac{1}{2}\sum_{i=1}^{k+1}\sum_{j=1}^{k+1} \gamma_{ij} z_i^* z_j^* + \sum_{i=1}^{m+n-1}\sum_{j=1}^{h-1} \delta_{ij} x_i s_j + \sum_{i=1}^{m+n-1}\sum_{j=1}^{k+1} \phi_{ij} x_i z_j^* + \sum_{i=1}^{h-1}\sum_{j=1}^{k+1} \varphi_{ij} s_i z_j^*,$$

Where $\bar{\pi}^L = \pi / w_n$ is the normalized profit per unit of land. This profit function is linearly homogeneous by construction, and symmetry can be ensured by imposing $\alpha_{ij} = \alpha_{ji}$, $\beta_{ij} = \beta_{ji}$ and $\gamma_{ij} = \gamma_{ji}$. Only h–1 land use shares appear in the profit function since the last one can be computed by difference and it is therefore redundant. Input and output intensities can be derived as in (3.a) and (3.b), whereas the optimal land use shares can be derived by solving the system (4) which contains h–1 equations with the land additivity constraint $\sum_{j=1}^{h} s_j = 1$. The resulting equations are linear function of the output prices, input prices & fixed factors.

Estimation

Since micro-data on land use are typically censored (most farms do not usually allocate land to all the possible land uses) assuming normal disturbances and implementing Maximum Likelihood (ML) leads to inconsistent estimates of the land use shares and input and output intensities equations (Amemiya, 1973). We address this issue by specifying a Tobit system of equations (Tobin, 1958) and, following Pudney, (1989), we treat one of the shares as a residual category, defined by the identity:

(6) $$s_h = 1 - \sum_{j=1}^{h-1} s_j ,$$

and estimate the remaining h–1 equations as a joint system. When the number of equations is higher than three the ML estimation of a Tobit system requires the evaluation of multiple Gaussian integrals which is computationally extremely intensive. In this paper we follow the practical and computationally feasible solution proposed by Yen et al. (2003), who suggest approximating the multivariate Tobit with a sequence of bivariate models, deriving a consistent Quasi Maximum Likelihood (QML) estimator (details are in Fezzi and Bateman, 2011). We also account for possible heteroskedasticity in the error term allowing the standard errors to vary across observations as a function of a vector of exogenous variables.

This QML estimator is consistent, allows the estimation of cross-equation correlations and the imposition of cross-equation restrictions.

Data sources

In order to correctly assess the financial, policy and environmental drivers of land use change, this analysis employs a unique database, which integrates multiple sources of information dating back to the late 1960s. The resulting data, collected on a $2km^2$ grid square (400ha) basis, cover the entirety of England, Wales and Scotland (Great Britain, GB) and encompass, for the past 40 years: (a) land use shares and livestock number, (b) environmental and climatic determinants, (c) policy and other drivers. In this analysis, however, we do not include yield and profits data, since the necessary information is simply not available at the disaggregated level required by this analysis. This is the main reason why a measure of financial impact upon farms we rely on FGM. Indeed, if profits data would have been available, the theoretical model illustrated in the previous section would have allowed us to include them directly within the modelling framework.

Data on agricultural land use hectares and livestock numbers, derived from the June Agricultural Census (JAC) on a 2km (400 ha) grid square resolution are available on-line from EDINA (www.edina.ac.uk), which aggregates information collected by the Department of Environment, Food and Rural Affairs (DEFRA), and the Welsh Assembly. These data cover the entirety of GB for seventeen, unevenly spaced, years between 1969 and 2006. This yields roughly 60,000 grid-square records each year. Regarding livestock numbers, we distinguish between dairy cows, beef cows and sheep. Concerning agricultural land use types, we explicitly model cereals (including wheat, barley, oats, etc.), oilseed rape, root crops (potatoes and sugar beet), temporary grassland (grass being sown every 3 to 5 years and typically part of an arable crop rotation), permanent grassland (grassland maintained perpetually without reseeding) and rough grazing. These six land uses together cover more than 88% of the total agricultural land within the country and will be the h-1 explicitly modelled land uses. We include the remaining 12% in an "other" land category encompassing horticulture, other arable crops, woodland on the farm, set-aside, bare, fallow and all other land (ponds, paths, etc.). Descriptive statistics for the agricultural land use types and livestock numbers are reported in Table 1 for three illustrative years and for the total dataset.

For each $2km^2$ grid square we consider a detailed specification of the environmental determinants influencing farmers' decision making. For each grid square, we represent climate including (a) average temperature in the growing season (April-September) and (b) accumulated rainfall during the growing season. Those values are 5km grid square climatic averages for the period 1961-1990, and are calculated from the monthly data available from the Met Office website (www.metoffice.gov.uk) and interpolated to 2km to match with our land use data. This is the same baseline used by the UKCIP09 (www.ukcip.org.uk) to derive climate change scenarios.

Table 1: *Descriptive statistics for agricultural land-use in the panel dataset.*

Land-Use	Area Means								UK Total			
	NW	NE	EWM	EA	LSE	SW	WA	SCT	Mean	s.d.	Max	Min
Wheat	52.8	7.4	67.4	105.1	59.3	32.0	2.7	5.1	31.9	47.5	271.7	0
Barley	50.9	21.1	43.9	63.2	42.7	34.7	7.8	22.6	32.5	41.8	296.6	0
Other Cereal	3.7	2.0	5.5	3.7	6.4	4.9	1.9	3.0	3.7	6.5	113.1	0
Oilseed Rape	9.8	0.8	11.0	12.8	11.4	4.5	0.3	2.3	5.6	11.2	124.7	0
Root Crops	10.3	3.6	16.1	32.3	2.2	2.0	0.7	2.1	7.0	16.2	167.4	0
T Grassland	23.7	39.0	33.0	10.7	32.4	53.1	31.0	29.9	31.1	35.7	268.2	0
P Grassland	93.6	173.3	116.4	35.9	93.1	168.9	193.5	50.3	95.2	94.9	395.3	0
Rough Graze.	78.7	86.4	10.2	5.9	9.7	20.2	92.2	252.2	121.9	161.0	400.0	0
Other Land	30.1	16.2	41.5	65.2	56.5	34.4	17.0	0.0	23.2	31.6	289.5	0
Total Ag Land	353.6	349.9	344.9	334.7	313.7	354.8	347.1	367.5	352.6	67.0	400.0	0
Dairy	42.5	161.3	84.9	20.7	54.9	145.5	82.1	19.4	57.6	91.8	1129	0
Beef	143.0	208.9	165.9	56.3	110.7	218.2	194.8	87.6	130.2	125.5	1221	0
Sheep	743.7	935.4	596.3	79.3	346.4	582.7	1865.9	420.4	608.6	766.4	11290	0

Areas: North West (NW), Yorkshire and North East (YNE), East and West Midlands (EWM), East Anglia (EA), London and South East (LSE), South West (SW), Wales (WA) and Scotland (SCT)

We also include other environmental and topographic variables which influence farm's decisions. Specifically, considering soils we include depth to rock (*dr*), volume of stones (*stone*) and 5 dummy variables to represent soil texture (fine, medium fine, medium, coarse, peaty). Those soil characteristics are derived from the 1km raster library of the European Soil Database (Van Liedekerke et al., 2006), which we aggregate at a 2km level. Finally, we include mean elevation in the square (*alt*) and the share of agricultural land with slope higher than 6 degrees (*smore6*), both derived via GIS analysis from the Ordnance Survey, Digital Terrain Model.

Regarding the policy determinants, we include the share of each grid square designated as National Park, Nitrate Sensitive Area (NSA) and Environmentally Sensitive Area (ESA). ESAs, introduced in 1987 and undergone various extensions in subsequent years, were launched to safeguard and enhance areas of particularly high landscape, wildlife or historic value. Participation in ESA schemes is voluntary, and farmers receive monetary compensation for engaging in environmentally friendly farming practices, such as converting arable land to permanent grassland, establishing hedgerows, etc. NSA were established in 1990 and extended in subsequent years. These were introduced in order to test the effects of farming practices on nitrate levels in aquifers, as well as to reduce nitrate levels in selected ground-waters used for public water supply. The NSA is voluntary. Finally, farms located within the boundaries of National Parks can benefit from direct payments if they manage their land by environmental planning and carry-on low-intensity activities. Note that prices and technology are not modelled explicitly here but encompassed via yearly dummies (fixed effects).

Results

We implement the QML approach to estimate two censored Tobit systems: the 3 livestock intensity (dairy cows, beef cows, sheep) equation system and the 6 land use shares (cereal, oilseed rape, root crops, temporary grassland, permanent grassland, rough grazing) system. We use a full quadratic specification of all the environmental determinants (i.e. second order polynomials with interactions) to capture the possible non-linear relations. For illustrative purposes Table 2 reports an abbreviated form of one of the estimated equations; that for cereals.

Table 2: *Land use share equations parameter estimates for cereals*

Variable	Estimated coefficient
mean altitude	0.123 ***
mean altitude squared	-0.000 ***
mean temperature	67.591 ****
mean temperature squared	-2.623 ****
accumulated rainfall	-0.145 ***
accumulated rainfall squared	0.000 ****
depth to rock	0.123
depth to rock squared	-0.000 ***
volume of stones	-170.663 ****
volume of stones squared	895.805 ***
share of agricultural land with slope higher than 6 degrees	-0.085 ****
dominant soil = fine	1.684 ***
dominant soil = medium fine	4.152 ****
dominant soil = coarse	1.715 ***
dominant soil = peat	-12.332 ****
share of urban area	-0.110 ****
share of nitrate sensitive area	0.002
share of national park	-0.061 ****

share of environmentally sensitive area	-0.033 ****

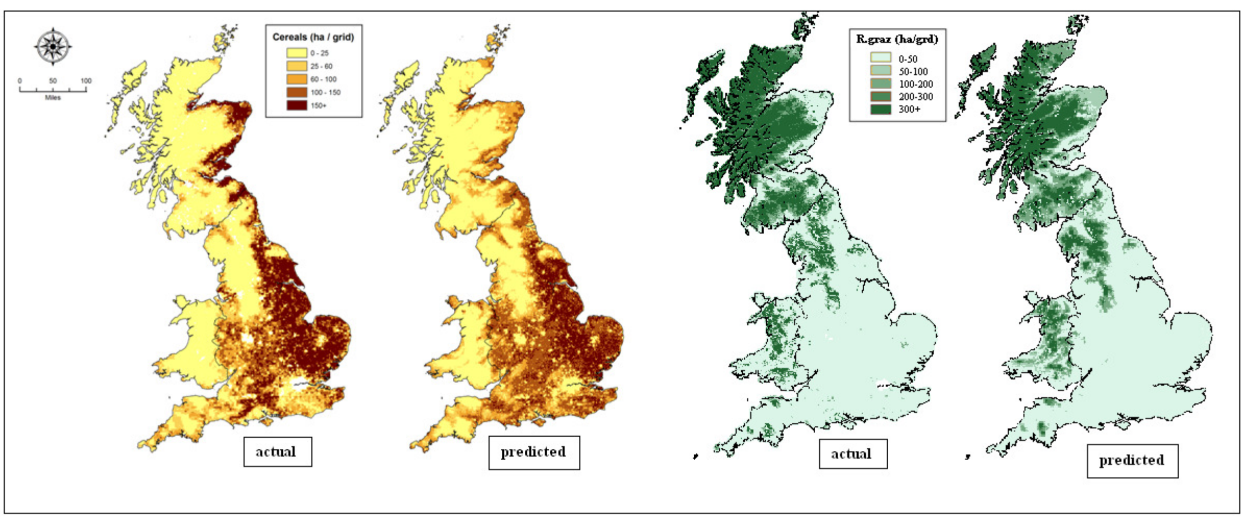
Notes: "*" = t-stat > 2, "**" = t-stat > 3, "***" = t-stat > 4, "****" = t-stat > 10.

Examining Table 2, the sign and magnitude of the coefficients are consistent with our expectations. Considering the environmental determinants of land use, favourable conditions for crop growth (lower volume of stones, deeper soils, flatter land, etc.) increase the share of arable land. However, effects are non-linear. For example consider the influence of climate. Both the coefficients of rainfall and temperature describe inverse U-shaped relations. Finally, considering the policy variables, ESA and National Parks decrease the intensity of agricultural production, reducing the amount of arable land and also the heads of livestock (not reported in the table but available upon request).

Predictive ability

In order to analyze the forecasting ability of our model, Figure 1 maps actual and predicted shares of cereals and rough grazing in 2004. The model performance is highly satisfactory with the two maps showing essentially the same spatial patterns of land use. However, some minor differences can be seen (e.g. in the Midlands the model predicts more cereals then there actually are and in the East of Scotland the model predicts less cereals than observed) and the actual data results in being somehow blockier than the predicted ones, with some grid squares with high cereal shares shown right next to grid squares with very low shares. This is not likely to be a shortcoming of the model, but is more probably a drawback of the raw JAC data, resulting from the parish level record allocation and collection procedure and the subsequent grid square conversion procedure.

Figure 1: Cereals and rough grazing in 2004: model predictions (LHS) and JAC data (RHS)



3. Climate change scenarios

This section illustrates the land use and livestock numbers predictions obtained by implementing the econometric land use model under different climate change scenarios. The scenarios are based on the predicted changes in temperature and precipitation outlined in the UKCIP (2009) report and is used to examine, *ceteris paribus*, the impact of changes in the climate variables on agriculture in the UK.

The UKCIP climate projections

The UKCIP (www.ukcip.org.uk) provides the most up-to-date predictions regarding future UK climate. Importantly, these predictions are spatially explicit, and presented at a 25km grid square resolution. For purposes of our analysis, we concentrate on the UKCIP09 predicted changes in monthly average temperature and precipitation in the crop growing season (from April to September). Descriptive statistics for the predicted climatic variables used in the model are reported for 2004 (base year), 2020, 2040 and 2060 in Table 3 below.

Table 3: Descriptive Statistics of the Climatic variables for 2004, 2020, 2040 and 2060

	Units	Mean	Standard dev	Minimum	Maximum
2004 (base)					
Temperature	^{o}C	11.7	1.5	4.7	14.9
Precipitation	Mm	450.8	172.7	206.7	1699.9
2020 (High)					
Temperature	^{o}C	12.9	1.6	5.9	16.2
Precipitation	Mm	446.9	175.3	201.9	1654.8
2020 (Low)					
Temperature	^{o}C	13.0	1.6	6.0	16.3
Precipitation	Mm	443.7	174.0	198.0	1654.5
2040 (High)					
Temperature	^{o}C	13.6	1.7	6.5	17.1
Precipitation	Mm	429.1	180.1	190.3	1591.2
2040 (Low)					
Temperature	^{o}C	13.4	1.6	6.4	16.9
Precipitation	Mm	432.4	172.2	192.6	1598.9
2060 (High)					
Temperature	^{o}C	14.2	1.8	7.4	18.1
Precipitation	Mm	404.8	171.8	171.2	1522.9
2060 (Low)					
Temperature	^{o}C	13.8	1.7	6.7	17.2

Precipitation	Mm	420.0	171.5	184.0	1542.5

This data refers to the low and high emission scenarios, which corresponds respectively to the SRES B1 and the SRES A1FI in the IPCC Special Report on Emissions Scenarios (Nakicenovic et al., 2000). The mean temperature increases over time with the maximum average seasonal temperature being slightly above 18 °C in 2060 (compared with the baseline maximum of 14.9 °C). Precipitation in the growing season, on the other hand, is forecasted to decrease. Overall, the scenarios show increasingly hot and dry growing seasons. As an illustration, Figures 2 and 3 represent the precipitation and the mean temperature in 2004 and 2040. Rainfall is reduced, particularly in the East and in the central part of the country. Temperature increases very significantly throughout England and Wales.

Figure 2: *Precipitation in the growing season (April - September), year 2004 and UKCIP projections for 2040 high scenario.*

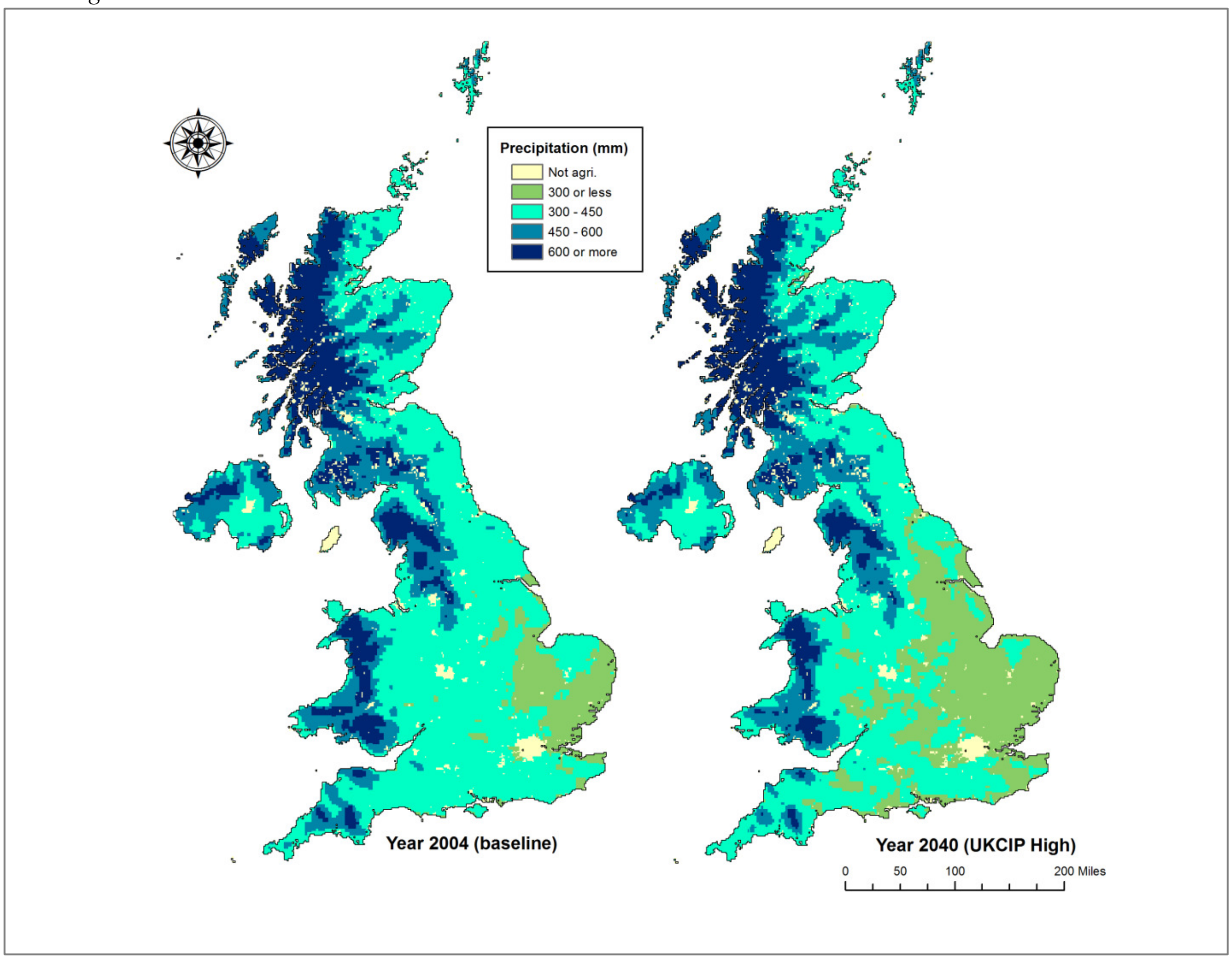
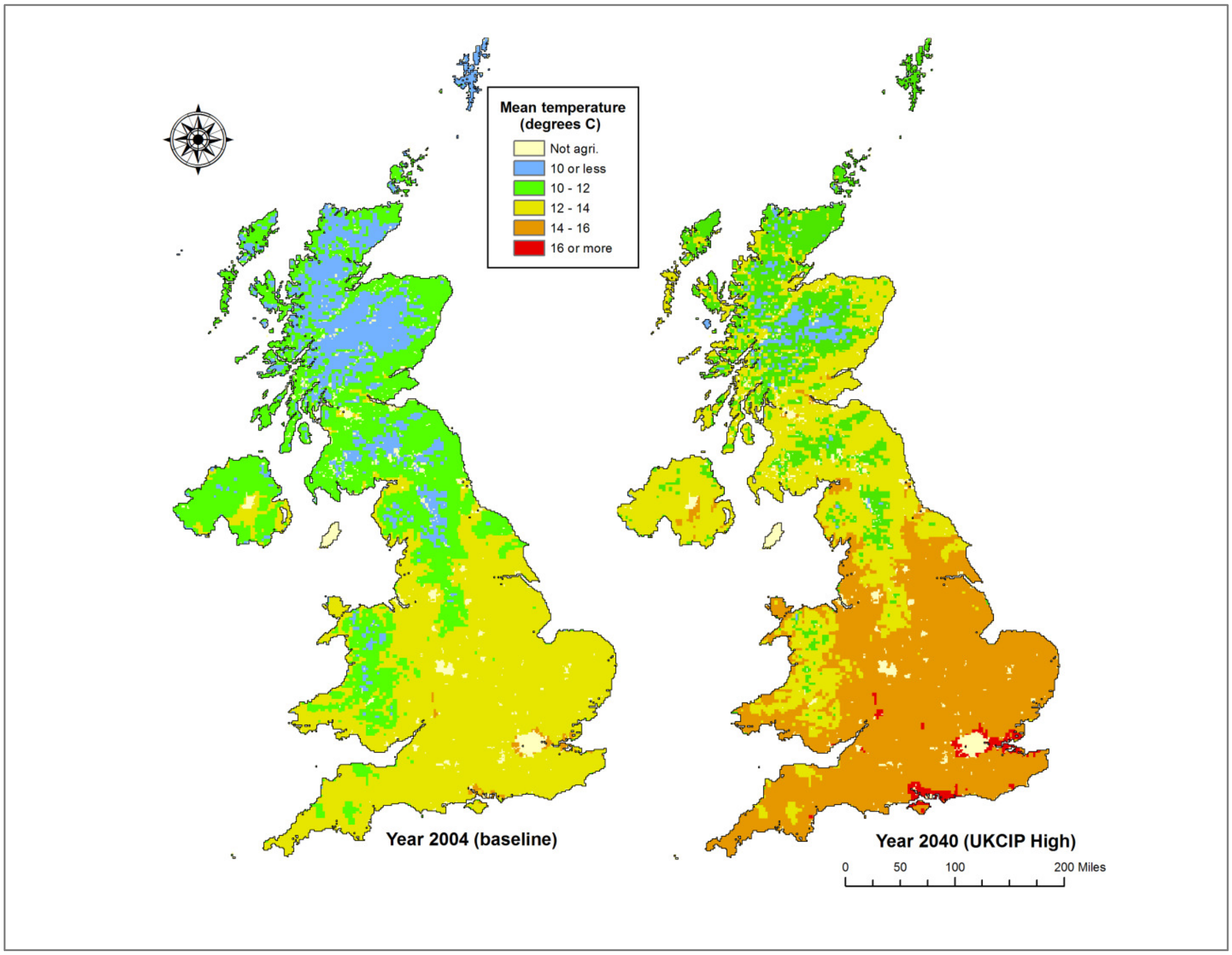


Figure 3: *Mean temperature in the growing season (April - September), year 2004 and UKCIP projections for 2040 high scenario.*



Land use change predictions

In this section we implement the econometric land use model illustrated in Section 2 to predict the impact of climate change on agriculture in United Kingdom using the UKCIP scenarios illustrated in the previous section. Therefore, we extend the model estimated on GB to the entire UK, i.e. including also Northern Ireland. Note that these scenarios, particularly the most distant in the future, predict temperatures which are far above those experienced in the UK in the past 50 years and, therefore, are outside the range of data used to estimate the model. For this reason, the results have to be interpreted cautiously. In particular, since the CSERGE land use model uses observed farmers' behaviour to predict the future, it cannot predict the introduction of new crop types which have not been significantly present in the UK farmland in past (e.g. tomatoes, vineyards, etc.).

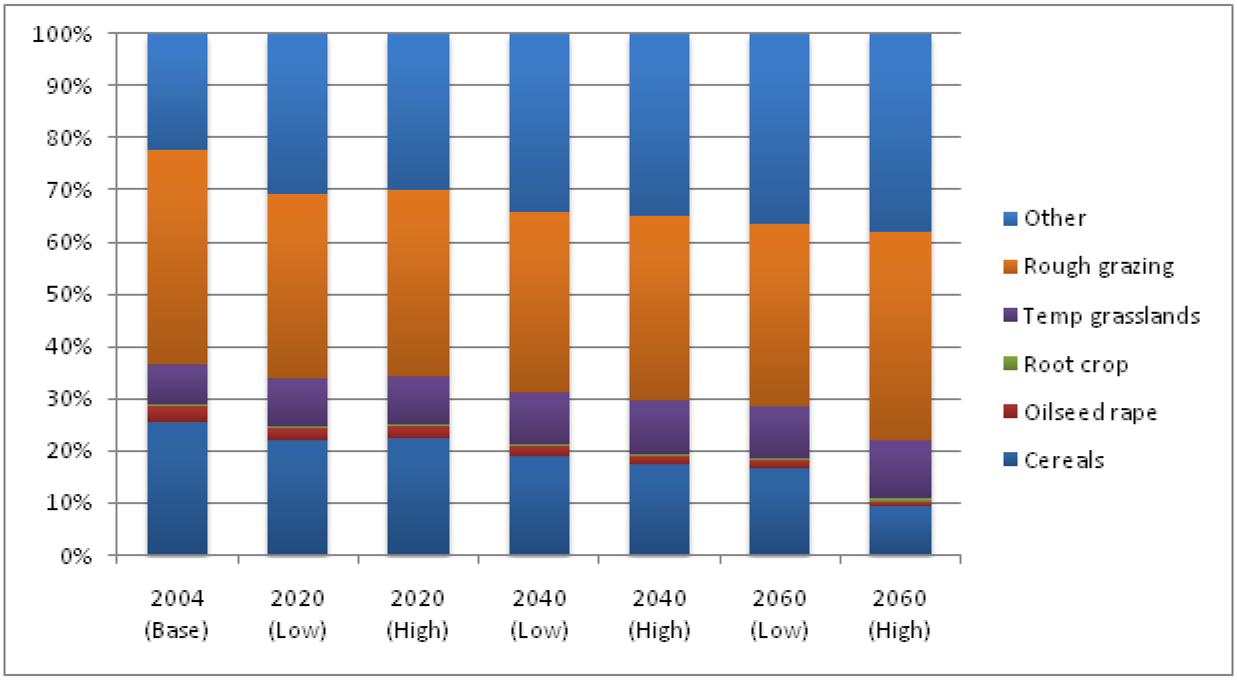
Descriptive statistics for predicted levels of the different land uses and livestock intensities are reported in Table 4. The figures for cereals and oilseed rape indicate a moderate decrease in their mean predicted levels for the period 2020-2060. The average predicted levels of temporary grasslands, permanent grasslands decline over time. Rough grazing first decreases in the North and then slightly increases in the South. The predicted patterns are somewhat similar for livestock intensities: the figures in Table 3 indicate a significant decline in the mean predicted levels for dairy, beef and sheep over time. Interestingly, the "other" category which encompasses farm woodland, vegetables and other arable crops is foreseen to increase more or less steadily. This can reflect the creation of climatic conditions suitable for the cultivation of new or marginal crops.

Table 4: *Average predicted land uses and livestock intensities*

Year	Cereals	Oilseed rape	Root crop	Temp grasslands	Perm grasslands	Rough grazing	Dairy	Beef	Sheep	Other
2004 (Base)	61.050	7.410	0.668	19.441	85.141	98.217	28.699	90.783	535.807	53.472
2020 (Low)	47.873	4.437	0.987	21.015	110.633	74.274	49.357	84.254	524.480	65.277
2020 (High)	48.453	4.530	0.959	20.992	110.770	74.929	48.829	86.117	530.044	63.888
2040 (Low)	41.168	3.377	1.124	22.262	113.513	71.001	55.208	75.607	498.387	71.948
2040 (High)	37.777	2.927	1.168	22.816	113.613	72.364	57.277	72.380	488.457	73.730
2060 (Low)	36.762	2.837	1.250	22.757	110.373	72.699	57.242	67.274	473.826	77.701
2060 (High)	21.731	1.294	1.445	26.088	107.023	84.346	65.746	55.641	431.824	82.582

The predicted patterns in land uses described above can be summarised in the form of a bar chart given below. Figure 5 plots the percentage shares of the mean predicted levels of all the land uses for the years 2004, 2020, 2040 and 2060.

Figure 4: *Bar Chart showing the percentage shares of the mean predicted levels.*



To enhance the variation over time, we now focus on the predicted *changes* in land use and livestock numbers. Figure 5 shows the changes in the predicted levels of different land uses in UK in 2020, 2040 and 2060 compared to the base year (2004). The production of cereals is predicted to slightly decline in the South, particularly the south East and increase in the rest of the country. The production of oilseed rape is predicted to remain roughly the same in North-West England and Wales with substantial increases in the East and SW England and the East Midlands. Root crops will remain roughly the same in most parts of England and Wales. The maps indicate an increase in temporary grasslands in the West and decreases in the East. Permanent grasslands are predicted to decline in most parts of England with a small increase in the hilly areas in Scotland and in the North of England. Rough grazing is expected to be replaced by more intensive grassland types in the north of the country, thanks to the increase in temperatures, but is also expected to increase in the south. We believe this latter feature should be taken cautiously and could be well explained by the extrapolation outside the range of data used for estimation.

Figure 6 shows the changes in predicted livestock numbers in England and Wales in 2020, 2040 and 2060 compared to the base year (2004). The overall number of dairy cows is expected increase substantially, particularly in Northern Ireland, England and Wales and in the flat areas of Scotland. On the other hand, beef cows are expected to decrease. Finally, the numbers of sheep are predicted to witness a dramatic a decline in most of England and Wales but to increase in Scotland, particularly in the highlands.

Figure 5: *Predicted changes in land-use (ha per 2km grid square, high emission scenarios) compared to the base year 2004*

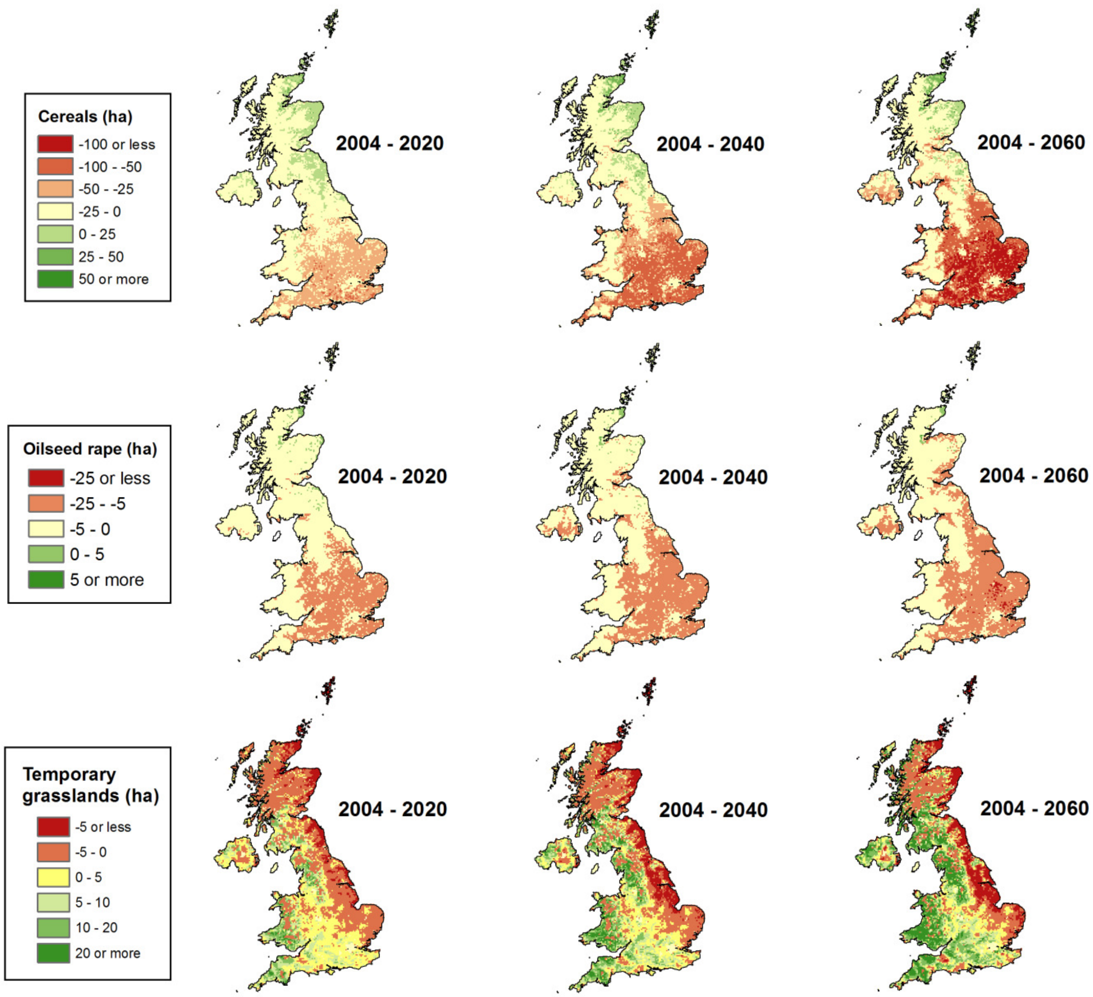


Figure 5 (cont.): *Predicted changes in land-use (ha per 2km grid square) compared to the base year 2004 (continued)*

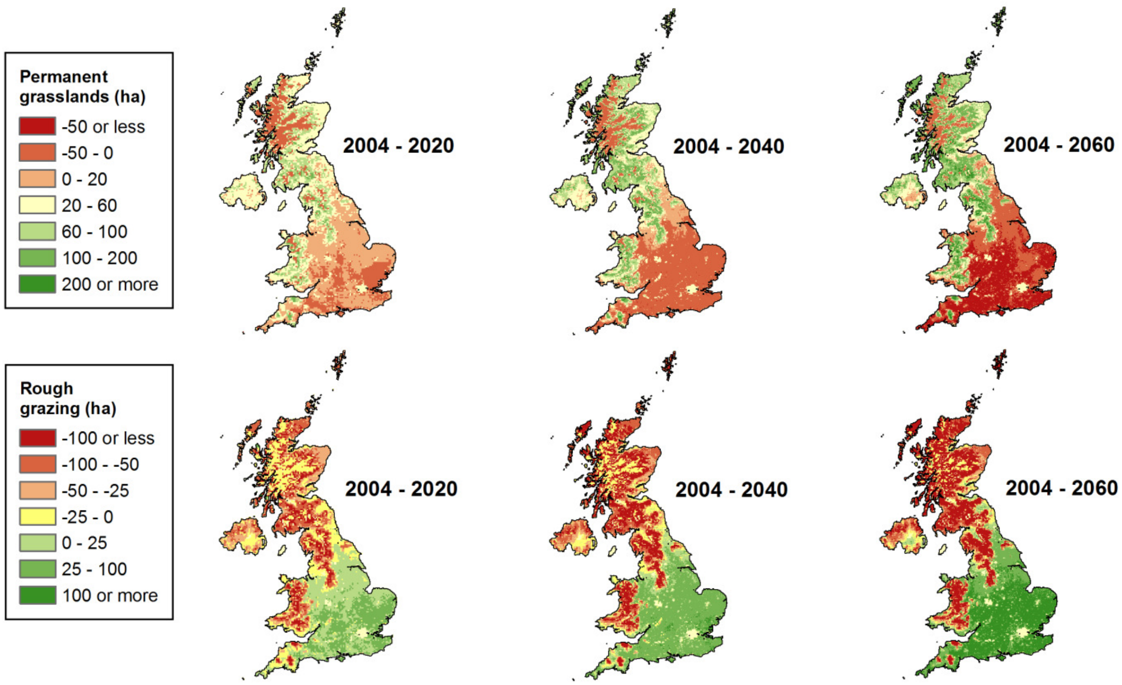
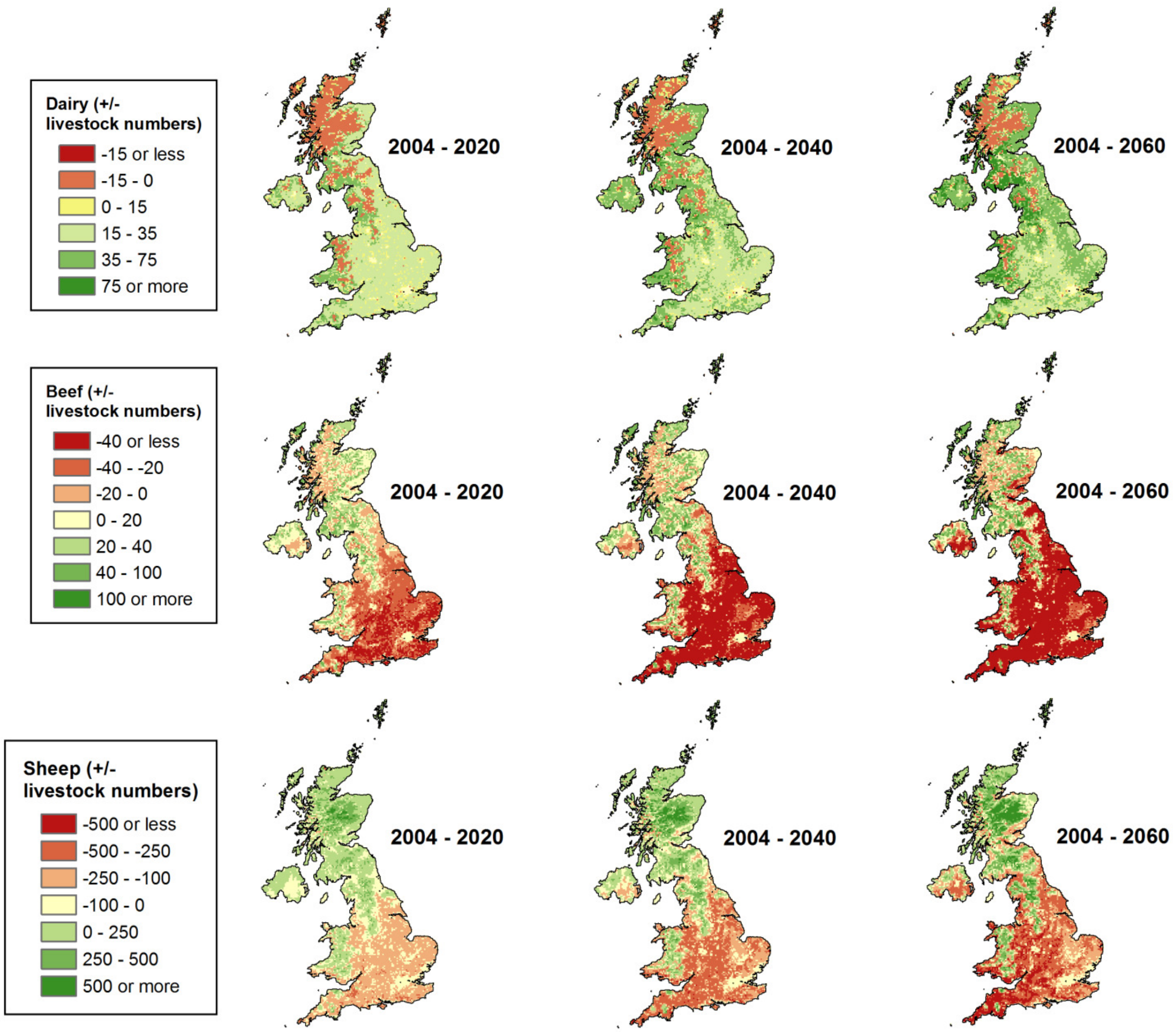
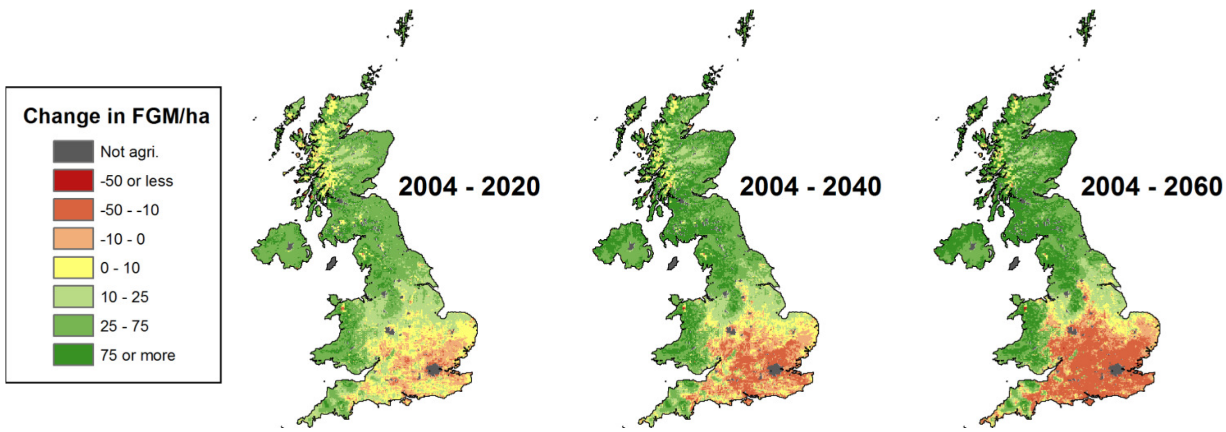


Figure 6: *Predicted changes in livestock numbers (per 2km grid square) compared to the base year 2004*



When combined, the land use and livestock intensity results mapped in Figures 5 and 6 predict the profile of farm activities across the period to 2060. This in turn allows us to calculate the implied farm gross margin at different points during that period. Figure 7 illustrates changes in FGM across this area as evaluated using the prices in year 2004, the baseline[2] (Appendix 1 provides an analysis of the variation in these estimates induced by changes in agricultural prices for different outputs; illustrating that such variation can alter absolute FGM values considerably although the overall spatial pattern in changes remains similar to that illustrated in Figure 7).

Figure 7: *Impact of climate change (UKCIP low emission scenario, 2020, 2040, 2060) upon farming in England & Wales calculated as the induced change in annual farm gross margin (£/ha) in 2020 compared to its level in 2004.*



Maps, such as that illustrated in Figure 7, have to be interpreted with caution. It should be remembered that the main objective of this particular modelling exercise was to investigate both land use change and the role of the natural environment (and in particular climate change) in determining that change. By predicting land use change we can link our model to the variety of ecosystem services which derive from such change (e.g. changes in farm bird populations; in diffuse agricultural water pollution; in the impact of land use change on recreation; etc.). However, a downside of this choice is that we cannot directly estimate profit from land use change[3]. Instead we have to rely upon the simpler measure of FGM. As there is not a simple correlation between FGM and profit or some other economic theoretic value measure we have to be circumspect about the welfare implications of these maps.

However, accepting those caveats, the findings do indicate some interesting trends in FGM. First, looking across the three maps we can see that the same set of land uses, assessed using the gross margins arising in three different years do result in some variation in absolute FGM values. This is due

[2] FGM forecasts for 2010 taken from Fezzi et al. (2010b) as follows: cereals = £290/ha, root crops = £2425/ha, oilseed rape = £310/ha, dairy = £576/head, beef = £69/head, sheep = £9.3/head.
[3] A separate 'Ricardian' analysis of the impact of climate change upon farm profitability as reflected in land values is undertaken for the same area and reported in Fezzi et al., (2010a).

to variation in prices and costs across those years. This is a reflection of the inherently variable business of farming, where business conditions can change quite substantially over fairly short periods of time. Nevertheless, all three maps do show some similarities in terms of the relative trends they exhibit. In particular, there is a clear north-south trend with strong increases in the north and small decreases in the driest areas in the south, which progressively become more and more significant with the warming and the drop in precipitation. It should be noted however that this assumes a constant policy environment across an agricultural sector which has been the subject of repeated changes in its institutional structure. Therefore such forecasts have to be treated with caution.

4. Caveats

Several caveats need to be taken into account when considering the results produced by this analysis. Firstly, the model scenarios are not predictions of the future, but rather represent the impact of climate change *ceteris paribus*, i.e. keeping all other drivers of land use and agricultural production fixed to their baseline levels (year 2004). Therefore, for example, market prices and government involvement (subsidies, levies, milk quota, etc.) are assumed to stay constant. However, changes in both prices and agricultural policies can be expected to take place in the future. For example, global warming could cause major shifts in the supply of all the main agricultural products, while the development of the Chinese and Indian economies could have significant implications for the demand. Also the UK policy is likely to change, in accordance with the various reforms of the Common Agricultural Policy (CAP).

Another important driver of change is technological innovation. In our analysis, however, technology is also assumed to stay constant at the 2004 levels. Therefore, also yields and husbandry practices are assumed to not vary. Related to this, the introduction of new crop types (e.g. vineyards) is not contemplated by the model. For this reason the predictions in the warmest areas (e.g. Cornwall, South East of England) are subject to the highest degree of uncertainty, being outside the range of data used to estimate the model. In particular, the results for the most extreme scenarios (e.g. 2060 high emissions) for these areas should be interpreted cautiously. The results for the North of England, Wales, Scotland and Northern Ireland, on the other hand, should be more robust.

Considering our measure of financial impacts, FGM, two important limitations need to be acknowledged. Firstly, since FGM is defined as the difference between revenues and variable costs, all farm fixed costs (e.g. machineries, buildings, rent, etc.) are not included in the analysis. Secondly, conversion costs are also not included. In other words, all changes in land use and FGM refer to equilibrium conditions, but do not take into account possible costs encountered in order to reach these new equilibriums.

Finally, our analysis focuses on the impact of changes in temperature and precipitation, and not other things that might be affected by climate change. For example, Mendelsohn and Dinar (2009) and others suggest that increased CO_2 fertilization increase crop yields. However, there may be a tradeoff between quantity and quality, as the projected increase in crop growth is offset by a decline in nutritional value (Jablonski, Wang, and Curtis, 2002). Another factor which is likely to change in the future is pollination. Current research (e.g. Potts et al., 2010) is evidencing a significant decrease in recent years. Among the most important drivers are land-use change with the consequent loss and fragmentation of habitats increasing, pesticide application and environmental pollution and climate change. This could have a significant impact on yields.

5. Conclusions

The analysis develops a novel, spatially explicit model for estimating changes in agricultural land use as a result of changes in any combination of policy, price or environmental drivers. A detailed spatially and temporally variable dataset is compiled and applied to this model to yield estimates of farm land use under analyst controlled scenarios. UKCIP climate change predictions are applied to this model and land use change impacts are estimated. These are in turn employed to calculate farm gross margin estimates of the value of changes in provisioning ecosystem services.

Our analysis remains incomplete. Yet findings to date suggest that changes in ecosystem inputs induced by climate change will have a substantial influence upon the gross margins generated by farm food production. Interestingly climate change seems likely to generate both positive and negative impacts across different part of the UK. These patterns include a new north-south divide, reversing the characteristic direction of that inequality with the winners in this case being in northern areas and losers being in areas of the south of England.

SECTION 2

- Provisioning services: the NEA scenarios -

1. Introduction

The purpose of economic analysis is to aid decision making. As discussed in the Economic Analysis chapter, decision making seeks to examine the trade-offs implied by each of a set of feasible options, so identifying that option which offers the best net benefits for society. For this reason, economic analysis is less interested in the total value of ecosystem services (not least because, for essential services total values may be infinite) than in the change in value generated under one state as opposed to another. A key measure then will be the change in value arising from a move from some baseline to an alternative state. The present chapter assesses a number of such moves, considering shifts to a number of the states described in the NEA Scenarios chapter. In essence therefore, this chapter values those scenarios in terms of the changes relative to a baseline which they imply for certain selected ecosystem services.

This chapter does not pretend to value the impact of future scenarios upon all ecosystem services. This is in part a reflection of the state of available data and knowledge (and as such is an indicator of the need for further research in this area). As discussed at some length in the Economic Analysis chapter and supporting documents, economic values (for any good, not just ecosystem services) are contextual. By this we mean that marginal values (the value of a single unit change in a good) vary across space and time. So the value of a recreational visit may vary according to the location of that visit (e.g. because of the habitat type at that location). Similarly the value of sequestering a tonne of carbon is likely to alter over time as the state of the climate alters. This information is not available for all of the ecosystem services considered in the Economic Analysis chapter. Rather we focus upon a subset of ecosystem service related goods for which we do have sufficient data to undertake defensible valuations. Obviously this subset does not represent the totality of values generated in the move from one state to another. Consequently, the valuations reported in the present chapter are necessarily partial and should not be taken as indicating the overall value of ecosystem service changes arising under each scenario.

A further caveat concerns the scenarios themselves. As discussed in the NEA Scenarios chapter, these are not the product of a modelling exercise in which trends are extrapolated and estimates of the future produced. Rather the scenarios are hypothetical future worlds drawn in major part from a process of interaction with relevant agencies. As such they represent in some considerable part aspirations and fears regarding the future, covering a wide spectrum of possible states. In particular they do not reflect the consequences of particular policy implementations, market shifts or environmental changes.

Despite these caveats, the present chapter does, we feel, amply demonstrate one very important and fundamental result; that methods now exist to unite natural sciences with economic assessments so as to estimate the value of changes arising under different states and thereby inform decision analysis. This is, arguably, the most important finding of the NEA in terms of its implications for the future in that it paves the way for a new approach to decision making in which ecosystem services can be directly incorporated into decision making. That this incorporation does not require a wholesale rejection of standard approaches to decision analysis, but rather an extension of current approaches, should significantly facilitate the acceptance and uptake of such techniques.

1.1 Valuing Scenarios of Ecosystem Service Change: Goods and Scenarios

Our demonstration of scenario valuations is executed through a series of linked case studies. These concern a set of ecosystem service goods for which we can generate spatially and temporally sensitive data for each of the states described in the NEA Scenarios chapter. This work is conducted for the NEA by the SEER project[4] at the University of East Anglia in collaboration with colleagues at the British Trust for Ornithology and the School of Earth and Environment at the University of Leeds.

Five integrated ecosystem service goods are considered, as follows:

- Agricultural food production;
- Terrestrial carbon storage and annual GHG emissions;
- Biodiversity (assessed using birds as an indicator species);
- Open-access recreation;
- Urban greenspace amenity.

In each case changes are calculated between a baseline (discussed subsequently) and the situation envisioned for the UK in 2060 under the six states described in the previous NEA Scenarios chapter. These scenarios are described as follows:

- ***Go with the Flow (GwF)*** essentially follows today's socio-political, economic trends and results in a future Britain that is roughly based on today's ideals with some leaning towards improving the environmental and sustainability performance of the UK. Current ideas being developed in academic, government and the media about the way forward for the UK have been adopted. Environmental improvements are still important in the governments vision for a future UK, but the public are less keen on adopting many global or national environmental

[4] The *Social and Environmental Economic Research (SEER) into Multi-Objective Land Use Decision Making* project is held by the Centre for Social and Economic Research on the Global Environment (CSERGE) at the School of Environmental Sciences, University of East Anglia. SEER is funded by the Economic and Social Research Council (ESRC; Funder Ref: RES-060-25-0063).

standards (business and industry even less so). This stand-off continues to dominate and a lot of environmental progress is hindered.

- ***Green and Pleasant Land (GPL)*** is a storyline where the conservation of biodiversity and landscape are the dominant driving forces. Whilst it is recognised that biodiversity often provides essential benefits to society, its intrinsic value is accorded a pre-eminence in policy and legislation. A preservationist attitude arises because the UK can afford to look after its own backyard without diminishing standards of living. Tourism and leisure is consequently boosted by this drive and increases its share of overall UK GDP – and by the decline in popularity of many of late-20th century holiday destinations because of climate change (e.g., France, Spain and Italy). The countryside is very much a managed, cultural landscape but the focus is now on trying to maintain, protect and improve the aesthetic appeal. In general, landscape preservation often coincides with biodiversity conservation although one major source of conflict is between the importance of recognising habitat and ecosystem change and the preservation of landscapes.

- In the ***Nature@Work (NW)*** scenario the conservation of biodiversity as an end in itself is less of a priority compared to maintaining and enhancing the output of ecosystem services. Adapting to climate change is also a priority, which means that some non-native species are introduced to provide food, energy or shade. A campaign of promoting ecosystem services in multifunctional landscapes as essential to maintaining the quality of life in the UK is now embedded in all walks of society (primary schooling all the way to large industry). Society accepts that some trade-offs have to be made and as a result becomes more environmentally aware. Habitat restoration and creation is seen as an important component of this campaign but the explicit conservation of species is sometimes overruled by a 'greater' ecosystem service benefit; this sometimes results in habitat conversion (e.g., semi-natural grassland to woodland). As well as carbon mitigation, an important focus is the enhancement of societies' resilience to climate change through 'ecosystem-based adaptation'. Modern technology is used were appropriate though and even GM biotechnology is adopted if it can be shown to enhance ecosystem service provision. This includes the use of drought-tolerant crops to maintain production and reduce soil erosion. 'Optimal Service Provision' is key, and many ecosystem services in the landscape are a result of careful examination of the trade-offs through scientific and community review.

- In the ***World Markets (WM)*** storyline unfettered economic growth through the complete liberalisation of trade is the main goal. International trade barriers dissolve, agriculture subsidies disappear and farming, for example, is now industrial and large-scale. Consumption in society is high which results in greater resource use and imports. There is competition for land and this coupled with reduced rural and urban planning regulations on housing, agriculture and industry mean that biodiversity is often the loser. Technological development in all industries is mainly privately funded but nevertheless is burgeoning. Food is cheap and plentiful but of low quality. As in land-based food production, food supplies from the seas are equally seen as source for exploitation without recourse to any sustainable management. Fish stocks plummet and a few species have been wiped out. Most fish is imported from Asia now. Desalination plants are built in areas on the east coast to meet water demand for the south and eastern counties. 'Home-grown' fossil fuel energy production is declining and has been overtaken by imports of gas from abroad and privately funded nuclear industry in the UK.

Consequently, coastal areas are built upon to accommodate power plants and gas pipeline stations. Supplies of other ecosystem services increasingly become privatised.

- In ***National Security (NS)*** UK industry is protected from foreign investors and imports. Trade barriers and tariffs are increased to protect jobs and livelihoods in the UK; immigration is also very tightly controlled. Technological development is state funded and many industries are subsidised by the state (including agriculture). Food, fuel, timber and mineral resources are prioritised over biodiversity conservation. Climate change results in increases in global energy prices forcing many countries to attempt greater self-sufficiency (and efficiency) in many of their core industries. Britain is no exception and agricultural and other primary industries 'optimise' (rather than intensify) accordingly.

- ***Local Stewardship (LS)*** has elements of *National Security* but is more environmentally benign and although localism is a dominant paradigm, society is less nationalistic. Political power has been devolved and many major issues are decided at a regional or local level (except crucial national aspects like defence); local timber and energy production is encouraged and there is great pride the numerous local food products. This scenario focuses on optimising resources and consumption is reduced to more sustainable (and healthy) levels - GDP is low but sustainable. The 'Tragedy of the Commons' would not be recognised in the UK; societal equity fits alongside environmental equity. People travel less and depend more on local resources; more of our food and leisure activities take place in the immediate locale. Technological development occurs in localised areas due to private innovation and a government initiative for developing sustainable technology. The implementation of the sustainable management of resources is a priority and society relies less on technological innovation. Low carbon economies spring up and there is greater use of alternative economies such as LETS (Local Exchange Trading Systems) schemes. Through local specialisation the UK becomes less homogenised - landscape become more distinct and even local economies vary considerably. Social and environmental regulation has advanced though, particularly in workers welfare and rights and in environmental protection. Although economic growth is slower compared to other storylines, the economy is more stable.

All of these scenarios were further modified according to two different responses to climate change as taken from the simplified UKCIP-09 Low and High Emissions Scenarios for 2050-2079, discussed in the NEA Scenarios chapter. In sum then we assess changes to all five of our goods under twelve scenarios.

Note that the GWF scenario is not a conventional economic 'business as usual' baseline in that it does not attempt to model future trends based upon best available data (on policy and market trends and environmental change forecasts) but is rather a product of the ideologies summarised in the discussion given above. As such is does not constitute an acceptable baseline for comparison with other scenarios. Consequently all economic analyses in this chapter compare the situation envisioned in 2060 under each of the above scenarios with a consistent baseline for the year 2000[5].

[5] Land use under the baseline is taken from the CEH Land Cover map 2000 while population data is taken from the UK Census 2001 (on the assumption that any error this slight discrepancy causes will be insignificant).

The valuation of changes under each scenario informs decision analysts regarding the trade-offs across the set of goods under consideration. Such information is clearly an important input to decision making. However, alongside caveats regarding the incomplete set of goods being considered, we also emphasise the point raised in the Economic Analysis chapter that, while the valuation of ecosystem service flows is a very important improvement over sole reliance upon market prices, sustainability requires that we also consider the impacts of flow changes upon the levels of stocks of relevant ecosystem services. This is again highlighted as an important area for future research.

2. Valuing scenarios for agricultural food production

2.1 Introduction and methodology

Estimating the changes in agriculture related provisioning services in the different scenarios is the focus of this chapter. For the Baseline and each scenario we analyze the variation in agricultural land types and livestock numbers. We then derive the economic impact on farmers in terms of Farm Gross Margin (FGM), defined as the difference between revenues from agricultural activities and associated variable costs. As stressed in the NEA Economics chapter, while this is a commonly applied approach, it is not a theoretically ideal measure, being only a fair approximation of the net economic value. That said, the trends in relative values provide some useful information regarding the likely changes in agricultural productivity of the in the four scenarios.

The agricultural land and livestock scenarios are derived by using the CSERGE econometric agricultural land use model (Fezzi and Bateman, 2010) illustrated in the previous section, to split the agricultural land uses predicted in each of the NEA scenarios and then calculate the corresponding livestock numbers. As discussed in the NEA Scenarios chapter, each scenario is used to generate maps describing the corresponding land use for all of the UK. Following some harmonisation of scales[6] and categorisations[7] the CSERGE land use model was applied to the area of each 2km grid square across Great Britain predicted to be farmland under each scenario. Within each of these grid squares the CSERGE model predicts the share of farmland under each agricultural land use and predicts the predict livestock numbers (dairy cows, beef cows and sheep) where appropriate. As discussed in the NEA Economics chapter, these shares are predicted from the estimated effect that policy, prices and the natural environment have upon farm land use and, therefore, differ between the low and high emission scenarios because of the varied impact of climate change. Note however that we do not allow

[6] The NEA Scenario maps are generated at a 1km grid square scale. These are rescaled to the 2km grid square basis used in the CSERGE agricultural land use model.

[7] The NEA Scenarios team used a somewhat different categorisation of land to the CSERGE model. First the NEA Scenarios categories 'upland', 'improved grassland' and 'arable' were classified as 'agricultural' land with the 'upland' category taken as our 'rough-grazing' land use. The NEA Scenarios category 'improved grassland' was split into permanent or temporary grassland according to the shares predicted by the CSERGE model. A similar approach was taken to reallocate the broad NEA Scenarios category 'arable' into 'cereals', 'oilseed rape', 'root crops' (potatoes and sugar beet) and 'other arable'.

for the effect of new technologies such as the possible introduction of new crop varieties or husbandry practices.

2.2 Agricultural land use scenarios

2.2.1 Baseline

The baseline scenario describes agriculture in Great Britain in the year 2000. The land use hectares and livestock numbers are reported in Table 1. This shows a highly heterogeneous picture, with the flatter and warmer lowlands of south-east England dominated by arable cultivation and the hilly north-west primarily devoted to grazing systems. Wales and Scotland are also characterized by the presence of a high percentage of low-quality agricultural land, which translates into the highest shares of rough-grazing of the entire Great Britain. Livestock rates are strongly related to land use with dairy stocking rates being higher in the south and west while sheep numbers are highest in northern upland areas and Scotland.

Table 1: Average land use (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the baseline scenario (2000)

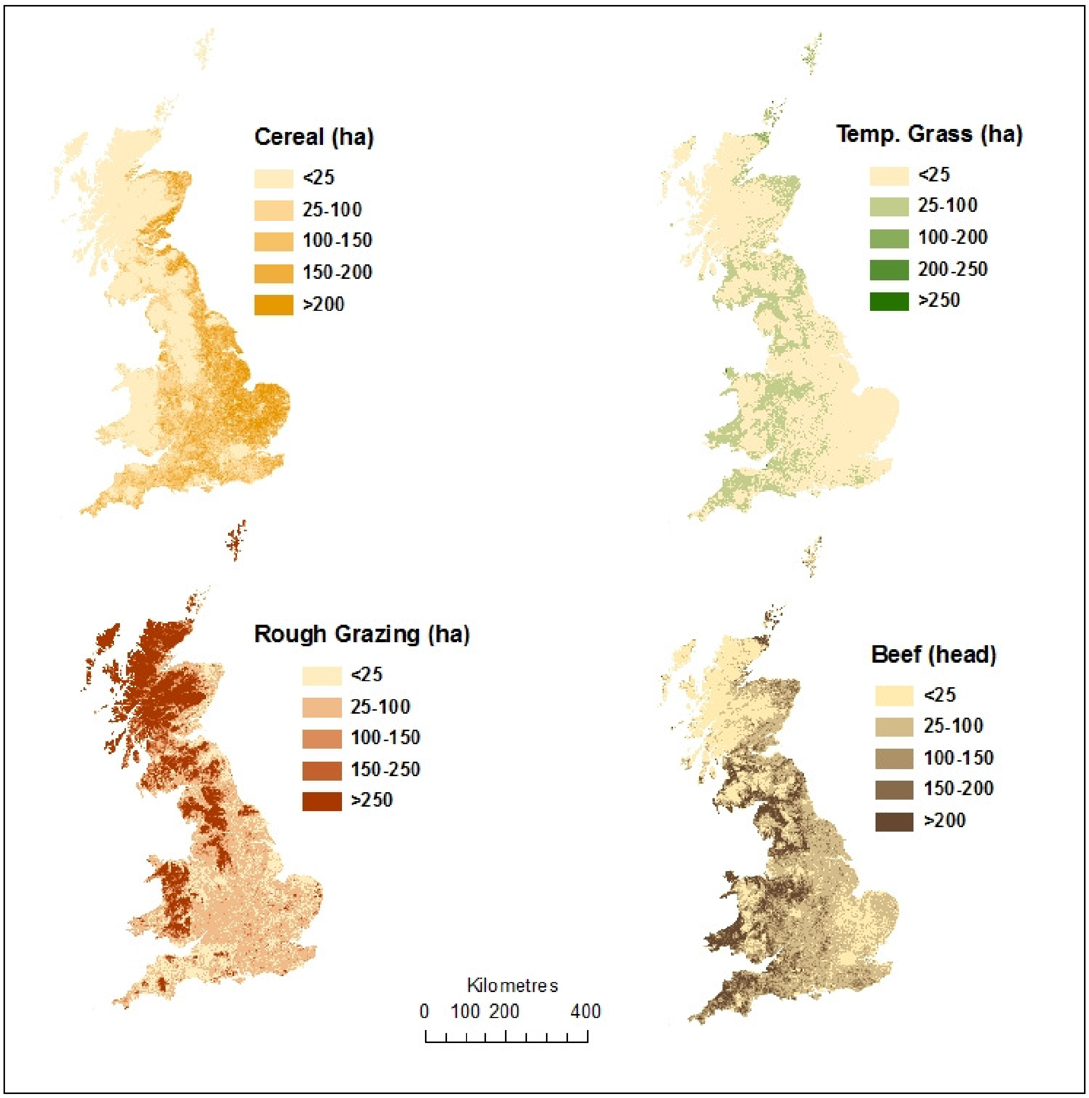
Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	19.0	132.2	1.7	59.9	11.3	53.3	52.1	15.5	69.6	336.3
East of England	21.2	158.5	2.3	73.9	3.7	19.9	46.5	4.9	29.2	124.9
London	2.8	25.5	0.5	4.9	4.0	27.9	46.4	23.3	44.0	162.8
North East	10.0	66.2	0.3	24.7	21.0	64.5	122.7	19.8	105.9	593.2
North West	2.3	34.9	0.4	10.6	21.3	112.8	130.1	49.3	129.9	761.6
South East	11.7	96.8	1.1	26.1	14.9	69.9	52.8	31.4	72.2	296.4
South West	6.4	83.2	1.3	29.5	24.5	124.8	48.1	52.9	121.4	611.9
West Midlands	10.9	85.8	1.4	28.6	23.4	100.7	58.2	45.2	117.0	533.9
Humber	12.6	96.3	1.2	40.7	12.7	56.0	101.7	14.5	80.2	523.6
Scotland	3.5	25.4	0.1	8.0	14.3	36.2	227.6	9.9	53.2	509.6
Wales	0.5	12.6	0.3	5.1	21.8	125.1	150.6	48.9	124.8	903.0
GB	**7.9**	**64.8**	**0.8**	**24.5**	**16.0**	**66.7**	**131.1**	**24.8**	**79.5**	**511.8**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 1 illustrates the Baseline distribution of selected land use types: cereals (the dominant arable crops), temporary grassland (rich grassland used mainly for dairy and beef cows) and rough-grazing.

The Distribution of beef cattle is also shown. Considering these maps we note that cereals are located in most of the lowland, flatter areas of the country, such as the south and east coast of England and eastern Scotland. Temporary grassland, on the other hand, is concentrated in the wetter south-west of England and in the lowland areas of Scotland and Wales. While rough grazing has some minor presence in all areas, it is concentrated in the uplands of northern England, Scotland and Wales, in which it is the major if not the only one agricultural land use. Beef cattle are abundant in the areas where there is either temporary or permanent grassland but become absent in the more extreme upland areas.

Figure 1: Cereals, temporary grassland, rough grazing and beef cows, baseline scenario.



In the following analyses we contrast this Baseline with the situation described in each of the scenarios.

2.2.2 Comparing the Baseline with the Go with the Flow (GwF) scenario

High emissions GwF scenario

The changes from the baseline into the high emissions *GwF* scenario are reported in Table 2. The most striking observation here is the significant decrease in arable which takes place throughout the country, most especially in the south. This loss in cereals and oilseed rape is partially balanced by an increase in root crops (particularly in the south-west of England and in the areas surrounding London) and in other arable crops. We can attribute a significant part of this change in arable land composition to the increase in temperatures and decrease in precipitation in the growing season (see discussion in Fezzi et al., 2010a). Considering grassland, while there is a noticeable increase in temporary grassland in the south and a smaller decrease in the north, there is a significant decrease in permanent grassland this being replaced by increases in the rough grazing and 'other arable' categories. Overall, the warmer temperatures and the increase of nutrient-rich pastures mean an increase in the number of dairy cows (especially in the east of England) and a general decrease in beef and sheep in most areas except Scotland where warmer climates increase sheep stocking densities in the far north.

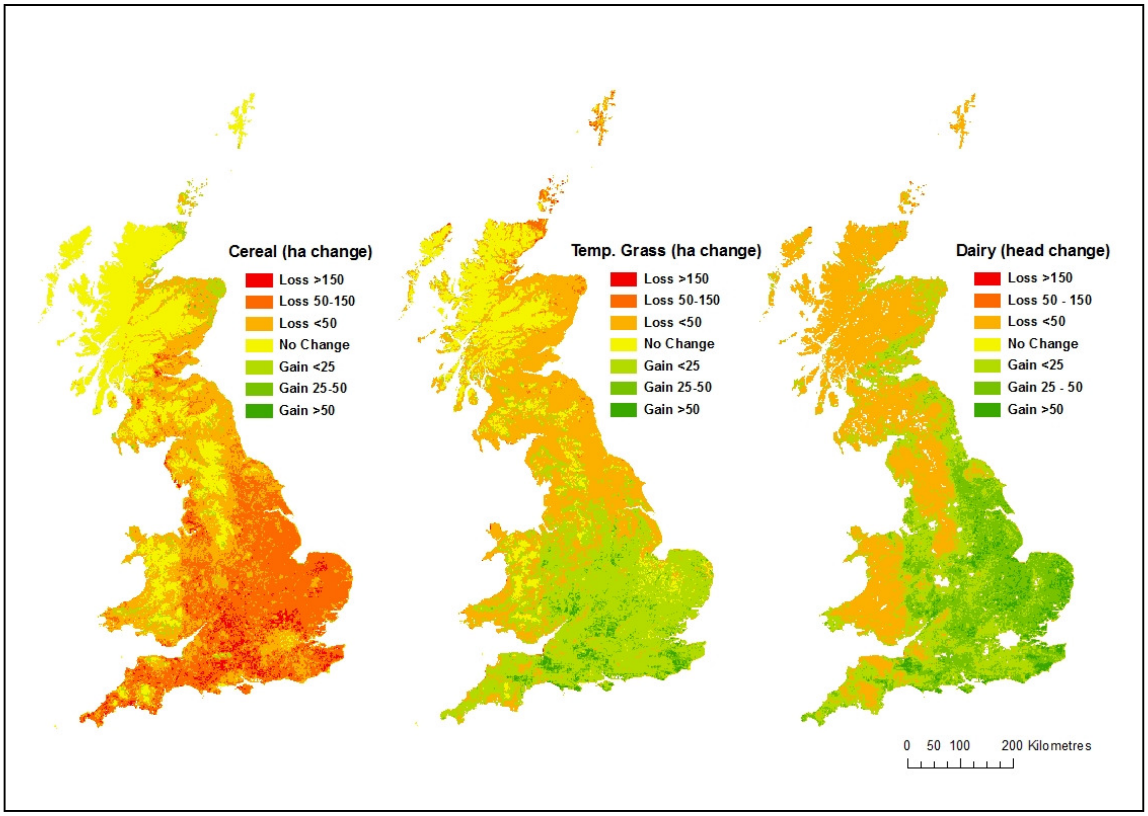
Table 2: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the *GwF* high emissions compared to the baseline

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-15.5	-73.1	1.9	69.4	5.9	-26.4	10.1	15.6	-61.8	-238.3
East of England	-19.3	-98.8	3.5	89.7	8.2	-16.3	7.3	25.4	-28.8	-121.6
London	-2.8	-25.5	13.4	14.8	9.0	-22.8	5.9	13.2	-42.9	-158.7
North East	-5.0	-16.2	1.1	9.8	-10.1	-17.2	19.0	0.2	-51.4	-77.7
North West	-2.2	-26.9	6.8	22.1	-2.9	-37.2	19.8	-4.7	-74.7	-241.6
South East	-11.5	-88.6	8.7	88.0	18.2	-52.9	14.8	16.8	-68.6	-287.2
South West	-6.4	-78.9	21.6	67.8	12.1	-67.9	20.6	4.3	-99.6	-419.9
West Midlands	-10.7	-64.9	4.0	71.4	8.0	-50.4	15.3	7.0	-89.8	-342.7
Humber	-9.2	-40.9	1.8	35.4	-2.4	-18.0	12.7	9.7	-58.5	-175.5
Scotland	-2.0	-5.8	0.8	3.9	-8.6	-8.6	13.8	-2.2	-23.4	62.4
Wales	-0.5	-10.9	7.0	7.9	-1.3	-48.9	25.8	-8.4	-78.8	-277.1
GB	**-6.6**	**-40.6**	**5.2**	**36.9**	**0.6**	**-29.1**	**15.4**	**4.4**	**-53.6**	**-147.5**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 2 presents maps of changes from the Baseline to *GwF* High scenario for selected land use types and livestock: cereals, temporary grassland and dairy cows. It is interesting to observe how cereals are replaced by temporary grassland with higher dairy stocking density throughout lowland England and Scotland.

Figure 2: Changes in cereals, temporary grassland and dairy cow numbers between the 2000 Baseline and the *GwF* High scenario.



Low emissions GWF scenario

The changes from the Baseline into the low emissions *GwF* scenario are reported in Table 3. The figures are similar to those in the high emission *GwF* scenario (Table 2), but somewhat less extreme. There is, nevertheless, a significant decrease in cereals and oilseed rape, and an increase in other arable and root crops. The pattern of grassland and livestock changes is similar to although weaker than, that observed before.

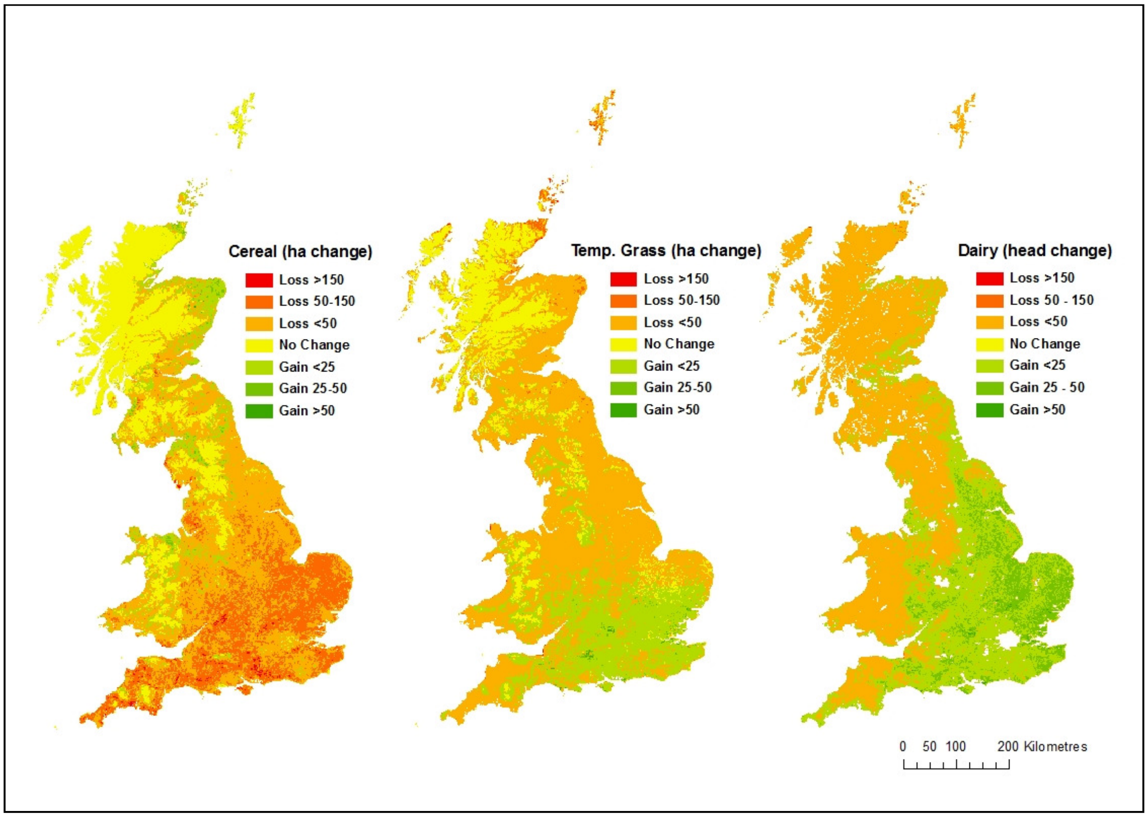
Table 3: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the *GwF* low emissions compared to the baseline

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-9.3	-38.0	1.2	41.2	-2.3	-18.3	8.4	29.1	-66.7	-263.9
East of England	-12.6	-57.0	1.8	55.9	2.6	-9.8	5.8	37.5	-29.0	-124.2
London	-2.7	-20.3	2.2	19.5	3.0	-14.0	3.7	21.4	-43.9	-162.7
North East	-2.6	-5.5	0.8	4.7	-11.1	-16.7	14.6	6.6	-67.8	-118.7
North West	-1.8	-12.7	4.4	21.0	-6.1	-37.3	15.3	3.9	-90.1	-303.0
South East	-10.1	-53.9	2.4	62.5	3.6	-30.0	10.4	28.7	-71.8	-296.1
South West	-5.7	-55.9	12.7	59.7	0.1	-47.4	14.8	14.6	-114.0	-495.8
West Midlands	-7.6	-29.7	2.0	44.5	-2.2	-36.8	11.0	18.5	-103.5	-410.1
Humber	-5.4	-19.9	1.2	21.4	-5.2	-16.3	10.3	19.1	-69.2	-212.8
Scotland	-1.2	-1.4	0.5	2.0	-8.6	-8.1	10.1	-0.1	-31.7	49.1
Wales	-0.4	-6.8	4.1	10.8	-4.4	-44.6	16.1	-2.9	-96.5	-366.6
GB	**-4.6**	**-22.9**	**2.8**	**26.1**	**-4.2**	**-22.4**	**11.2**	**11.7**	**-63.2**	**-182.3**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 3 presents maps of changes for selected land use types and livestock: cereals, temporary grassland and dairy cows. Changes are somehow more muted than under the *GwF* High emission scenario: the decrease in cereals is less strong, and there are also some clearer increases in the east of Scotland. The geographic threshold at which the switch to temporary grassland occurs is noticeably more southerly than before and this is reflected in more gentle increases in dairy cow numbers in those areas.

Figure 3: Changes in cereals, temporary grassland and dairy cow numbers between the 2000 Baseline and the GWF Low scenario.



2.2.3 Comparing the Baseline with the Green and Pleasant Land (GPL) scenario

High emissions GPL scenario

We now compare the high emissions GPL scenario with the baseline. The changes in land use and livestock numbers are reported in Table 4. In the GPL scenario a high amount of land is converted from intense land uses to more extensive ones. In particular, cereals and oilseed rape decrease significantly, substituted partly by other arable and temporary grassland. Furthermore, rough grazing increases through-out the country, replacing permanent grassland and arable land. Finally, beef and sheep numbers decrease, while dairy cows numbers grows as a result of the increase in temporary grassland.

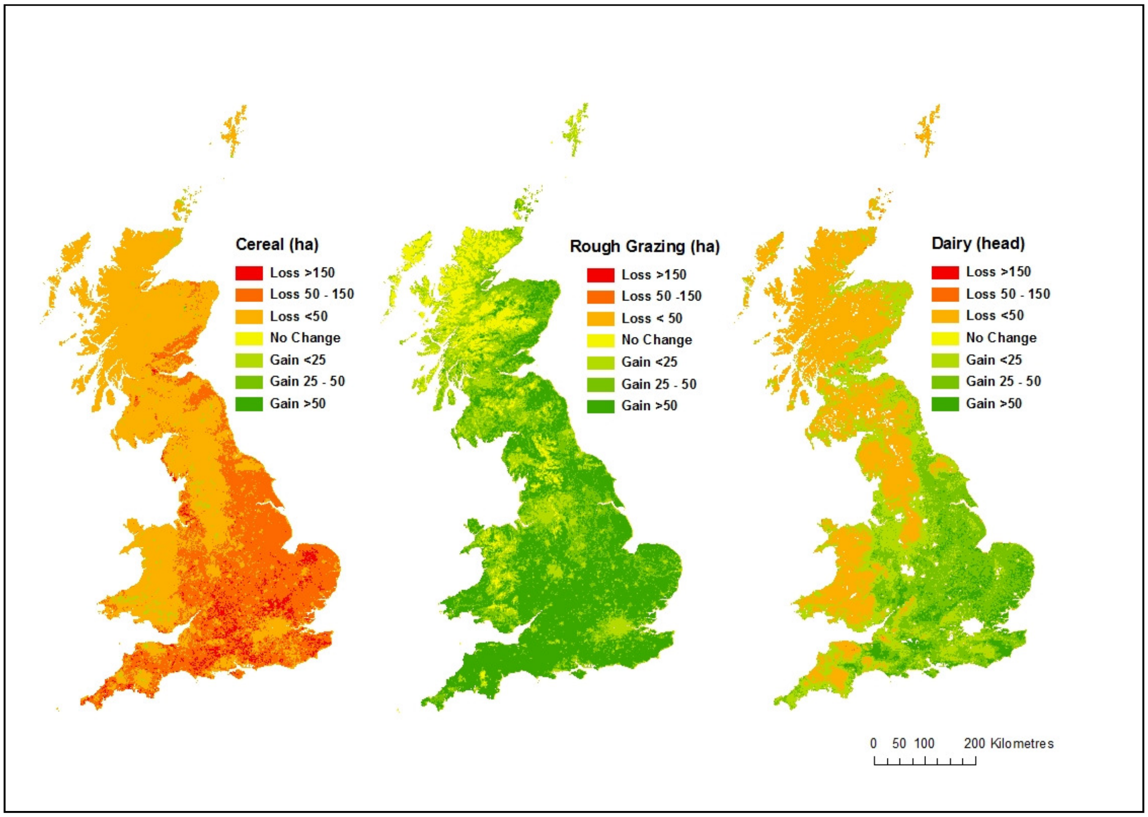
Table 4: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the GPL high emissions compared to the baseline.

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-16.4	-87.3	1.1	38.0	6.1	-26.9	53.3	32.2	-66.7	-261.8
East of England	-19.8	-113.2	2.1	49.6	8.8	-16.4	57.4	41.4	-29.0	-124.0
London	-2.8	-25.5	8.6	8.7	11.5	-21.8	19.9	28.6	-43.6	-162.3
North East	-6.1	-26.7	0.8	2.6	-10.1	-18.0	41.7	8.3	-65.9	-95.0
North West	-2.2	-29.4	4.7	12.7	-3.5	-39.8	38.3	3.8	-90.5	-294.5
South East	-11.6	-91.2	4.8	47.3	19.8	-52.4	62.3	34.9	-71.3	-295.7
South West	-6.4	-80.5	11.9	29.8	12.5	-70.2	74.5	19.0	-114.1	-486.5
West Midlands	-10.8	-71.2	2.1	39.3	9.3	-49.7	56.1	23.8	-102.1	-398.8
Humber	-10.1	-53.8	1.1	17.9	-3.0	-20.4	44.2	19.7	-69.3	-205.2
Scotland	-2.3	-10.2	0.6	1.3	-8.2	-6.5	21.4	1.3	-29.3	66.2
Wales	-0.5	-11.6	3.7	2.4	-0.5	-46.6	41.2	-0.2	-94.6	-341.5
GB	**-6.9**	**-46.7**	**3.0**	**18.9**	**1.1**	**-28.8**	**42.6**	**14.5**	**-62.2**	**-171.0**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 4 presents maps of changes for selected land use types and livestock: cereals, rough grazing and dairy cows. We observed a significant decrease in cereals in the entire country, a widespread increase in rough grazing and small, positive changes in dairy cows stocking rates in the lowland, particularly in the South and East of England.

Figure 4: Cereals, rough grazing and dairy cows, changes from the baseline to GPL, high emissions scenario.



Low emissions GPL scenario

We now compare the low emissions GPL scenario with the baseline. The changes in land use and livestock numbers are reported in Table 5. The scenarios is similar to the GPL high emissions, but with lower losses in cereals. Because of the global warming being less significant, also the increase in other arable is lower than the one in the high emissions scenario. Overall the trends are the same as those in the high emissions world, but somehow more muted.

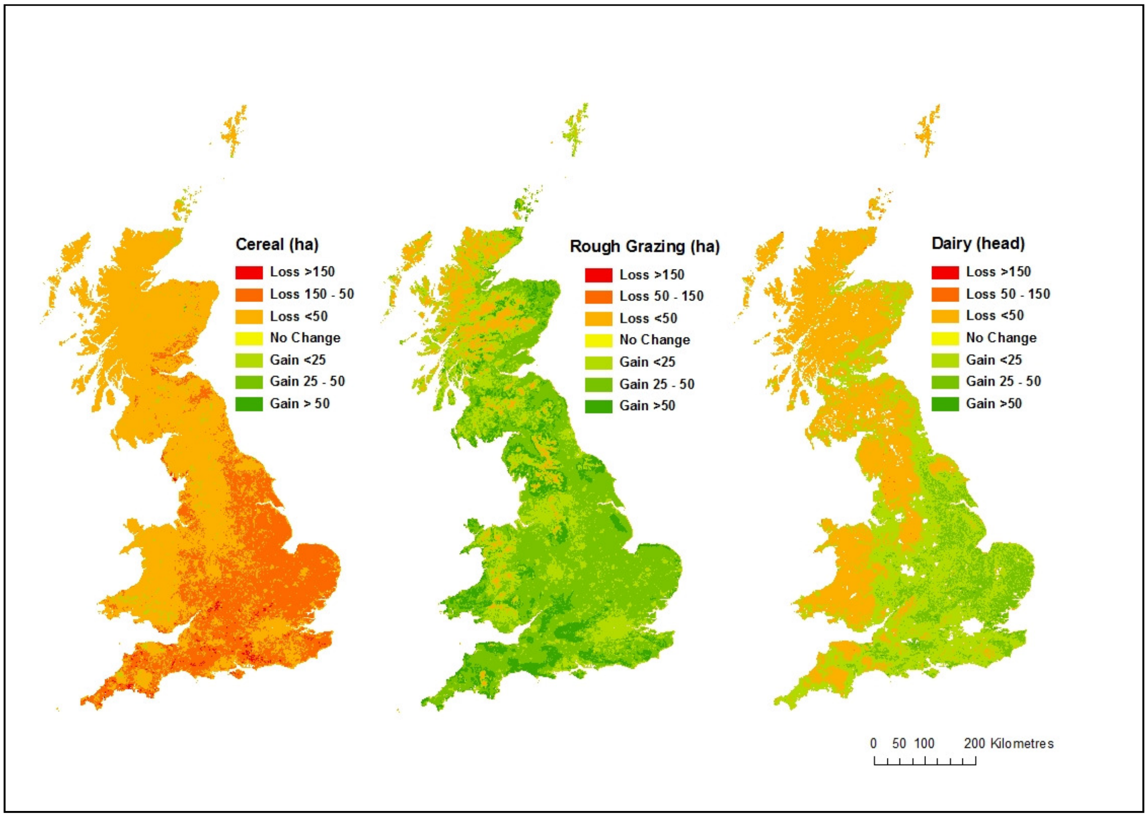
Table 5: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the GPL low emissions compared to the baseline.

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-11.6	-60.3	0.5	16.9	-1.5	-16.2	37.2	18.2	-58.9	-225.6
East of England	-14.6	-79.1	0.9	27.1	3.0	-9.1	35.8	25.8	-28.6	-121.0
London	-2.7	-21.4	1.6	14.1	4.0	-11.9	10.5	16.7	-41.9	-157.3
North East	-4.4	-19.9	0.5	-2.2	-10.4	-15.2	35.2	3.3	-46.9	-43.4
North West	-2.0	-21.7	2.5	8.8	-5.3	-34.5	33.2	-1.1	-69.0	-211.2
South East	-10.5	-66.6	1.3	35.2	3.6	-29.8	35.5	17.8	-66.8	-282.1
South West	-5.9	-65.1	7.3	28.3	0.7	-46.2	45.0	7.5	-93.6	-395.7
West Midlands	-8.6	-46.8	0.9	22.0	-0.8	-32.6	35.2	11.5	-82.4	-313.6
Humber	-7.2	-38.8	0.6	6.3	-5.0	-16.6	35.6	11.0	-56.6	-161.6
Scotland	-1.8	-7.4	0.3	-0.4	-8.0	-5.1	19.0	-0.2	-19.9	85.1
Wales	-0.4	-9.9	2.2	3.3	-2.7	-37.4	29.5	-3.2	-71.7	-232.9
GB	**-5.4**	**-34.0**	**1.5**	**11.8**	**-3.5**	**-20.0**	**30.2**	**6.9**	**-49.8**	**-126.8**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 5 presents maps of changes for selected land use types and livestock: cereals, rough grazing and dairy cows. The maps are similar to those in Figure 4 but highlight smaller changes.

Figure 5: Cereals, rough grazing and dairy cows, changes from the baseline to GPL, low emissions scenario.



2.2.3 National Security (NS) scenarios

High emissions NS scenario

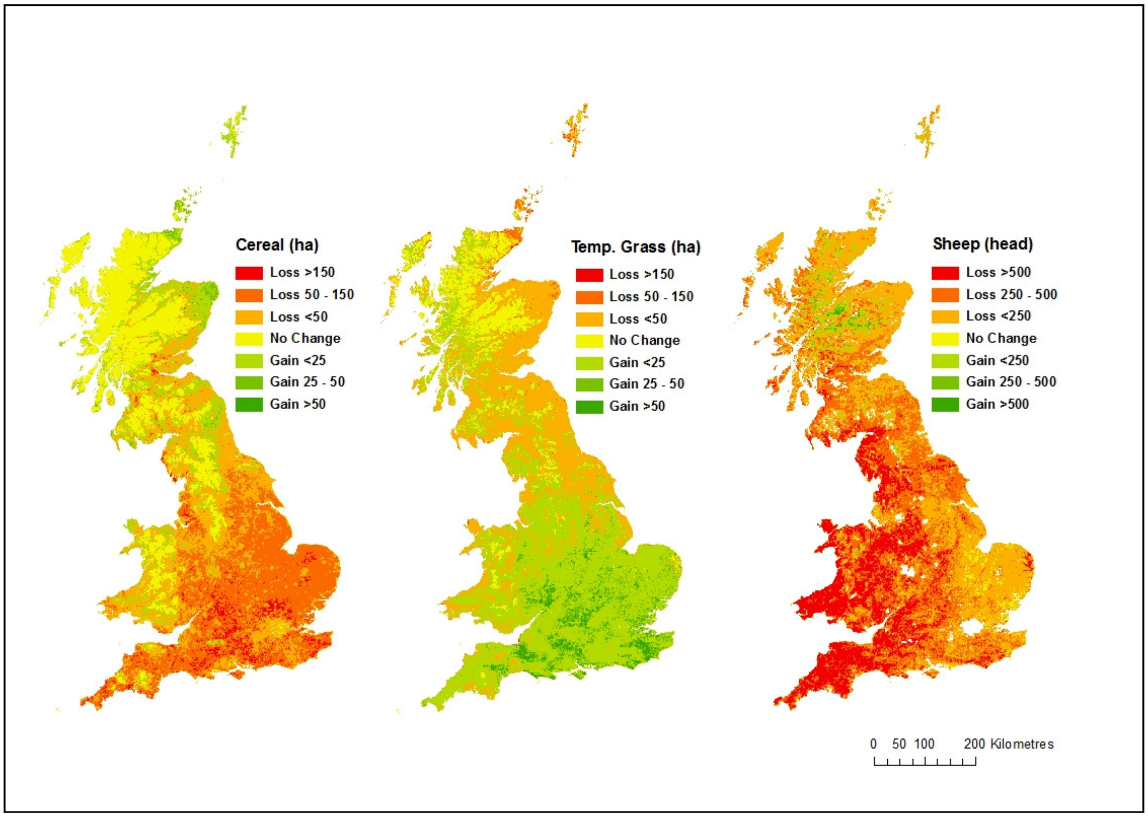
We now compare the high emissions NS scenario with the baseline. The changes in land use and livestock numbers are reported in Table 6. This scenario presents an overall increase in arable land (but a decrease in cereals due to climate change) and temporary grassland. This appears to happen via conversion of rough grazing and permanent grassland, which decreases through-out the country. This strongly decreases sheep numbers and beef, but does not seem to have any significant effect on dairy numbers which actually increase. Maps of selected land uses (cereals, temporary grassland) and sheep numbers are presented in Figure 6.

Table 6: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the NS high emissions compared to the baseline.

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-15.0	-65.6	2.5	87.3	9.7	-21.1	-24.3	33.5	-66.1	-282.8
East of England	-19.1	-93.2	4.2	105.4	15.5	-14.4	-21.1	43.6	-29.0	-124.3
London	-2.8	-25.5	18.5	20.0	15.0	-20.8	-19.3	28.3	-43.9	-162.6
North East	-3.9	-4.2	1.4	19.7	-8.4	-8.1	-56.3	9.0	-65.8	-254.5
North West	-2.2	-23.3	12.5	38.1	-0.7	-25.8	-59.2	7.0	-86.5	-429.9
South East	-11.5	-87.6	10.2	102.4	24.9	-49.9	-20.6	32.5	-71.3	-296.1
South West	-6.4	-78.3	27.1	81.9	15.6	-62.9	-17.8	16.9	-113.3	-518.1
West Midlands	-10.7	-61.4	5.3	88.7	12.2	-44.4	-23.7	22.5	-103.0	-436.0
Humber	-8.8	-32.5	2.7	49.7	-0.6	-10.2	-47.3	21.5	-67.1	-308.9
Scotland	-1.7	-1.1	1.5	9.1	-7.4	-2.1	-103.0	1.4	-30.5	-168.4
Wales	-0.5	-9.2	14.2	20.7	0.2	-41.4	-60.7	-2.4	-94.4	-514.5
GB	**-6.4**	**-36.5**	**7.4**	**48.5**	**3.6**	**-23.1**	**-58.0**	**14.4**	**-62.1**	**-294.7**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 6: Cereals, temporary grassland and sheep changes from the baseline to NS, high emissions scenario.



Low emissions NS scenario

We now compare the low emissions NS scenario with the baseline. The changes in land use and livestock numbers are reported in Table 7. The results are similar to those in the high emissions scenario, but somehow more muted.

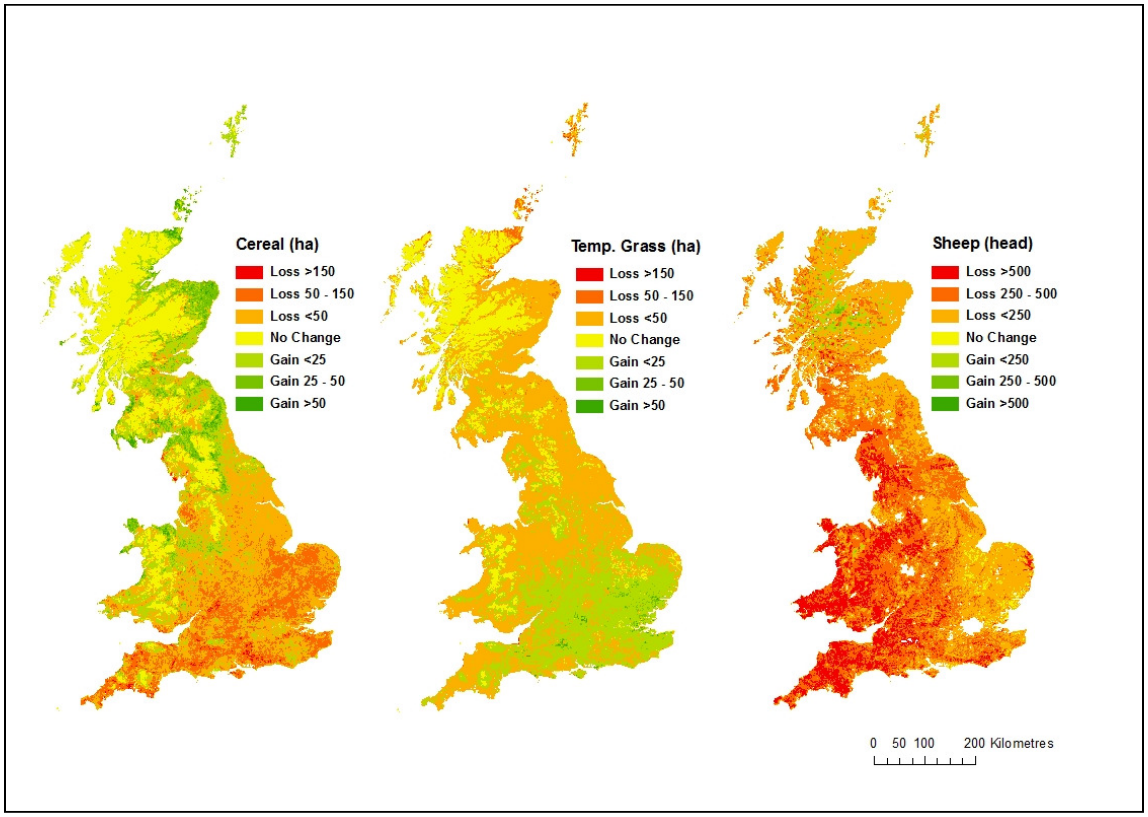
Table 7: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the NS low emissions compared to the baseline.

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-8.2	-27.2	1.6	54.1	-1.3	-14.2	-26.2	16.3	-62.2	-266.0
East of England	-12.0	-48.8	2.2	66.4	5.3	-6.2	-24.4	26.7	-28.8	-122.5
London	-2.7	-19.1	3.1	26.1	3.2	-14.5	-22.6	10.6	-42.9	-159.9
North East	-0.9	9.7	1.0	14.2	-10.4	-13.7	-56.2	-0.2	-56.0	-226.4
North West	-1.6	-4.8	8.2	38.5	-5.3	-33.4	-60.0	-4.9	-76.6	-390.8
South East	-9.8	-47.1	2.9	76.2	4.2	-29.0	-25.5	14.1	-68.9	-290.8
South West	-5.6	-50.8	17.5	79.5	0.1	-47.2	-22.8	1.8	-102.3	-459.0
West Midlands	-7.1	-19.4	2.7	60.4	-1.4	-34.5	-28.4	6.3	-91.4	-384.6
Humber	-4.7	-9.6	1.7	33.2	-4.6	-12.9	-47.5	9.4	-60.3	-286.6
Scotland	-0.7	5.8	0.9	8.4	-8.2	-6.3	-102.2	-2.3	-27.0	-161.9
Wales	-0.3	-1.4	9.9	29.2	-5.3	-49.2	-62.3	-12.6	-84.8	-465.4
GB	**-4.1**	**-15.2**	**4.4**	**38.2**	**-3.6**	**-20.9**	**-59.6**	**3.6**	**-56.3**	**-272.3**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 7 presents maps of changes for selected land use types and livestock: cereals, temporary grassland and sheep. The main different with the high emissions scenario is the increase in cereals in the lowland and upland fringe in Scotland, Wales and North of England, which is certainly more evident.

Figure 7: Cereals, temporary grassland and sheep changes from the baseline to NS, low emissions scenario.



2.2.4 Nature at Work (NW) scenarios

High emissions NW scenario

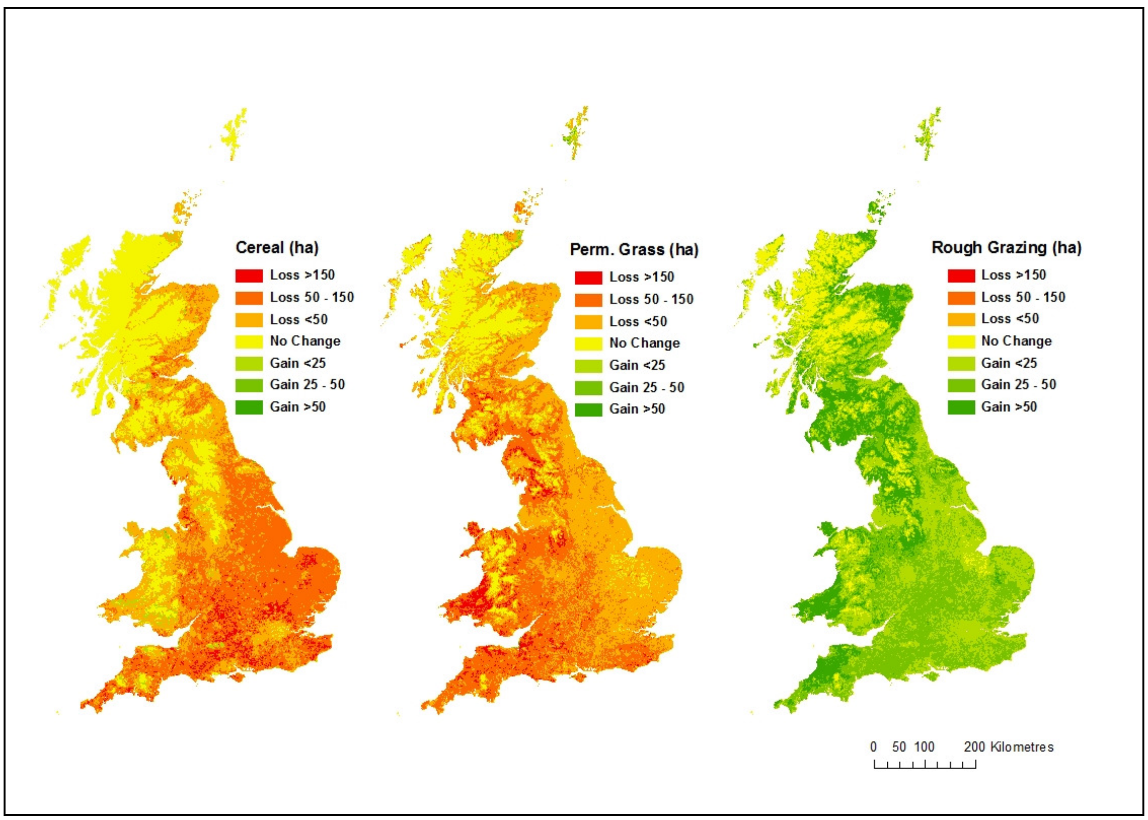
We compare the high emissions NW scenario with the baseline. The changes in land use and livestock numbers are reported in Table 8. Arable decreases slightly, with the great losses in cereals and oilseed rape almost offset by the increase in other arable and root crops. On the other hand, temporary and permanent grassland are substituted by rough grazing, leading to a less intense use of the land. This is reflected in the stocking rates numbers, beef and sheep decrease and dairy present a geographically heterogeneous pattern, with increases in the South and drops in the North and Scotland. Figure 8 presents maps of changes for selected land use types and livestock: cereals, permanent grassland and rough grazing. The first two land uses decrease, particularly in the areas in which they are more present, and the latter increases even through-out the country.

Table 8: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the NW high emissions compared to the baseline.

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-15.8	-78.7	1.5	57.2	-0.4	-36.6	25.5	18.1	-68.9	-272.0
East of England	-19.5	-105.7	2.8	71.8	3.5	-17.7	24.7	31.8	-29.1	-124.4
London	-2.8	-25.5	11.6	12.6	4.4	-24.5	10.4	13.8	-44.0	-162.8
North East	-5.8	-23.6	0.9	4.5	-14.2	-35.7	36.3	-4.0	-81.7	-163.5
North West	-2.2	-27.6	5.4	18.9	-10.2	-67.3	39.1	-15.3	-110.4	-361.2
South East	-11.5	-89.6	7.2	74.2	5.5	-59.5	26.5	12.0	-72.2	-296.2
South West	-6.4	-79.3	18.8	57.7	-1.5	-89.5	36.1	-8.1	-119.6	-520.9
West Midlands	-10.8	-66.7	3.5	63.0	-3.9	-69.4	32.2	-1.8	-112.2	-435.0
Humber	-9.6	-46.3	1.4	27.8	-6.7	-33.8	27.3	8.6	-75.1	-238.8
Scotland	-2.3	-9.5	0.7	1.3	-10.9	-19.8	26.9	-5.1	-39.4	27.7
Wales	-0.5	-11.0	6.7	6.4	-9.4	-79.2	38.4	-21.7	-112.7	-437.9
GB	**-6.8**	**-43.9**	**4.5**	**30.1**	**-5.8**	**-44.0**	**29.9**	**-0.1**	**-70.8**	**-208.0**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 8: Cereals, permanent grassland and rough grazing changes from the baseline to NW, high emissions scenario.



Low emissions NW scenario

We compare the low emissions NW scenario with the low emissions baseline. The changes in land use and livestock numbers are reported in Table 9. These land use and livestock changes are very similar to those in the high emission scenario in Table 8. We observe a significant decrease in land use intensity, with lower stocking rates and arable land, and more rough-grazing.

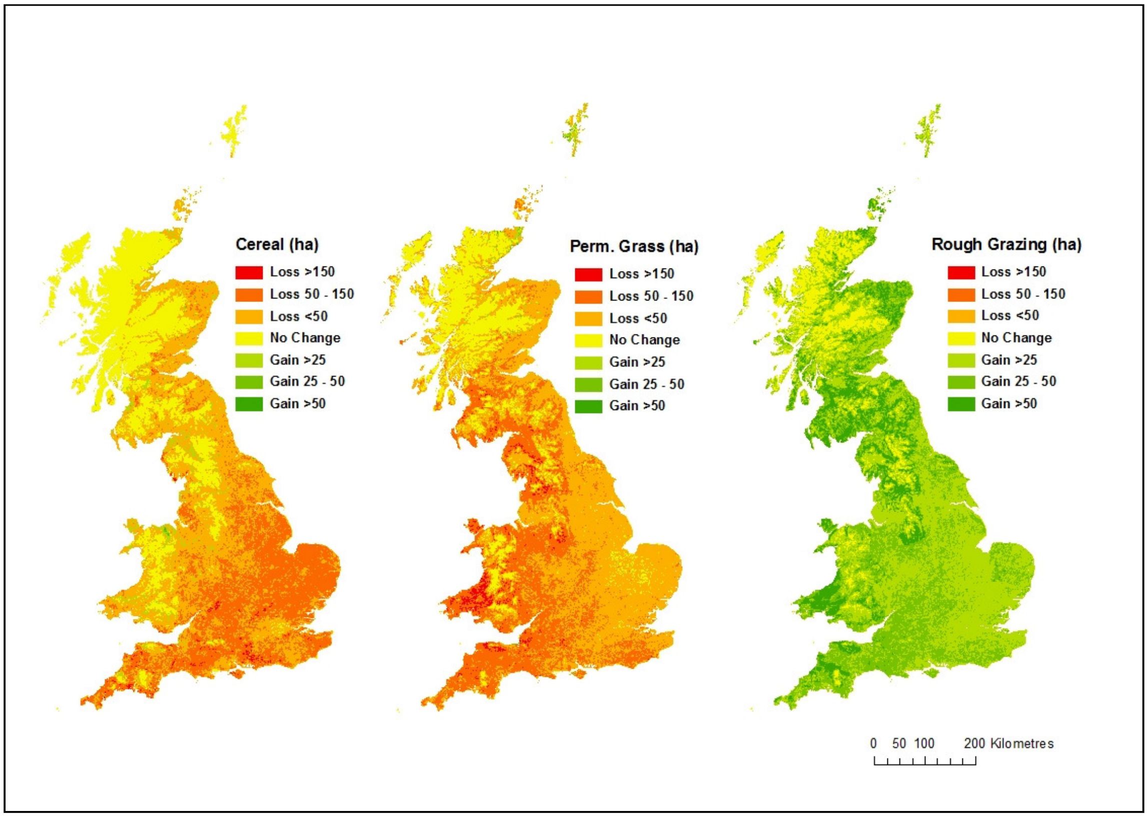
Table 9: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the NW low emissions compared to the baseline.

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-9.3	-38.0	1.2	41.2	-2.3	-18.3	8.4	7.8	-65.3	-251.4
East of England	-12.6	-57.0	1.8	55.9	2.6	-9.8	5.8	20.1	-29.0	-122.1
London	-2.7	-20.3	2.2	19.5	3.0	-14.0	3.7	6.9	-43.7	-159.5
North East	-2.6	-5.5	0.8	4.7	-11.1	-16.7	14.6	-7.5	-64.1	-121.2
North West	-1.8	-12.7	4.4	21.0	-6.1	-37.3	15.3	-18.9	-92.5	-302.6
South East	-10.1	-53.9	2.4	62.5	3.6	-30.0	10.4	2.4	-71.1	-290.7
South West	-5.7	-55.9	12.7	59.7	0.1	-47.4	14.8	-14.9	-110.0	-462.2
West Midlands	-7.6	-29.7	2.0	44.5	-2.2	-36.8	11.0	-9.5	-101.4	-379.7
Humber	-5.4	-19.9	1.2	21.4	-5.2	-16.3	10.3	2.0	-66.0	-206.1
Scotland	-1.2	-1.4	0.5	2.0	-8.6	-8.1	10.1	-5.7	-30.5	43.4
Wales	-0.4	-6.8	4.1	10.8	-4.4	-44.6	16.1	-23.7	-96.8	-350.8
GB	**-4.6**	**-23.0**	**2.8**	**26.2**	**-4.2**	**-22.5**	**11.2**	**-5.0**	**-62.0**	**-176.3**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 9 presents maps of changes for selected land use types and livestock: cereals, permanent grassland and rough grazing. Changes are even larger than those in Figure 8, decreases in cereals and permanent grassland are more widespread and also the increase in rough grazing is stronger.

Figure 9: Cereals, permanent grassland and rough grazing changes from the baseline to NW, low emissions scenario.



2.2.5 World Markets (WM) scenarios

High emissions WM scenario

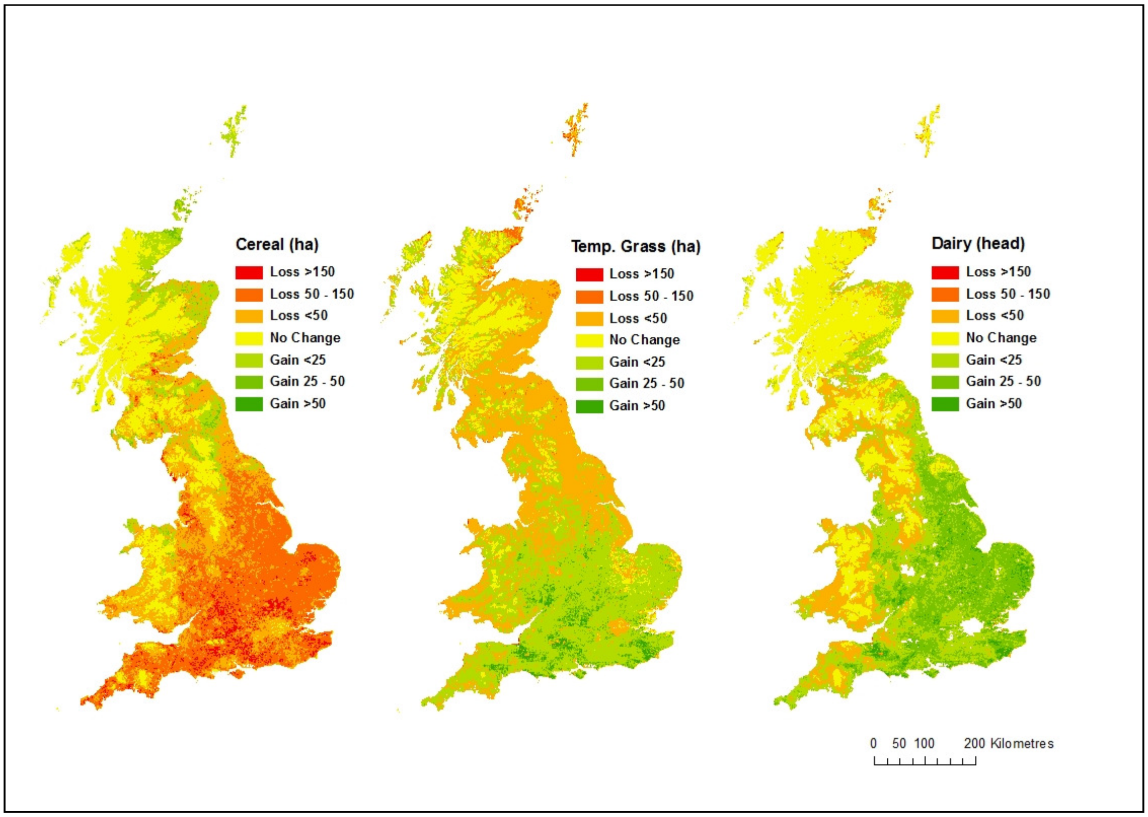
We compare the high emissions WM scenario with the baseline. The changes in land use and livestock numbers are reported in Table 10. Arable land overall increases slightly, with cereals and oilseed rape being replaced by other arable and root crops. Temporary grassland decreases in the North but increases in the South, remaining stable at the GB level. Rough grazing and permanent grassland decrease. This is reflected in the stocking rates numbers, strong decreases in beef and sheep and slightly positive for dairy. Figure 10 presents maps of changes for selected land use types and livestock: cereals, permanent grassland and rough grazing. Cereals decrease almost everywhere with the exception of the upland and some areas in Scotland where there is an increase. Temporary grassland clearly presents a North-South variation and dairy cows increase mainly in the South and East and decrease in the upland fringe.

Table 10: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the WM high emissions compared to the baseline.

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-15.0	-70.6	2.3	76.6	5.4	-27.1	-4.8	26.4	-66.6	-270.2
East of England	-19.1	-98.3	3.7	89.7	6.4	-16.8	-3.8	32.5	-28.8	-122.9
London	-2.8	-25.5	11.1	12.4	3.6	-24.7	-8.1	9.6	-16.6	-61.5
North East	-3.9	-6.6	1.3	20.2	-10.1	-15.3	-18.5	4.2	-67.6	-168.1
North West	-2.2	-24.3	11.6	36.1	-3.5	-37.7	-21.0	0.2	-90.3	-353.8
South East	-11.5	-88.5	9.1	88.8	19.4	-52.3	-4.0	26.2	-69.8	-289.2
South West	-6.4	-78.9	25.4	70.8	13.0	-67.4	-0.9	12.6	-113.4	-507.8
West Midlands	-10.7	-63.0	4.8	79.8	8.2	-50.4	-5.4	15.7	-101.4	-410.4
Humber	-8.8	-36.5	2.7	45.7	-2.9	-18.1	-14.0	16.0	-69.0	-246.5
Scotland	-1.7	-2.1	1.6	11.0	-8.6	-7.9	-37.1	-1.2	-32.3	-39.7
Wales	-0.5	-9.3	13.2	21.5	-1.3	-47.0	-25.9	-6.3	-98.0	-440.6
GB	**-6.4**	**-38.2**	**6.9**	**44.0**	**0.6**	**-28.8**	**-19.4**	**9.3**	**-63.0**	**-227.1**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 10: Cereals, permanent grassland and dairy cows changes from the baseline to NW, high emissions scenario.



Low emissions WM scenario

We compare the low emissions WM scenario with the low emissions baseline. The changes in land use and livestock numbers are reported in Table 11. These land use and livestock changes are very similar to those in the high emission scenario in Table 10, albeit presenting more modest changes, particularly cereals. We observe a significant decrease the most extensive land uses: rough grazing and permanent grassland, and a slight increase in intensive arable land.

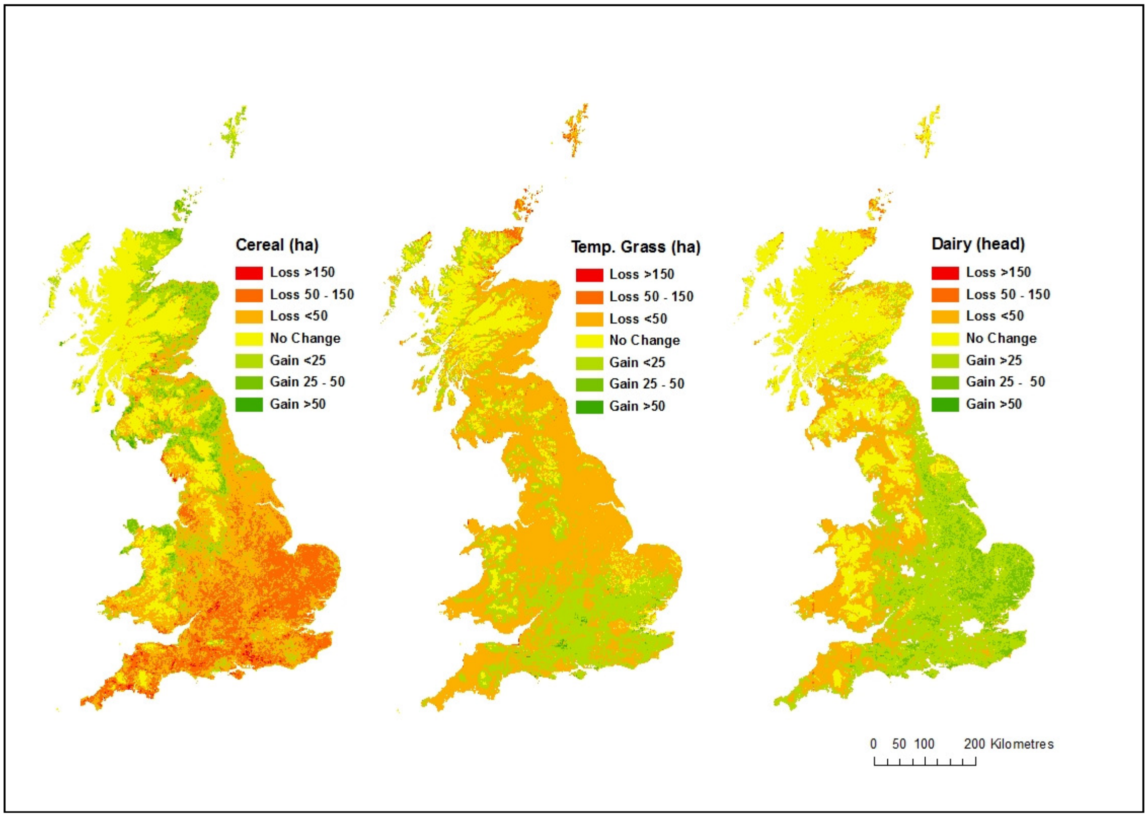
Table 11: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the WM low emissions compared to the baseline.

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-9.2	-36.8	1.4	43.8	-2.4	-18.7	-7.8	13.1	-61.9	-249.0
East of England	-12.8	-57.9	1.7	53.9	1.7	-11.1	-7.0	20.5	-28.6	-120.8
London	-2.7	-20.4	2.3	19.2	-0.2	-20.1	-9.7	5.4	-16.4	-60.4
North East	-1.7	4.0	0.9	13.0	-11.1	-15.5	-20.7	-1.8	-52.8	-127.4
North West	-1.8	-10.1	6.7	32.2	-6.3	-37.0	-24.3	-6.8	-74.9	-297.5
South East	-10.0	-50.5	2.8	69.2	2.9	-31.4	-7.5	12.9	-67.8	-283.2
South West	-5.7	-54.0	15.7	69.1	-0.4	-49.0	-4.2	1.0	-101.0	-438.8
West Midlands	-7.4	-25.2	2.4	53.0	-2.6	-37.4	-8.6	4.1	-88.4	-347.3
Humber	-5.4	-17.2	1.6	27.8	-5.4	-16.4	-17.0	6.8	-59.8	-213.8
Scotland	-1.0	3.2	0.8	9.2	-8.8	-8.4	-38.8	-3.3	-26.2	-27.4
Wales	-0.3	-3.1	8.2	26.5	-4.7	-44.0	-29.4	-12.2	-82.5	-352.3
GB	**-4.5**	**-19.6**	**3.8**	**33.6**	**-4.6**	**-23.0**	**-22.0**	**1.8**	**-54.9**	**-195.0**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 11 presents maps of changes for selected land use types and livestock: cereals, permanent grassland and rough grazing. Changes are even smaller than those in Figure 10, decreases in cereals are more muted, and the area where temporary grassland is increasing is now smaller and corresponds only to the very South of the country. Finally, the growth in dairy cows in the South East is almost offset by the drop in numbers in the rest of GB.

Figure 9: Cereals, permanent grassland and dairy cows changes from the baseline to WM, low emissions scenario.



2.2.6 Local Stewardship (LS) scenarios

High emissions LS scenario

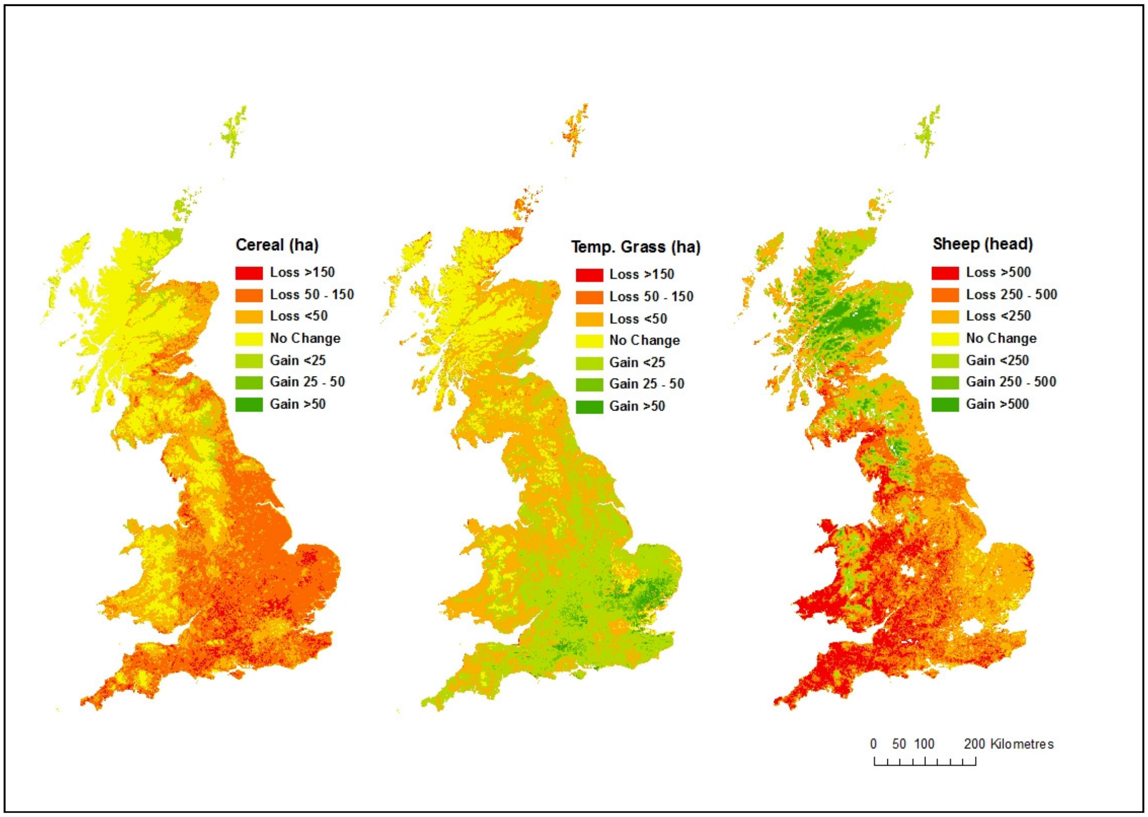
We compare the high emissions LS scenario with the baseline. The changes in land use and livestock numbers are reported in Table 12. Arable decreases overall, particularly cereals and oilseed rape. Temporary grassland increases in the South but decrease in the North and in Wales, permanent grassland increases in the East but is replaces by other land uses in the rest of GB. Rough grazing increases almost everywhere. Again, beef and sheep numbers drop everywhere with the exception of Scotland, and dairy cows increase. Figure 12 presents maps of changes for selected land use types and livestock: cereals, permanent grassland and sheep. Cereal hectares decrease strongly, particularly in the South. Temporary grassland increases in the South, particularly in the East and decreases in the North and Wales. Finally, sheep density strongly increases in the Scottish highlands, but significantly drops elsewhere.

Table 12: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the LS high emissions compared to the baseline.

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-15.8	-82.6	1.4	48.8	5.5	12.8	17.5	48.0	-65.4	-252.7
East of England	-19.4	-107.9	2.6	64.1	19.3	12.8	8.7	61.7	-28.7	-122.3
London	-2.8	-25.5	7.6	8.3	2.3	-17.4	15.3	15.8	-16.6	-61.1
North East	-5.7	-25.0	0.8	4.3	-7.3	-3.2	30.4	16.6	-52.5	-65.5
North West	-2.2	-28.7	5.3	15.9	-4.9	-33.3	39.2	6.4	-86.5	-272.7
South East	-11.5	-90.5	6.3	61.0	11.2	-15.6	27.4	40.8	-70.4	-287.8
South West	-6.4	-79.9	16.1	43.8	4.5	-36.4	42.1	24.4	-113.2	-469.6
West Midlands	-10.7	-69.1	2.9	50.5	3.9	-21.1	31.3	29.8	-98.5	-371.0
Humber	-9.5	-48.6	1.4	25.7	-1.3	2.5	21.3	30.4	-64.3	-190.5
Scotland	-2.2	-9.2	0.7	2.1	-8.0	-6.8	19.8	2.3	-26.7	62.8
Wales	-0.5	-11.3	5.7	4.6	-5.8	-51.4	50.3	-6.1	-101.7	-352.8
GB	**-6.7**	**-44.8**	**3.9**	**25.3**	**-0.3**	**-13.4**	**26.7**	**19.5**	**-60.1**	**-164.1**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 12: Cereals, temporary grassland and sheep changes from the baseline to LS, high emissions scenario.



Low emissions LS scenario

We compare the low emissions LS scenario with the low emissions baseline. The changes in land use and livestock numbers are reported in Table 13. These land use and livestock changes are very similar to those in the high emission scenario in Table 12 but, again, somehow more muted. We observe a significant decrease in land use intensity, with lower stocking rates, less arable land, and more rough-grazing.

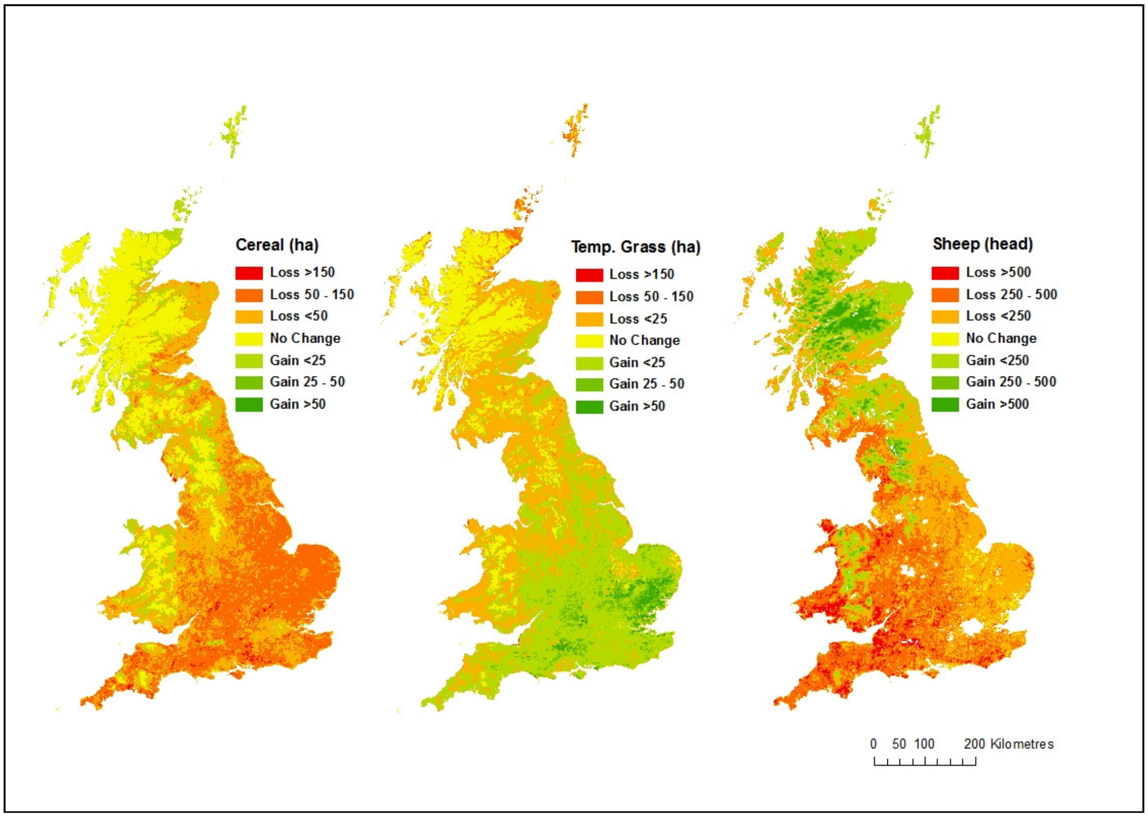
Table 13: Average change in land use hectares (ha per 2km grid square) and livestock numbers (heads per 2km grid square) in the LS low emissions compared to the baseline.

Region	OSR	CE	RC	OA	TG	PG	RG	D	B	S
East Midlands	-11.2	-56.1	0.7	22.7	7.4	21.2	16.0	44.1	-43.1	-194.8
East of England	-14.0	-74.0	1.1	34.3	24.2	21.8	7.6	61.2	-23.5	-117.5
London	-2.7	-21.2	1.9	15.6	6.0	-10.2	13.3	19.6	-16.0	-58.8
North East	-4.1	-17.2	0.6	-0.1	-6.3	1.4	27.7	13.7	-29.2	7.2
North West	-1.9	-17.5	3.9	16.6	-4.6	-31.5	36.1	2.1	-65.3	-191.6
South East	-10.4	-63.0	1.7	43.7	14.5	-8.4	23.2	39.1	-61.3	-266.2
South West	-5.9	-62.1	9.8	39.5	7.9	-26.5	38.1	24.1	-87.2	-362.1
West Midlands	-8.3	-41.5	1.3	29.8	6.2	-14.9	28.6	27.0	-70.7	-277.7
Humber	-6.7	-33.3	0.8	12.0	-0.1	8.7	19.7	26.7	-41.4	-127.4
Scotland	-1.6	-5.2	0.4	1.6	-7.4	-3.7	18.3	1.1	-16.1	93.2
Wales	-0.4	-7.2	4.7	12.0	-5.3	-49.5	47.3	-9.4	-82.6	-244.8
GB	**-5.2**	**-30.7**	**2.3**	**17.5**	**1.5**	**-8.2**	**24.4**	**17.6**	**-44.1**	**-109.6**

Notes: OSR = oilseed rape, CE = cereals, RC = root crops, OA = other arable, TG = temporary grassland, PG = permanent grassland, RG = rough grazing, D = dairy, B = beef, S = sheep.

Figure 13 presents maps of changes for selected land use types and livestock: cereals, permanent grassland and rough grazing. Changes similar to those in Figure 12.

Figure 13: Cereals, temporary grassland and sheep from the baseline to LS, low emissions scenario.

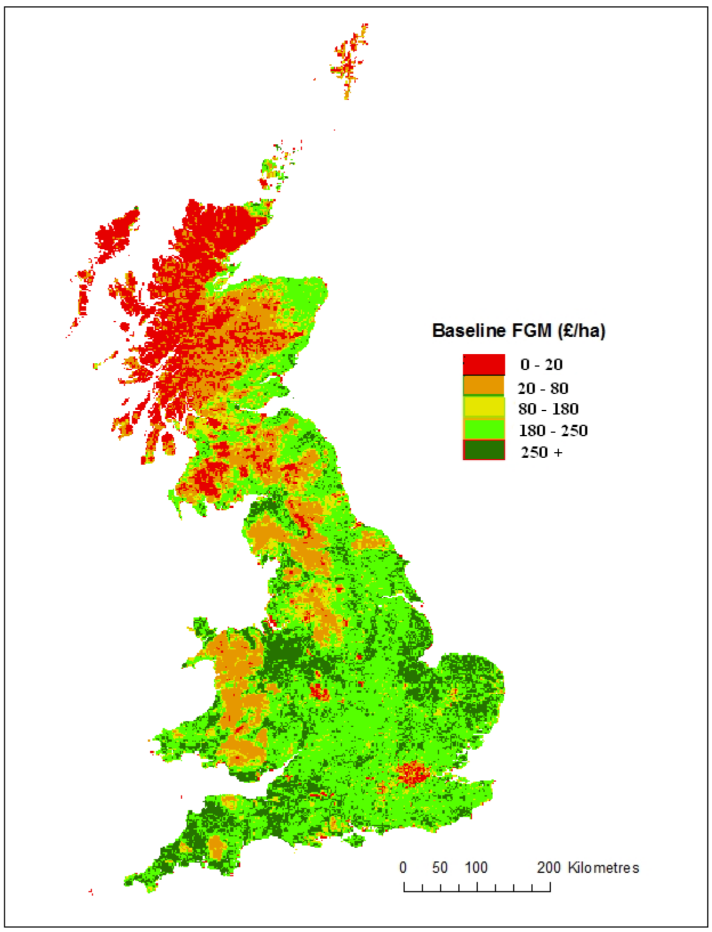


2.3 Farm gross margin impacts

We now move to consider farm gross margin (FGM) under the various scenarios. These are evaluated using the prices in year 2004 (as discussed in the NEA Economics chapter)[8]. Two important limitations need to be acknowledged. Firstly, since FGM is defined as the difference between revenues and variable costs, all farm fixed costs (e.g. machineries, buildings, rent, etc.) are not included in the analysis. Secondly, conversion costs are also not included. In other words, all changes in land use and FGM refer to equilibrium conditions, but do not take into account possible costs encountered in order to reach these new equilibriums. Bearing these caveats in mind, FGMs can be used to analyze the trends in overall agricultural productivity in the different scenarios.

We begin by considering the FGM in 2000 baseline, reported in the first column of Table 14 and represented in Figure 14. The figure highlights how the farms with the highest FGM are located in the lowland and southern areas of the country, while those in upland areas have relatively low FGM levels. This reflects the variation in physical environmental conditions across the country.

Figure 14: Baseline FGM/ha (year 2000)



[8] FGM for 2010 taken from Fezzi et al. (2010b) as follows: cereals = £290/ha, root crops = £2425/ha, oilseed rape = £310/ha, dairy = £576/head, beef = £69/head, sheep = £9.3/head.

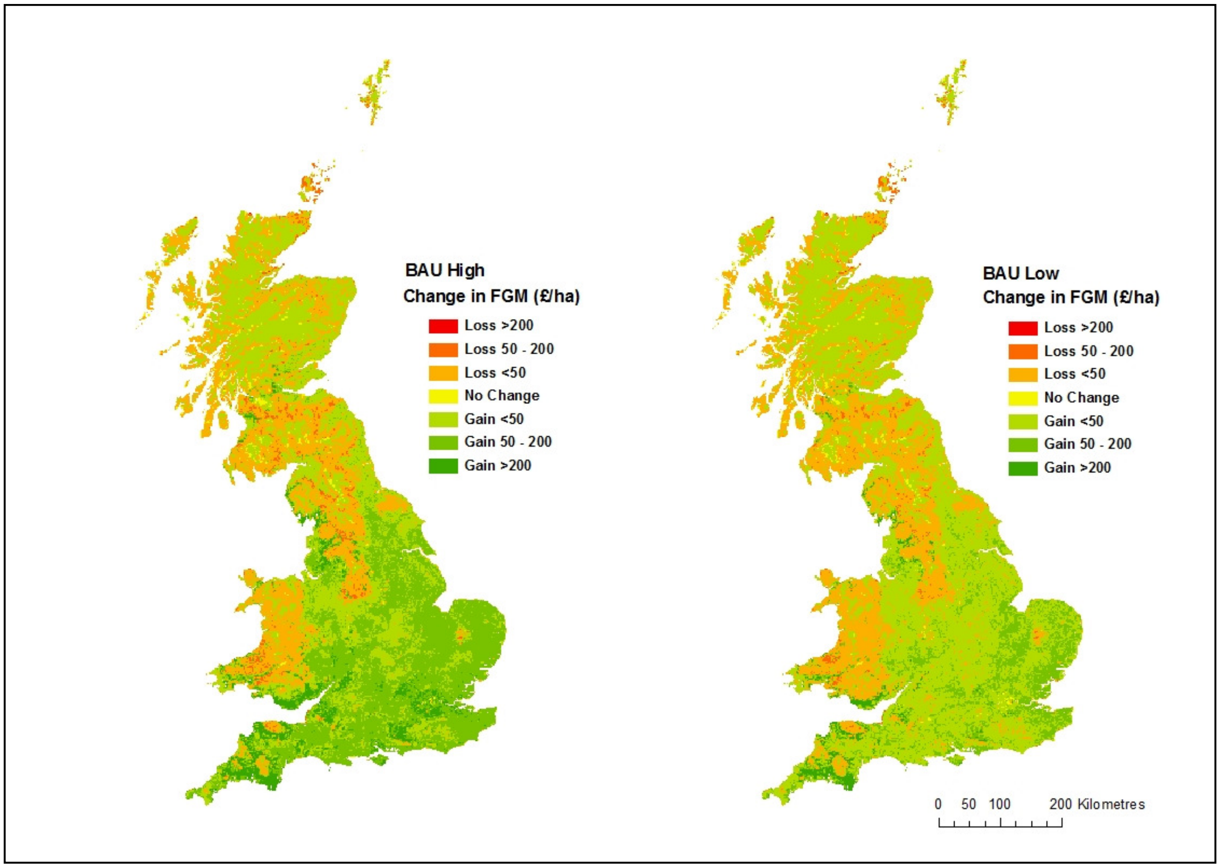
Table 14: FGM per hectare (FGM/ha) in the baseline and changes in FGM per hectare (□FGM/ha) in the scenarios.

	Base (FGM/ha)	GWF (□FGM/ha)		GPL (□FGM/ha)		NS (□FGM/ha)		NW (□FGM/ha)		WM (□FGM/ha)		LS (□FGM/ha)	
Region		high	low	high	low	high	low	high	low	high	low	high	low
East Midlands	250.2	25.6	10.6	-16.3	-32.3	60.1	35.5	-12.8	-29.6	32.7	10.4	29.0	27.8
East of England	262.3	55.8	35.2	3.4	-17.6	90.6	57.2	18.6	-3.4	49.5	23.9	61.6	59.2
London	157.0	280.9	49.2	174.7	26.4	418.3	83.9	222.5	9.5	232.8	51.0	178.4	104.3
North East	172.5	-8.5	-10.1	-24.4	-26.4	16.6	10.7	-45.7	-45.6	7.1	2.7	-1.4	3.1
North West	183.8	25.0	9.3	-1.8	-17.4	90.3	57.2	-28.7	-41.8	68.8	32.8	11.8	11.6
South East	245.5	94.6	26.9	27.7	-23.3	132.4	48.1	31.9	-36.7	95.9	33.7	69.7	40.3
South West	257.0	136.0	69.0	34.0	-2.0	195.1	122.6	62.5	-19.4	163.9	95.4	89.7	62.3
West Midlands	250.0	25.6	5.1	-15.2	-30.7	61.8	33.2	-26.1	-50.8	37.3	14.8	16.8	17.1
Humber	201.6	12.6	4.7	-19.4	-29.1	43.0	25.7	-22.9	-31.6	27.2	9.3	16.0	15.7
Scotland	77.1	-2.4	-3.8	-7.7	-8.9	9.0	4.9	-20.7	-20.6	8.5	3.8	-2.9	-0.4
Wales	159.7	14.1	-5.5	-11.1	-17.9	79.5	47.1	-29.6	-57.2	66.4	33.5	-6.2	-2.3
GB	**173.1**	**32.8**	**12.2**	**-1.6**	**-16.2**	**66.7**	**37.7**	**-6.1**	**-28.7**	**49.1**	**23.4**	**23.7**	**19.5**

Note: FGM taken from Fezzi et al. (2010b) as follows: cereals = £290/ha, root crops = £2425/ha, oilseed rape = £310/ha, dairy = £576/head, beef = £69/head, sheep = £9.3/head.

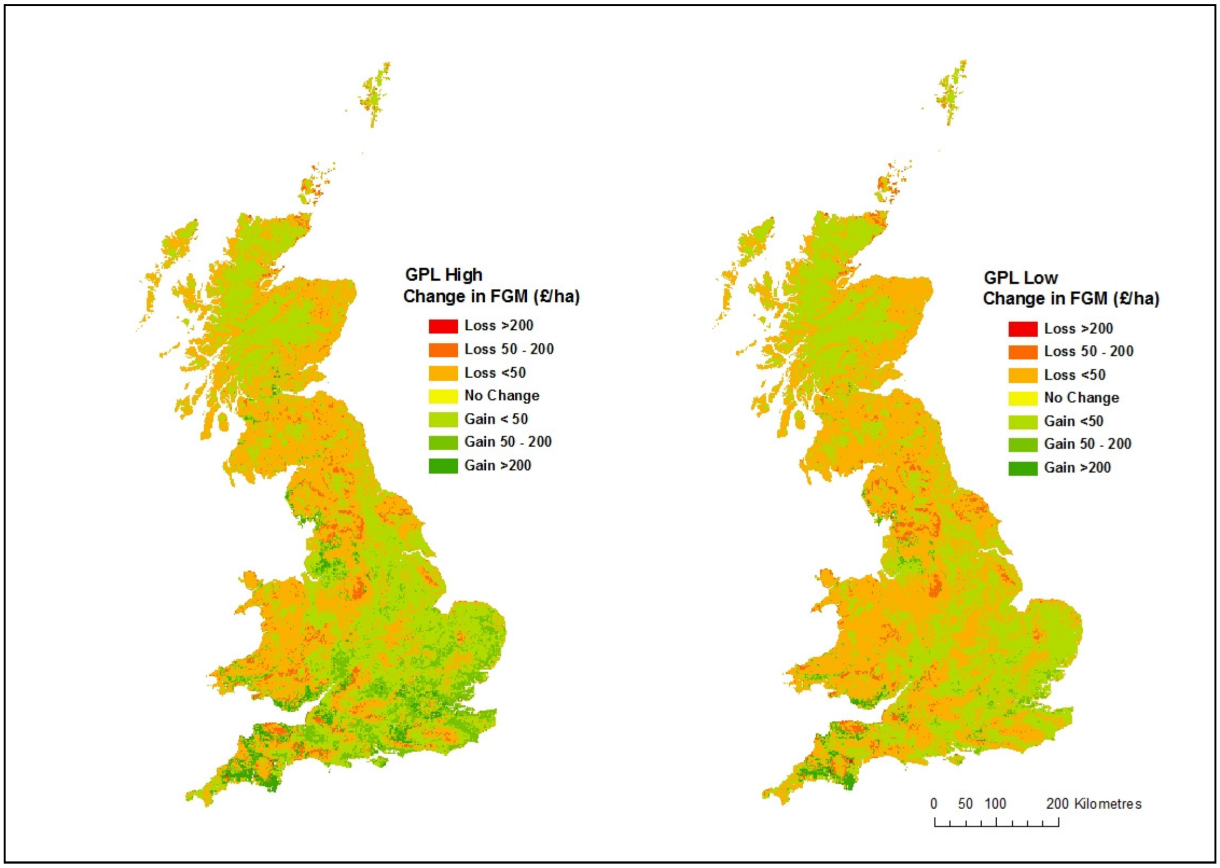
Considering the two GWF scenarios, represented in Figure 11, we notice how those have a positive impact for most of the country. The areas which suffer some moderate losses are the upland fringes where, by recalling Figure 2, the model predicts a decrease in dairy cows stocking rates (dairy farms have typically high farm gross margin, see for example, Fezzi et al. 2010b).

Figure 15: FGM/ha changes from the baseline to the GWF high and low emissions scenarios



We now move to consider the changes in the alternative policy scenarios as opposed to the baseline, reported in columns 5 to 14. Considering the GPL scenarios, changes are mapped in Figure 16. According to our results moving from the baseline to GPL will have a negative impact on agriculture, with overall costs higher in the low emission scenario then in the high emissions one. However, there is significant spatial heterogeneity, with some areas in the South having gains, particularly in the high emission scenario, and the rest of the country being worse-off.

Figure 16: FGM/ha changes from the baseline to the GPL high and low emissions scenarios



The results of the NS scenarios are reported in columns 7-8 and in Figure 17. Moving away from the baseline into the NS scenario will increase agricultural production and FGM/ha through-out the country. However, the effect is particularly positive in the South and East of England. Results are similar between the low and high emissions scenarios, with higher gains taking place in the latter.

Figure 17: FGM/ha changes from the baseline to the NS high and low emissions scenarios

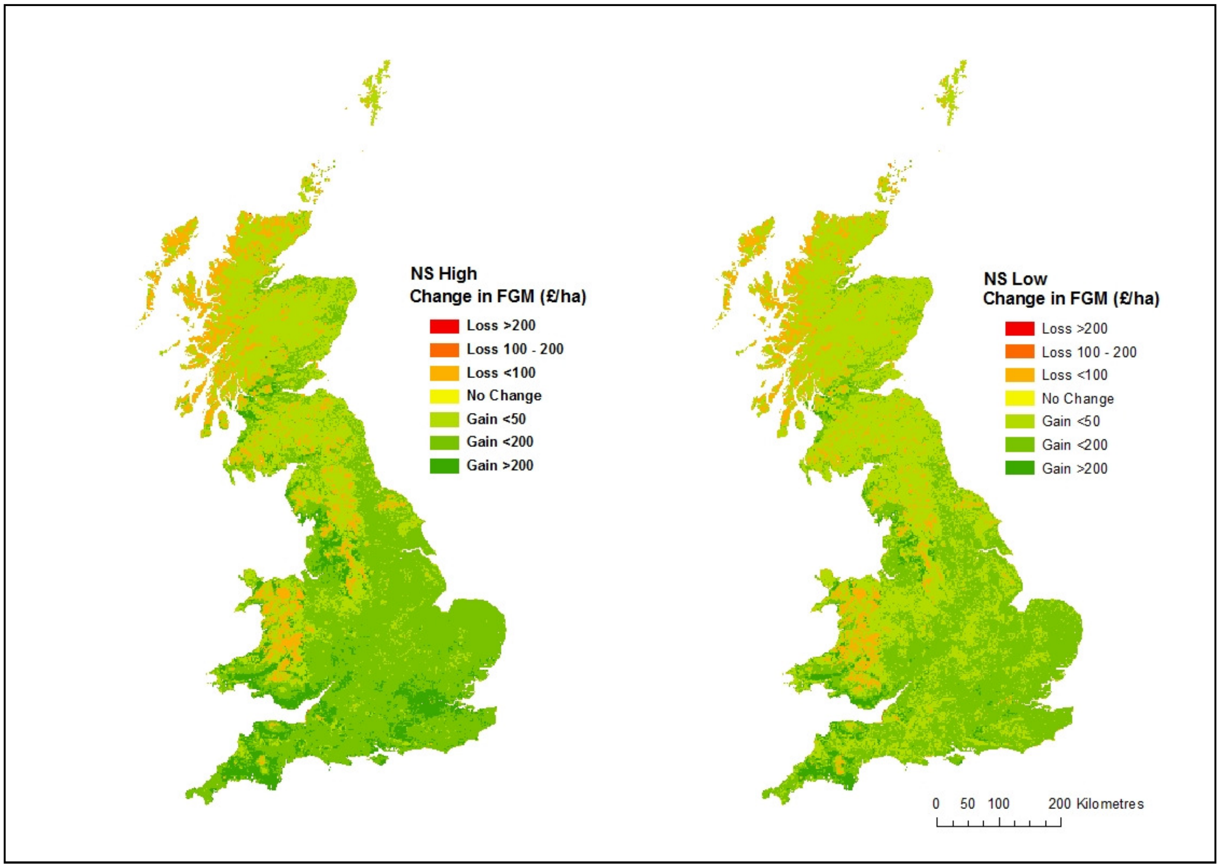
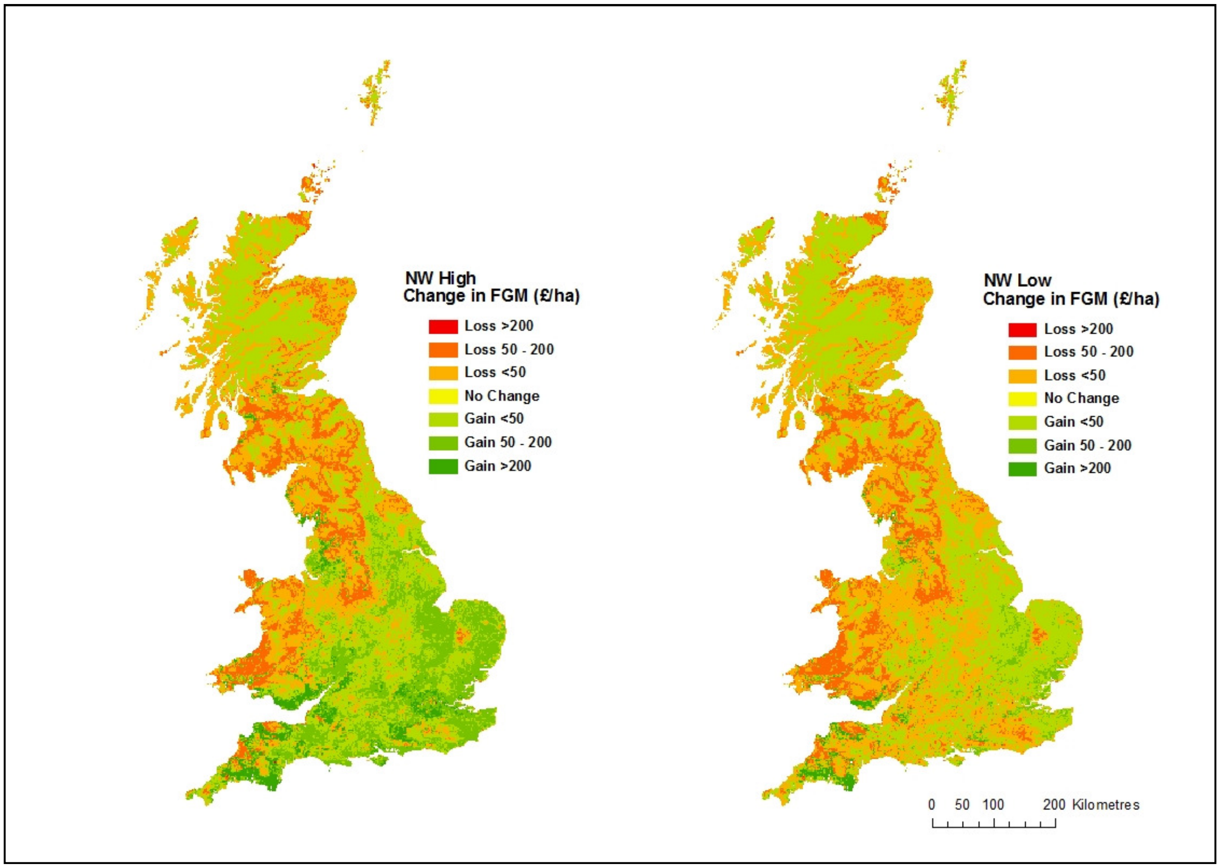
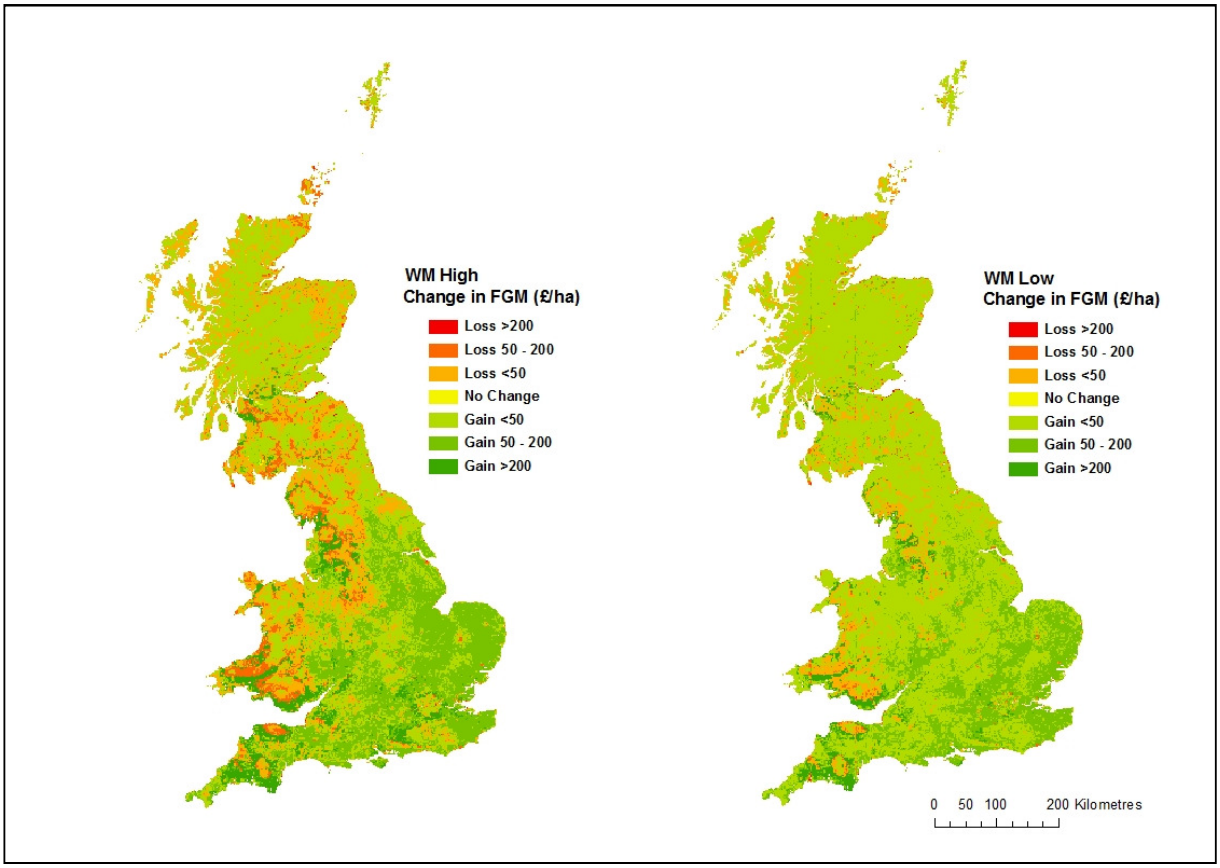


Figure 18: FGM/ha changes from the baseline to the NW high and low emissions scenarios



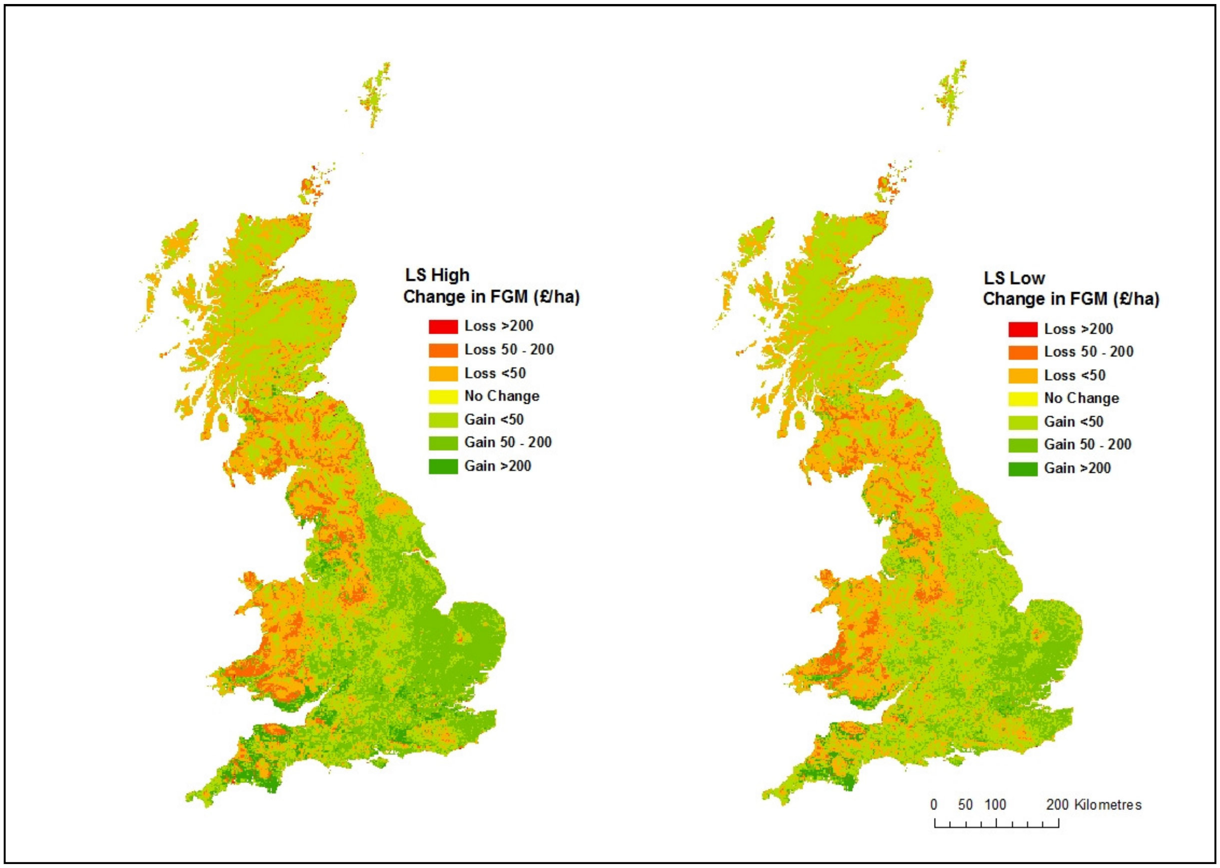
The results of the NW scenarios are reported in columns 9-10 and in Figure 18. According to our modelling, moving away from the baseline into the NW scenario will result in overall financial impacts on farms similar to those in the GPL scenario but slightly more negative. However, as showed in the maps, farms located in the upland fringe will be the main bearers of the losses, while other farms will have slight gains, particularly in the high emissions scenario.

Figure 19: FGM/ha changes from the baseline to the WM high and low emissions scenarios



Considering the WM scenario, the results are reported in columns 11-12 and in Figure 19. Impacts will be highly positive through-out the country, particularly in the South. However, some localized losses will be present in some areas in Wales and in the North of England, mainly, particularly in the high emissions scenario.

Figure 20: FGM/ha changes from the baseline to the LS high and low emissions scenarios



Considering the LS scenario, the results are reported in columns 13-14 and in Figure 20. Impacts will be overall positive, particularly in the South and in the high emissions scenario. However, there are regions which are worse-off. For example, in Wales the average FGM drops by £7.7/ha and £5.1/ha in the high and low emission scenarios respectively. Other areas which present losses are the upland fringe areas in the North of England and Scotland.

2.4 Summary and conclusions

This chapter described in terms of land use and farm incomes (Farm Gross Margin) in Great Britain (GB), in a baseline year (2000) and a series of scenarios for 2060. Table 15 presents the summary statistics for all the scenarios for the entire GB. The first column contains the data relative to the baseline, which highlights the significant heterogeneity with characterized the GB farming system. In fact, the FGM/ha of the 3rd quartile is more than 7 times the FGM/ha of the 1st.

Considering the GWF scenarios, the expectation is an increase in agricultural incomes, coming from the warmer climate and the possible introduction of new crops varieties (great increase in the "other" category). Another source of revenues, according to these scenarios, will be the increased dairy cow numbers, directly proportional to the growth in temporary grassland. This increase in the mean FGM does not seem to be reflected in the lowest income farms, since the 1st quartile does not change significantly from the baseline.

Table 15: Summary statistics for FGM per hectare (FGM/ha) in the baseline and in the various scenarios.

	mean (£/ha)	**median (£/ha)**	**std. error (£/ha)**	**min (£/ha)**	**1st quart. (£/ha)**	**3rd quart (£/ha)**	**max (£/ha)**	**GB TOTAL (£ billions)**	**□ TOTAL (£ billions)**
baseline	173.1	223.4	113.3	0.0	34.9	268.6	1182.3	**3.10**	0.00
GWF high	205.9	227.4	184.1	0.0	34.8	301.3	1980.7	**3.69**	0.59
GWF low	185.3	214.6	151.5	0.0	35.0	280.5	2073.3	**3.32**	0.22
GPL high	171.5	198.0	133.7	0.0	34.8	254.8	1721.6	**3.07**	-0.03
GPL low	156.9	188.4	114.8	0.0	35.1	236.7	1777.1	**2.81**	-0.29
NS high	239.8	269.2	218.6	0.0	25.3	340.1	2202.9	**4.30**	1.20
NS low	210.8	247.5	186.1	0.0	25.8	311.1	2221.4	**3.78**	0.68
NW high	167.0	164.8	159.0	0.0	31.5	253.3	1697.0	**2.99**	-0.11
NW low	144.4	147.4	120.3	0.0	32.0	227.4	1871.6	**2.59**	-0.51
WM high	222.2	242.3	205.4	0.0	38.9	308.9	6039.1	**3.98**	0.88
WM low	196.5	229.0	169.9	0.0	40.5	284.7	6047.6	**3.52**	0.42
LS high	196.8	223.8	164.0	0.0	33.3	299.7	2272.1	**3.53**	0.43
LS low	192.6	224.6	145.6	0.0	36.7	297.7	1697.0	**3.45**	0.35

Note: FGM taken from Fezzi et al. (2010b) as follows: cereals = £290/ha, root crops = £2425/ha, oilseed rape = £310/ha, dairy = £576/head, beef = £69/head, sheep = £9.3/head.

Considering the alternative policy scenarios, achieving higher environmental quality (GPL and NW) will come at significant costs for the farming community. Interestingly, while the GPL does not seem to affect poorer farmers (1st quartile does not change) it will hit richer farmer more heavily (strong reduction of the 3rd quartile).

Encouraging agricultural production under the NS and WM scenarios will, as one would expect, boost agricultural incomes, increase arable land shares and stocking rates. However, the total amount of agricultural land will decrease significantly. In particular the scenarios envisage a loss of low productivity land, actually used as rough grazing and permanent grassland. Overall, however, the agricultural output is expected to increase (column 9) and, while this will be beneficial for both the high income farmers and low income ones in the WM scenario, it will actually affect negatively the poor farmers in the NS scenario (e.g. 1st quartile in NS high from £34.9/ha to £25.3/ha).

Table 16: Summary statistics for FGM per hectare (FGM/ha) in the baseline and in the various scenarios.

	ΔFGM mean (£/ha)	**ΔFGM median (£/ha)**	**ΔFGM std. error (£/ha)**	**ΔFGM 1st quart. (£/ha)**	**ΔFGM 3rd quart (£/ha)**
GWF high	32.8	6.8	123.9	-7.2	39.2
GWF low	12.2	2.7	87.0	-9.9	19.2
GPL high	-1.6	-7.0	74.3	-29.9	6.4
GPL low	-16.2	-18.6	55.8	-38.5	0.0
NS high	66.7	29.1	155.0	-3.5	77.2
NS low	37.7	14.2	120.8	-4.9	47.6
NW high	-6.1	-6.5	111.7	-44.6	9.1
NW low	-28.7	-19.8	73.7	-62.7	1.0
WM high	49.1	13.2	148.4	0.3	43.0
WM low	23.4	7.8	112.4	-1.7	20.7
LS high	23.7	7.3	98.2	-9.1	39.2
LS low	19.5	8.0	72.2	-5.0	36.6

Note: FGM taken from Fezzi et al. (2010b) as follows: cereals = £290/ha, root crops = £2425/ha, oilseed rape = £310/ha, dairy = £576/head, beef = £69/head, sheep = £9.3/head.

Finally, also in the LS scenario agricultural incomes are higher, both per hectare and total GB. Again, however, low income farmers do not seem to benefit from this increase but are actually slightly worse-off.

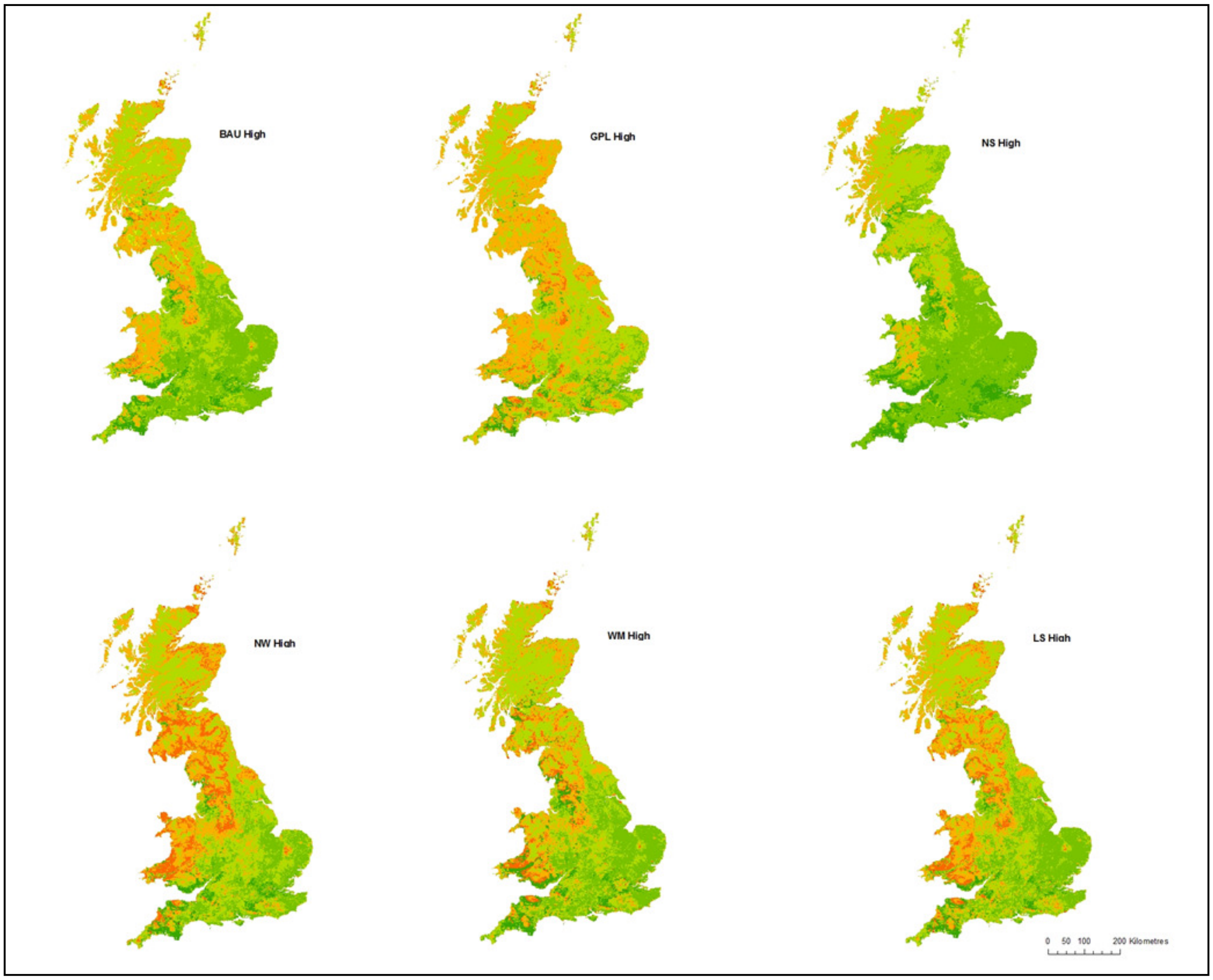
Table 16 summarizes the changes in FGM/ha. Interestingly even the scenarios which deliver the higher benefits for agriculture overall (NS, WM and LS), reported in column 1, presents some farms and areas which are worse-off. In particular, the 1st quartile of changes is negative in all the scenarios but WM high emissions. Conversely, the 3rd quartile is positive in all the scenarios, highlighting that there are farm benefiting significantly even when the overall incomes are expected to decrease, like in the GP and NW worlds. As a further illustration, Table 17 reports the percentage changes relative to Table 16.

Table 17: Summary statistics for FGM per hectare (FGM/ha) in the baseline and in the various scenarios.

	ΔFGM mean (%)	**ΔFGM median (%)**	**ΔFGM std. error (%)**	**ΔFGM 1st quart. (%)**	**ΔFGM 3rd quart (%)**
GWF high	18.9	3.0	109.4	-20.6	14.6
GWF low	7.0	1.2	76.8	-28.4	7.1
GPL high	-0.9	-3.1	65.6	-85.7	2.4
GPL low	-9.4	-8.3	49.2	-110.3	0.0
NS high	38.5	13.0	136.8	-10.0	28.7
NS low	21.8	6.4	106.6	-14.0	17.7
NW high	-3.5	-2.9	98.6	-127.8	3.4
NW low	-16.6	-8.9	65.0	-179.7	0.4
WM high	28.4	5.9	131.0	0.9	16.0
WM low	13.5	3.5	99.2	-4.9	7.7
LS high	13.7	3.3	86.7	-26.1	14.6
LS low	11.3	3.6	63.7	-14.3	13.6

Note: FGM taken from Fezzi et al. (2010b) as follows: cereals = £290/ha, root crops = £2425/ha, oilseed rape = £310/ha, dairy = £576/head, beef = £69/head, sheep = £9.3/head.

Figure 21: FGM/ha changes from the baseline to all high emissions scenarios

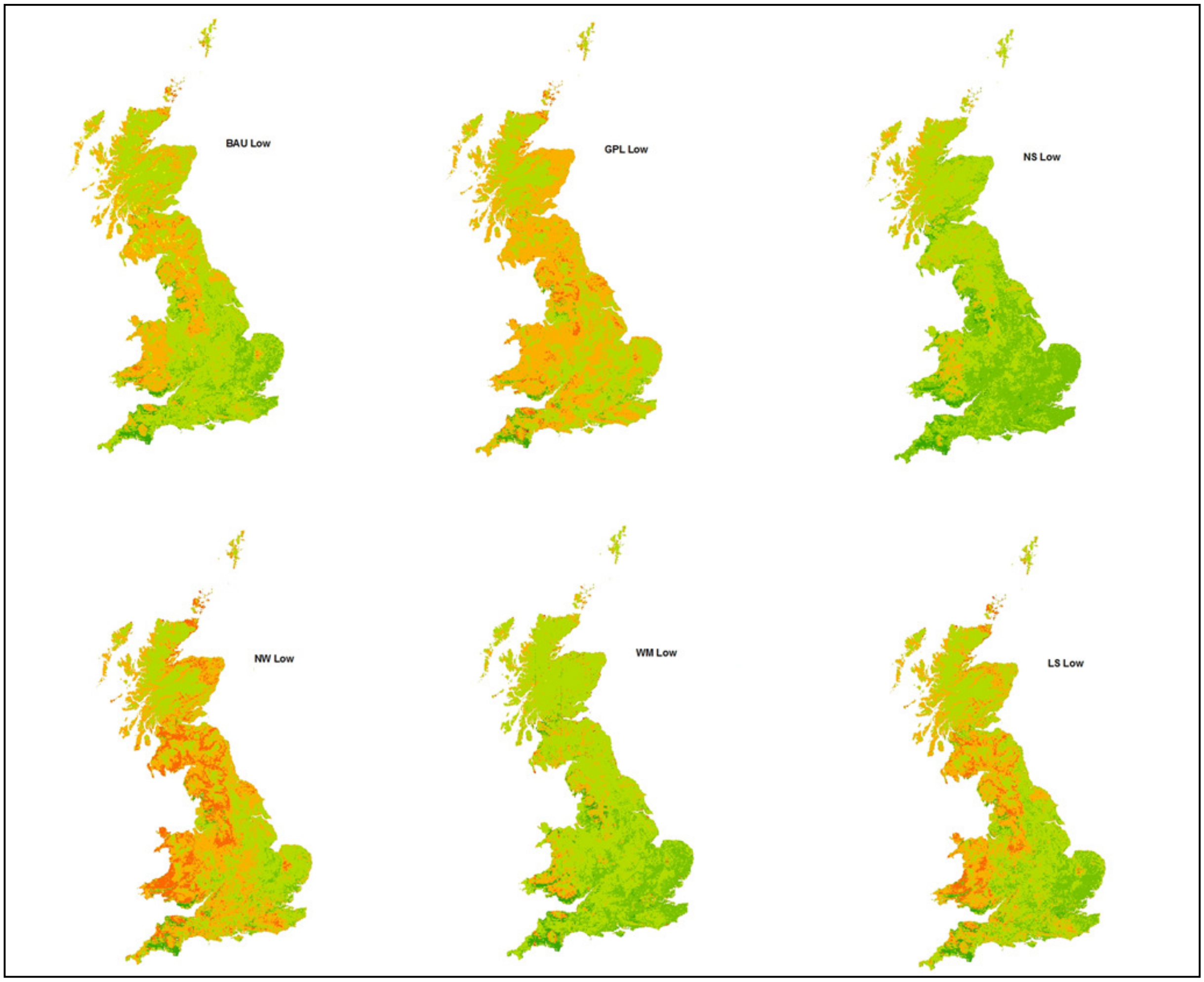


Finally, Figures 21 and 22 summarize visually the changes in FGM/ha, distinguishing between the low and high emission scenarios. In almost all scenario the South of the country seem to be better-of from the changes (possibly with the exception of GLP and NW in the low emissions), while is the North of England, Wales and Scotland which bear the highest losses, particularly the upland fringe (exceptions are WM and NS low emissions). This is well highlighted in the GWF, NW, LS scenarios.

Furthermore, as one would expect, the differences between the scenarios are much stronger than the differences between high and low emissions. However, it seems that in high emission scenarios the heterogeneity in impact is somehow higher. For example, considering the WM, the positive effects in the

South of the country are higher in the high climate change scenario, but also the negative impacts in the North are stronger with high climate change. This is also quite evident in the GWF and LS scenarios.

Figure 22: FGM/ha changes from the baseline to all low emissions scenarios



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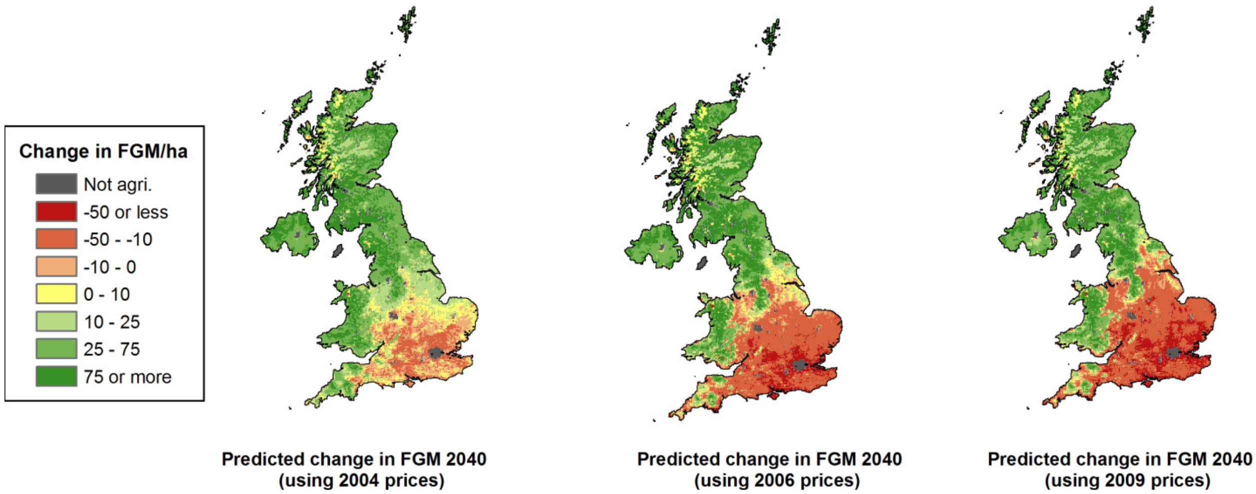
Appendix 1: The impact of variation in annual prices upon predictions of FGM in 2040

Figure A1: The impact of variation in annual prices upon predictions of FGM in 2040 (low emissions)



The left hand panel of Figure A1 shows predicted land use for 2040 converted into farm gross margin values using the gross margins prevalent in 2004[9]. The middle panel repeats this analysis but using prices for 2006 (Nix, 2006)[10] and the right hand panel repeats this using 2009 prices (Nix, 2009)[11]. As can be seen, relatively short term variations in price result in substantial changes in the absolute level of FGM. However, the relative trends and spatial patterns remain robust to this variation.

[9] Gross margins taken from Fezzi et al., (2010b)

[10] FGM in 2006: cereals = £623/ha, root crops = £934.5/ha, oilseed rape = £222/ha, dairy = £534.2/head, beef = £71/head, sheep = £6.5/head, other = £623/ha.

[11] FGM in 2009: cereals = £500.5/ha, root crops = £1971/ha, oilseed rape = £292/ha, dairy = £651.6/head, beef = £66/head, sheep = £10.88/head, other =£500.5/ha.