Agriculture and Environment Research Unit
School of Life Sciences

A revisit to previous research into the current and potential climate change mitigation effects of environmental stewardship (BD5007)

Final Report

Agriculture and Environment Research Unit
School of Life Sciences
University of Hertfordshire
United Kingdom

Contents

List of abbreviations

C: carbon
CH_4: methane
CO_2: carbon dioxide
CSS: Countryside Stewardship Scheme

EDP: Excluding Displacement of Production.
ELS: Entry Level Stewardship
ES: Environmental Stewardship
ESA: Environmentally Sensitive Area

F: fen scenario
$FRAC_{LEACH}$: fraction leached
$FRAC_{GASM}$: fraction volatilised from manures
FYM: farmyard manure

GHG: greenhouse gas
GW: grazed woodland scenario

HLS: Higher Level Stewardship
$H_{(1.5)}$: Hedgerow 1.5m height

IPPC: Intergovernmental Panel on Climate Change

K: potassium

LCA: Life-Cycle Analysis
LFA: Less Favoured Area
LH: lowland heathland scenario

Mt CO_2: Million tonnes of Carbon Dioxide (CO_2)
MZ: maize scenario

N: nitrogen
NH_4^+: ammonium
NO_3^-: nitrate
NVZ: Nitrate Vulnerable Zone
N_2: dinitrogen
N_2O: nitrous oxide

OELS: Organic Entry Level Scheme
OMZ: organic maize scenario
OSB: organic spring barley scenario
OSIGSh(low): organic semi-improved grassland grazed by sheep (lowland)
OSIGC(low): organic semi-improved grassland grazed by cattle (lowland)
OSIGSh(up non-LFA): organic semi-improved grassland grazed by sheep (upland outside the LFA)
OSIGC(up non-LFA): organic semi-improved grassland grazed by cattle (upland outside the LFA)
OSIGSh(up LFA): organic semi-improved grassland grazed by sheep (upland inside the LFA)
OSIGC(up LFA): organic semi-improved grassland grazed by cattle (upland inside the LFA)
OSIG(cut): organic semi-improved grassland cut for silage
OTGIBC: organic temporary grassland grazed by intensive beef cattle scenario
OTGIBC(erosion): organic temporary grassland grazed by intensive beef cattle scenario where soil erosion is present

OUIGSh(low): organic unimproved grassland grazed by sheep (lowland) scenario
OUIGC(low): organic unimproved grassland grazed by cattle (lowland) scenario
OWW: organic winter wheat scenario
OUIGSh(non-LFA): organic unimproved grassland grazed by sheep (upland outside the LFA) scenario
OUIGC(non-LFA): organic unimproved grassland grazed by cattle (upland outside the LFA) scenario
OUIGSh(LFA): organic unimproved grassland grazed by sheep (upland inside the LFA) scenario
OUIGC(LFA): organic unimproved grassland grazed by cattle (upland inside the LFA) scenario

P: potassium
PAS: Publicly Available Specification

QELRC: Quantified Emission Limitation or Reduction Commitments

RB: reed bed scenario
RG: rough grazing scenario

SB: spring barley scenario
SDA: Severely Disadvantaged Area
SIGSh(low): semi-improved grassland grazed by sheep (lowland)
SIGC(low): semi-improved grassland grazed by cattle (lowland)
SIGSh(up non-LFA): semi-improved grassland grazed by sheep (upland outside the LFA)
SIGC(up non-LFA): semi-improved grassland grazed by cattle (upland outside the LFA)
SIGSh(up LFA): semi-improved grassland grazed by sheep (upland inside the LFA)
SIGC(up LFA): semi-improved grassland grazed by cattle (upland inside the LFA)
SIG(cut): semi-improved grassland cut for silage
SM: salt marsh scenario
SOC: soil organic carbon

t CO_2: tonnes of Carbon Dioxide (CO_2)
TGIBC: temporary grassland grazed by intensive beef cattle scenario with inorganic nitrogen only
TGIBC(clover): temporary grassland grazed by intensive beef cattle scenario with 30% clover
TGIBC(erosion): temporary grassland grazed by intensive beef cattle scenario where soil erosion is present

UIGSh(low): unimproved grassland grazed by sheep (lowland) scenario
UIGC(low): unimproved grassland grazed by cattle (lowland) scenario
UIGSh(non-LFA): unimproved grassland grazed by sheep (upland outside the LFA) scenario
UIGC(non-LFA): unimproved grassland grazed by cattle (upland outside the LFA) scenario
UIGSh(LFA): unimproved grassland grazed by sheep (upland inside the LFA) scenario
UIGC(LFA): unimproved grassland grazed by cattle (upland inside the LFA) scenario

WM: water meadow
WW: winter wheat

ABSTRACT

Environmental Stewardship was introduced to build on the already successful Environmentally Sensitive Areas (ESA) scheme and the Countryside Stewardship Scheme (CSS). Although primarily engaged with resource protection such as soil and water and the enhancement of biodiversity, the alterations in land use that are undertaken during the implementation of ES options do have implications for climate change mitigation. Defra project BD2302 quantified greenhouse gas (GHG) mitigation (excluding displacement of production) within Environmental Stewardship (ES) and established the potential for delivery of climate change mitigation under the scheme. A comprehensive review of this work has now been undertaken to ensure that the scenarios continue to be robust and that the parameters included within the calculations are optimal. Particular attention has been given to the highest ten performing options from BD2302.

The previous Life-cycle Assessment (LCA) approach used in BD2302 has been repeated with improvements to the method to quantify the net GHG emissions, either positive or negative, under each ES option relative to a baseline typical arable or grassland system. Improvements to the method include accounting for the impact of soil type, timing and method of incorporation on nitrous oxide emissions from livestock manure application, livestock dietary constituents on enteric methane production and methane during manure storage, and additional soil organic carbon equilibriums. Baseline scenarios have been reviewed and updated, and new baselines created as necessary. Options and option supplements not previously considered in the original BD2302 project have also been reviewed and included where relevant. An analysis of new ES options introduced since completion of BD2302, including the Uplands stand of the Entry Level Stewardship (ELS) scheme, have been conducted. Management scenarios have been constructed, and a comparison of the current management requirements of all ES options with the previous management specifications undertaken, differences highlighted, and then incorporated into the new management scenarios.

The net GHG balance of each evaluated ES option using the revised baseline scenarios, management scenarios where applicable, and revised emission factors and improved method has been calculated for both the original BD2302 option management scenarios and current ES option management scenarios. A direct comparison between the two has identified no significant impact on GHG emissions from alteration to the management specifications of ES options since completion of BD2302. The greatest impact has arisen where baseline scenarios have been modified, namely from temporary grassland to permanent grassland as was deemed necessary for selected options on grassland. The newly introduced ES options have further reduced

agricultural GHG emissions excluding displacement of production (EDP[1])). Certain new options, for example winter cover crops, achieve an emissions reduction without the removal of land from its original land use and from agricultural production (have minimal production displacement risk). The overall impact of minimal displacement risk options on agricultural greenhouse gas emissions has been estimated, in addition to the emissions reduction where displacement may be beneficial (from deep cultivated peat soils for example). In total, ES achieves a mean annual greenhouse gas emission reduction$_{(EDP)}$ of 4 Mt CO_2e year^{-1}, of which 68,000 t CO_2e year^{-1} is estimated to result at negligible production displacement risk.

---

[1] The implementation of certain ES options requires that land is removed from agricultural production or that productivity is reduced and this risks the displacement of that production elsewhere, either on the same farm or elsewhere inside or outside of the UK.

1.0. INTRODUCTION

Environmental Stewardship was introduced to build on the already successful Environmentally Sensitive Areas (ESA) scheme and the Countryside Stewardship Scheme (CSS). Although primarily engaged with resource protection such as soil and water and the enhancement of biodiversity, the alterations in land use that are undertaken during the implementation of ES options do have implications for climate change. The Fourth Carbon Budget Report (CCL, 2010) reports that UK agricultural greenhouse gas (GHG) emissions decreased from 61 Mt CO_2e in 1990, to 48 Mt CO_2e in 2008. A key driver in this reduction was the reform of the Common Agricultural Policy (CAP) and the increase in the area devoted to agri-environment schemes such as Environmental Stewardship (ES). Defra project BD2302 (Warner *et al*., 2008) focused on GHG mitigation within ES and established the potential for delivery of climate change mitigation under the scheme. A comprehensive review of this work has been undertaken to ensure that the scenarios continue to be robust and that the parameters included within the calculations are current. Baseline scenarios have been reviewed and updated, and new baselines created as necessary. Options and option supplements not previously considered in the original BD2302 project have also been reviewed and included where relevant. An analysis of new ES options introduced since completion of BD2302, including the Uplands stand of the Entry Level Stewardship (ELS) scheme, have been conducted. Management scenarios have been constructed, and a comparison of the current management requirements (Natural England 2010ab) of all ES options with the previous management specifications (Defra, 2005abc) undertaken, differences highlighted, and then incorporated into the new management scenarios.

Defra project BD2302 came under some challenge regarding the coverage of leakage and displacement of agricultural production. It was not envisaged that these issues would be addressed during the process of reviewing and refreshing the data and that the review would adopt the same calculation methodology used in BD2302, to allow a direct comparison of outputs for new and existing ES options. Reference to calculated GHG mitigation or reduction continues to exclude displacement of production (EDP) and this is referenced throughout the report. Although displacement of production has not been quantified, the results are discussed with focus on options where GHG emissions are potentially reduced but not necessarily agricultural production, or where additional GHG reduction benefit may be realised by relocating production elsewhere. Displacement risk (high, moderate and low) has been assigned to each option. The net GHG mitigation (achieved emissions reduction beyond production displacement), sub-divided as Category 1 and Category 2 options where relevant, has been estimated. Category 1 refers to options that reduce emissions without a reduction in productivity i.e. no displacement (e.g. winter cover crops). Category 2 refers to options where productivity is reduced but the equivalent production displacement elsewhere results in a likely net reduction in emissions (e.g. creation of fen on cultivated peat soils where the crop is transferred to mineral soils).

1.1. Project Aims

1. *Review the scenarios (that underpin the ES option calculations) to ensure that they reflect land-use change experienced under ES.*
2. *Review literature that has emerged since BD2302 to ensure that the emission parameters used in the calculations are appropriate*
3. *Calculate revised emission figures for ES options*
4. *Calculate revised emission figures for the ES scheme*

2.0. METHOD

2.1. Scope, boundary and baseline setting and management modifications under ELS, OELS and HLS options.

The previous Life-cycle Assessment (LCA) approach used in BD2302 has been repeated and refined to quantify the net GHG emissions, either positive or negative, under each ES option relative to a baseline typical arable or grassland system defined previously in Warner *et al*. (2008) in conjunction with Defra and Natural England. The original baseline scenarios have been updated and improved as necessary and in response to new data identified in Approach 1 and workshops held with Defra and Natural England Officers. Life Cycle Assessment is an internationally standardised method for the evaluation of all the environmental impacts (both positive and negative) of a product (or a service) throughout its complete life cycle (ISO 14040-43; PAS 2050 (British Standards Institute, 2008)) and has to date been successfully applied to agriculture and horticulture (Defra, 2003; Tzilivakis *et al*., 2005ab; Warner *et al*., 2008, 2010). For the purpose of this project the LCA has focused solely on greenhouse gases however the principles of the analysis will be applied. The alterations in land management associated with each ES option will have firstly, a direct impact on the processes that affect GHG emissions from within the immediate environment i.e. where the ES option is implemented (such as increased emissions of N_2O from the soil). Secondly, they will also have indirect impacts through, for example, the reduction or prohibition of the use of certain agro-chemical products. Each product has GHG emissions (namely CO_2 from the combustion of fossil fuels) associated with their manufacture, packaging and transport and these must also be taken into account. An LCA considers the impacts of the entire system and potential impacts throughout a product’s life, where in this case the product is each ES option.

A typical LCA consists of the following steps:

1. Goal and Scope Definition: describes the application covered, the reasons for carrying out the study, and the target audience. The scope is the detailed technical description of the "product system" under study, in this case the baseline scenario and each ES option.
2. Life Cycle Inventory Analysis: consists of the compilation and quantification of the environmental inputs and outputs for the product system throughout its life cycle. It will include GHG emissions from the manufacture of any products applied, the manufacture of machinery used and the fuel consumed for field operations, changes in N_2O or CH_4 emissions and C sequestration associated with changes in land use and/or management through implementation of ES options.

3. Life Cycle Impact Assessment: to interpret and evaluate the magnitude and significance of the potential environmental impacts of the product system. For each option the overall GWP balance will be calculated and compared with that of the baseline scenario.
4. Interpretation: the conclusions and recommendations are derived from the findings of the life cycle inventory analysis and impact assessment in line with the defined goal and scope. The overall impact of ES options on GHG emissions within England based on national uptake per hectare (ha) and maximum potential impact with assumed optimal uptake of those options with the greatest GHG mitigating properties.

2.2. Inventory of Greenhouse Gas Emissions from fossil fuels, nitrous oxide and methane, and carbon sequestration.

A further review of literature and Decision Support Tools has allowed revision and improvement of the GHG emission factors used in BD2302 and recalculation of changes in the net GHG balance associated with changes in land use and/or management from the implementation of ES option management protocols. The following sections detail where modifications have been made to the method of Warner et al., (2008).

2.2.1. Emissions from the combustion of fossil fuels.

Fossil fuel combustion emits GHG's, mainly CO_2. Fossil fuels power farm machinery for agricultural operations such as soil tillage and agro-chemical application. They are also used for the manufacture of agro-chemicals and farm machinery and for the transportation of such products to the farm. Recent reviews of emissions include fertilisers (Bentrup and Pallière, 2008), farm machinery and depreciation (Warner *et al*., 2010; Williams *et al*., 2009) and fuels (Jackson *et al*., 2009; Defra, 2009). The emission factors have been updated as appropriate for the following areas:

i. Product manufacture (Scope 3 emissions) of pesticides and fertilisers, their packaging, storage and transport (to farm).
ii. Application (spraying or spreading that accounts for weight of product), tillage operations (depending on soil types and depth, derived from regression equations) and drilling (Lewis *et al*., 2010; Warner *et al*., 2010; Williams *et al*., 2009).
iii. Machinery manufacture, based on depreciation per operation (Warner *et al*., 2010; Williams *et al*., 2009).

2.2.2. Emissions from soil

2.2.2.1. N_2O from soil

Nitrous oxide may be emitted from soils where any nitrogen (N) surplus to plant growth requirements are at risk of environmental loss. Pathways include denitrification of nitrate (NO_3^-) to mostly dinitrogen (N_2) if soils are anaerobic, nitrification (oxidation of ammonium (NH_4^+) from decomposing plant biomass to nitrate (NO_3^-)) when aerobic, nitrate (NO_3^-) leaching or ammonia (NH_3) volatilisation (Davidson and Schimel, 1995; IPCC, 2006; Jackson *et al*., 2009; Machefert *et al*., 2002; Oenema *et al*., 2005; Smith and Conen 2004; Smith *et al*., 2008). Emissions of N_2O from soils are further influenced by the incorporation of plant biomass (e.g. crop residues), the presence of legumes (e.g. clover) and crop irrigation (Abberton *et al*., 2008; Smith *et al*., 2008).

The IPCC (2006) methodology to calculate soil N_2O from arable crops was modified (Warner *et al*., 2008) using the nitrogen balance model SUNDIAL (Smith *et al*., 1995) to account for the impact of soil type and annual rainfall on denitrification, nitrification, NO_3^- leaching and NH_3 volatilisation. The same method has been reapplied but with N fertiliser recommendations from the revised RB209 Fertiliser Recommendations (2010). Further simulations with SUNDIAL have been undertaken to account for N removed by winter cover crops before spring cereals. Nitrogen may be lost to the environment from leaching and surface run-off ($FRAC_{LEACH}$), of which 1% forms N_2O (IPCC, 2006; Jackson *et al*., 2009). An increase in the proportion of N that is lost via leaching and surface run-off ($FRAC_{LEACH}$) has been made in the baseline scenarios where soil erosion is a risk. Options that reduce soil erosion and surface run-off (e.g. for maize, within field grass areas, 12 m buffer zones adjacent to watercourses) remove the additional N_2O emissions formed indirectly via the increased surface run-off in the baseline scenario.

The benefit (nutrients) of manures applied to a crop are realised by the crop. Greenhouse gas emissions derived from manure application (but not storage) have been assigned to the crop to which they are applied. This also includes any potential benefit to soil organic carbon (SOC) (section 2.2.4.2.). The IPCC (2006) calculates emissions from livestock manures based on a fixed proportion of that applied to the crop. The proportion available to the crop depends on the timing (more is available if application coincides with active crop growth during the spring) and method of its application (more is available if injected or incorporated into the soil rapidly compared to if surface applied) (RB209, 2010). The greater the availability of N to the crop, the more manufactured inorganic fertiliser N is substituted, and the greater the reduction of NO_3^- leaching and volatilisation of NH_3 (RB209, 2010). The application of manures (as fresh FYM) has been calculated as applied mainly to improved temporary grassland grown for silage in the baseline scenarios. The calculation of N_2O emissions associated with their application has been undertaken with MANNER (Chambers *et al*., 1995). The method adapts the proportion of total N applied within the manure that is leached (Frac$_{(LEACH)}$) and volatilised (Frac$_{(GASM)}$) from the IPCC (2006) methodology with values generated by MANNER (Chambers *et al*., 1999). This approach permits modification of soil and manure type, timing and method of application.

2.2.2.2. CH_4 from soil

The modification to emission factors of CH_4 are restricted to peat soils, specifically where they are rewetted. Those from aerobic mineral soils (Warner *et al*., 2008) remain unchanged. The ES options that involve the flooding of land include the restoration of fen and lowland raised bog, habitats that are located within the Midlands, the East or the North of England. These areas correspond to a cold, moist temperate zone with a default emission factor of 0.53 t CO_2e ha^{-1}year^{-1} (Jackson et al., 2009). Published data on the magnitude of CH_4 emission from peat soils cites water depth, the presence of vascular plants and the time of year as causing an increase in CH_4 emissions (Lindsay, 2010; Tuitilla *et al*., 2000; Worrall *et al*., 2003; 2010). Modifications to management such as rewetting, raises the water depth and influences the vegetation structure (potentially increases the extent of vascular plant coverage). A comprehensive review of related literature by Lindsay (2010) however notes firstly a lack of published evidence on the impact solely of increased water depth (although it is not discounted) and secondly, that elevated CH_4 emissions arise only where there is dominance of vascular plants (e.g. Cotton-grass (*Eriophorum* species) in 'aquatic hollows' between hummocks. The presence of *Sphagnum* in hollows results in negligible emissions. Further, the growth of Cotton-grass in drier areas where open water is absent, also has a tendency to be low i.e. not above emissions expected for wetland habitats (e.g. those cited by Jackson et al., 2009). Tuittilla *et al*. (2000) found that the bulk of CH_4 emissions from bog habitats were derived from Cotton-grass tussocks, and that emissions from *Sphagnum* dominated inter-tussock areas were negligible even where the water levels were deep.

The formation of CH_4 requires the simultaneous presence of three methanotrophic bacteria together with anaerobic conditions (Svensson and Sundh, 1992). Anaerobic conditions exist where waterlogging occurs (flooded soils or waterbodies). Aerobic conditions exist close to the surface at the air interface where the emission of CH_4 is reduced because part of it is oxidised to CO_2 before being emitted to the atmosphere (Lindsay, 2010). Oxidation is enhanced where *Sphagnum* species form mats across the surface slowing the passage of the insoluble CH_4 to the atmosphere and extending the period of time for which it is present within aerobic conditions and its potential to undergo oxidation. Certain vascular plant species (e.g. common cotton grass) permit the transfer of CH_4 from the lower anaerobic peat layers via the plant tissues directly to the atmosphere (the 'methane-shunt') that, as a consequence, limits the potential for oxidation of the CH_4 before it reaches the surface.

The magnitude and duration of elevated CH_4 levels due to rewetting, according to Lindsay (2010), is largely dependent on the pattern of vegetation re-establishment (Table 2.1).

Table 2.1. Revised CH4 emissions from wetland habitats (from Lindsay (2010)).

Land use	**t CO_2 e ha^{-1} $year^{-1}$**
Bog (vascular plant dominated hummock)	0.83
Bog (vascular plant dominated hollow)	3.25
Bog (*Sphagnum* dominated hollow)	*0.44
Bog (non-vegetated hollow)	0.88
Fen	4.75
Wet grassland	0.32

*estimate based on increased potential for CH_4 oxidation before release to the atmosphere

The revised calculations assume:

a) Year 1: formation of non-vegetated aquatic hollows (0.88 t CO_2e ha^{-1} $year^{-1}$) and dominance by Cotton-grass on terrestrial hummocks (0.83 t CO_2e ha^{-1} $year^{-1}$) (75%/25% split respectively).

b) Years 2 and 3: dominance by Cotton-grass in aquatic hollows (3.25 t CO_2e ha^{-1} $year^{-1}$)

c) Years 4 – 5: increased colonisation in aquatic hollows by *Sphagnum* species (0.83 t CO_2e ha^{-1} $year^{-1}$) at the expense of vascular plants.

Prolonged oxidation of peat soils is reported by some authors to remove or severely diminish the capacity of peat to release CH_4 for several years (Kettunen et al., 1999; Tuittila et al., 2000 cited Lindsay, 2010) but this is applicable to cut peatlands, The necessary combination of methanogenic bacteria is removed and takes several years to recover. Methane emissions from fen habitats are cited as greater due to the dominance of vascular plants that act as a methane-shunt in a similar manner to the vascular plants present in the hollows of bogs (Lindsay, 2010) (Table 2.1).

2.2.2.3. CO_2 from soil

The preservation of high C-containing peat soils and the prevention of the loss of that C as CO_2 is identified as a priority GHG mitigation strategy throughout northern Europe (Schils *et al.*, 2008; Smith *et al*., 2008). The loss of CO_2 is dependent on soil depth (a mean of 10.9 and 7.3 t CO_2e ha^{-1} $year^{-1}$ from drained lowland and upland peat soils respectively (Jackson *et al*., 2009)) or cultivation (15.0 t CO_2e ha^{-1} $year^{-1}$ (Freibauer, 2003)). The rewetting or removal of peat soils from cultivation is cited to arrest mineralisation and prevents the further loss of CO_2 (Dawson and Smith, 2007; Ostle *et* *al*., 2009). The rewetting of peat soils creates anaerobic soil conditions where the accumulation of SOC has potential to occur (section 2.2.4.2).

2.2.3. Emissions from livestock

2.2.3.1. N_2O

The benefit of nutrients are realised by the crop to which they are applied, the environmental burden has been assigned to soil N_2O emissions in section 2.2.2.1 where applicable. This section considers direct deposition onto grassland and storage when the animal is not grazed.

Livestock manures contain N. The fate of that N is determined by the form of the manure (grazing deposition, solid FYM or slurry), type of animal (cattle or sheep), the soil conditions to which that N is applied (wet or dry soils, whether actively utilised by growing plants) (RB209, 2010). Where livestock are housed, the deposition onto grass is replaced by a requirement to store manure produced during the housing period. The storage of livestock manures emits N_2O, the quantity of which depends on the method and period of storage, and the N content (specifically the crude protein content) of the diet and the efficiency with which the N is utilised (how closely the protein requirement for animal growth is balanced with total N intake) (Abberton *et al*., 2008; Freibauer, 2003; Jackson *et al*., 2009; Moorby *et al.*, 2007; Williams *et al*., 2009). Any deficit between total crude protein intake and the protein requirement for growth and body maintenance will be subject to excretion. Different feeds contain higher proportions of crude protein relative to their metabolisable energy (ME) content (Thomas, 2004). A greater proportion of feeds with higher crude protein results in a greater deposition of N. At lower stocking rates the reduced rate of N per ha applied as grazing deposition decreases the risk of N deposition to one localised area. Livestock may have a tendency to prefer particular areas of a field (e.g. near gateways or feeders) and such areas will receive greater quantities of N, often on poached and compacted topsoils with negligible grass growth. Where plant biomass with which to utilise the deposited N is absent, coupled with saturated soils and greater rainfall, it has a greater potential for environmental loss. This may be either as leaching or, because of the prevalence of anaerobic soil conditions and waterlogging, denitrification. A reduction in stocking rates or, where stocking rates are high, removal of stock during the winter, decreases N deposition onto wet soils and the risk of environmental N loss (ADAS, 2007), particularly from leaching and denitrification. Default annual N excretion values for individual livestock types have been cited from the Nitrate Vulnerable Zone (NVZ) Guidelines leaflet 3 (Defra, 2009). The total N from livestock per ha in the baseline scenarios has been adjusted to comply with Nitrate Vulnerable Zone rules (Defra, 2009) of a maximum of 170 kg N ha^{-1} farm limit and 250 kg N ha^{-1} field limit (Section

3.1). Stocking rates have been formulated in reference to the NVZ Guidelines Leaflet 3 (Defra, 2008), HLS Handbook (Natural England, 2008a) and RB209 (2010). Manure N is allocated as either deposition onto grass or FYM (in unconfined piles or stacks or composted in vessel with forced aeration and continuous mixing) (IPCC, 2006) for the given percentage of N excreted assigned to each category. The N_2O emissions have been calculated for stocking rates and N deposition rates specified in the NVZ Guidelines.

The N not utilised by the animal increases the quantity of N within the manure. For each kg of N excreted within the manure, the proportion that is emitted as N_2O is dependent on the soil conditions onto which they are deposited and the method of manure storage. When stored as solid manures, the presence of straw aerates manures sufficiently to allow both aerobic and anaerobic micro-sites to co-exist, allowing both nitrification and denitrification (Groenestein and Van Faassen, 1996; Monteny *et al*., 2006). The maintenance of completely anaerobic conditions within manures inhibits both pathways (Monteny *et al*., 2006). The improved temporary grassland baseline scenario (section 3.1.2) grazed by dairy cows has been replaced by intensive beef cattle. Manure management during housing is 100% solid FYM stored in unconfined piles or stacks. The liquid slurry based system used previously for the dairy cow scenario had lower N_2O emissions due to the increased probability that nitrification of ammonium (NH_4^+-N) to NO_3^- during storage was inhibited, denitrification of NO_3^- (and formation of N_2O) cannot proceed in the bulk of the liquid. Aerobic conditions and the potential to emit N_2O are restricted to the slurry-air interface of the liquid surface (Schils *et al*., 2008). The organic baseline scenarios compost the manure (Williams *et al*., 2009).

The second potential route for loss of N_2O is the deposition of N directly onto soils. As described previously for manures, the N within deposition is vulnerable to environmental loss, the magnitude of which is influenced by the time of year, soil conditions (water content) and soil type. DeVries *et al*. (2003) cite the proportion of N applied to organic soils that is denitrified as being double that of N applied to mineral soils. The IPCC (2006) provide a mean annual default emission factor for deposition onto grassland that differentiates between deposition in northern (Jackson *et al*., 2009) and southern Europe. In northern Europe an emission factor for leaching due to increased rainfall is included. It does not account for differences in soil type. The decision support tool MANNER allows calculation of the $Frac_{LEACH}$ monthly. Simulations with MANNER have been used to calculate the proportion of N leached where livestock are grazed for 12 months (no housing), 11 months (1 month housing of sheep during December) and 7 months (5 months housing for cattle December - April).

The deposition of N onto wet ground (for example water meadow) where anaerobic soil conditions prevail potentially increases the risk of denitrification and increased N_2O emission. Denitrification is a microbial process that is also temperature dependent, the presence of N in saturated wet soils during the spring as soil temperatures increase represents the period most vulnerable to elevated N_2O emissions (Smith *et al*., 1996). The IPCC (2006) and UK GHG Inventory (Jackson *et al*., 2009) use default annual denitrification N_2O values for deposition that do not account for seasonal changes to soil conditions and soil type. It does not permit differentiation of deposition onto predominantly unsaturated soils during lower rainfall periods where livestock are, for example, housed during the winter or where stock remain outside but are moved from areas dominated by organic soils (e.g. above the moorland line) to areas dominated by mineral soils (e.g. semi-improved grassland on naturally well drained soils below the moorland line). According to DeVries *et al*. (2003) the proportion of N that is denitrified in response to the application of N to wet organic soils is double to that from mineral soils. The IPCC (2006) methodology has been adapted specifically for organic soils that may be periodically wet during the year so that the proportion of N emitted as N_2O from denitrification due to deposition by livestock is double that of mineral soils (DeVries *et al*., 2003). The removal of sheep during the winter assumes does not necessarily assume that the stock are housed, they may be relocated onto fields where waterlogging does not occur and mineral soils are more prevalent (Table 2.1).

Table 2.2. N_2O-N emission (kg) per kg N deposited. The default value represents that originally used in BD2302.

Animal type	**Period of grazing (months)**	**Mineral soil**	**Organic soil**
Default (all types)		0.020	
Cattle (dairy, non-dairy	12 11 (housed December) 7 (housed December – April)	0.024 0.022 0.014	0.044 0.040 0.025
Sheep	12 11 (housed December) 7 (housed December – April)	0.014 0.013 0.008	0.024 0.022 0.014

A greater proportion of deposition N will be leached where livestock are grazed during the winter months. The IPCC (2006) assumes that a default 30% of N excreted is leached ($Frac_{LEACH}$). Where livestock are housed during the winter, an element of control is introduced and the majority of excreted N, if appropriately stored, will not be vulnerable to leaching. The $Frac_{LEACH}$ of deposition N has been reduced where stock are housed throughout the winter.

2.2.3.2. CH_4

Enteric fermentation is the main route by which CH_4 is produced from ruminant livestock is (Jackson et al., 2009). The type of animal and constituents of its diet (specifically the rate at which the animal is able to digest the feed) are the main factors related to the quantity of CH_4 produced (Abberton *et al*., 2008; Freibauer *et al*., 2003; Moorby *et al*., 2007; Smith *et al*., 2008). Slow digestion (low feed digestibility such as fibrous material contained in forage crops or straw) produces greater volumes of CH_4 (Duncan, 2008). Concentrates (cereal and maize grain) are classed as readily digestible feeds and produce lower volumes of CH_4 per kg of feed and per MJ of dietary energy intake (Beauchemin *et al*., 2008; Johnson and Johnson, 1995; Lovett *et al*., 2006; Mills *et al*., 2003; Smith *et al*., 2008a; Yan *et al*., 2000). The method used by Warner et al. (2008) has been modified based on the proportion of forage versus concentrates contained in the diet (Williams *et al*. 2009) to allow calculation of enteric CH_4 from livestock in response to alterations to the diet (for example replacement of silage with concentrates where the supplementary feeding of silage is prohibited). The dietary composition (total metabolisable energy requirement, quantity of concentrates, grass silage and grazing) have been derived from RB209 (2010) and Williams *et al*. (2009).

Methane is emitted from manures, the magnitude of which is dependent on the method of storage, storage temperature, source (animal type) and constituent of the diet (quantity of volatile solids within the feed) (IPCC, 2006; Monteny *et al*., 2006; Sommer *et al*., 2007). Methane production occurs where decomposition occurs under anaerobic conditions. The storage of manure as liquid slurry produces greater volumes of CH_4 compared to solid systems because of the prevalence of anaerobic conditions (Monteny, 2006). Storage at lower temperatures, below 15°C in particular, decreases the rate of CH_4 production (IPCC, 2006; Monteny, 2006) as does the covering of lagoons (Paustian *et al*., 2004). The method to calculate CH_4 from manures produced during housing accounts for the dietary composition (RB209, 2010; Williams *et al*., 2009), specifically the volatile solids per kg of dry matter of feed consumed which have been derived from Thomas (2004) in addition to storage method and storage temperature (IPCC, 2006). Manures produced within the baseline scenarios consist of FYM stored in unconfined piles or stacks at a mean temperature of less than 10°C, or composted in vessel with forced aeration and continuous mixing (assumed stored during the winter for application during the spring, the majority of the temperature below 10°C).

2.2.4. Carbon storage potential of land (sequestration)

2.2.4.1. Carbon storage potential of soil in England under different types of management

Soils contain C in the form of soil organic carbon (SOC). Different land uses have different quantities of SOC when at equilibrium, determined by the frequency of cultivation, soil water content (periodic or permanent flooding), presence of small particulate soils (clay soils), low pH (that inhibits microbial decomposition of organic matter to CO_2) and rate of return of organic matter from dead plant biomass (plant roots, leaves). The SOC baselines have been revised to include different land management categories based on soil type (Dyson *et al*., 2009) (Table 2.3).

Table 2.3. Mean SOC (t CO_2e) to a depth of 30 cm on mineral, organo-mineral, organic soils (Dyson et al., 2009).

Land use	**Organic**	**Organo-mineral**	**Mineral**	**Bradley *et al*., 2005**
Cultivated land	623.3	429.0	282.3	256.7
Grassland	729.7	634.3	352.0	293.3
Forest	839.7	447.3	392.3	366.7

The mean SOC figures cited by Bradley *et al*. (2005) were used previously. A distinction is made between grassland and cultivated land on mineral, organo-mineral or organic soils. Organo-mineral soils are typically present where periodic flooding permits the formation of an organic layer up to 40 cm deep above a mineral soil base layer. This may be where the groundwater is just below the soil surface and a small rise in water level submerges the land (groundwater gley soil) or where a impermeable clay layer prevents drainage maintain wet conditions for a proportion of the year (surface water gley soil). Habitats present on organo-mineral soils include periodically flooded grasslands (e.g. water meadow), wet heathland and moorlands. Cultivated land is subject to frequent disturbance and the baseline SOC is reported by several authors as being lower than other land uses (Bradley *et al*., 2005; Dyson *et al*., 2009; Smith *et al*., 2008). Temporary grassland is also cultivated but not as frequently. The baseline soil organic carbon (SOC) for temporary grassland has been revised using a combination of data for mineral soils from Dyson *et al*. (2009) and the Countryside Survey (2007) (Carey *et al*. 2008). A distinction exists between grassland that is actively managed as pasture, or semi-natural or natural grassland (semi-natural habitat). Pasture as defined by the Countryside Survey and Monitoring Landscape Change (MLC) classification includes improved managed grass where the improvement is often (but not always) ploughing and seeding (Cruickshank *et al*., 1998; Milne & Brown., 1997). Carey *et al*. (2008) identify SOC in neutral grassland and improved grassland in England (to a depth of 15 cm) as differing by a factor of 1.01. The revision of the scenario for temporary grassland cites the SOC values for non-ploughed grassland on mineral soils given by Dyson *et al*. (2009) in the top 30 cm, reduced by a factor of 1.01 as an estimate for temporary grassland. Organo-mineral soils (<40 cm organic surface layer) are subject to periodic flooding and are present in habitats such as marshy grassland (e.g. water meadows) and dwarf shrub communities (heathland). Deep peat soils (>40 cm organic layer) form in permanently wet areas and include bogs and fens.

2.2.4.2. Changes in SOC

SOC accumulation factors have been revised in response to recent publications (Dawson and Smith, 2007; Louwagie *et al*., 2008; Ostle *et al*., 2009; Schils *et al*., 2008) (Table 2.4).

Table 2.4. SOC accumulation (to 30 cm) from a change in land use.

Original land use	**New land use**	**t CO_2e ha^{-1} year^{-1}**
Cultivated	Temporary grassland	1.28
	Fertilised permanent grassland	4.40
	Sown unfertilised grassland	3.67
	Sown unfertilised grass margins	3.67
	Natural reversion	1.65
	Hedgerow	3.48
	Scrub	3.48
	Broadleaved woodland / tree strips	3.30
	Conifer woodland	3.30
Temporary grassland	Permanent grassland	0.73
	Permanent grassland (shaded areas)	0.37
	Unfertilised grass margins	0.73
	Hedgerow	0.55
	Scrub	0.55
	Broadleaved woodland / tree strips	0.37
	Conifer woodland	0.37
	Marshy grassland	2.93
Fertilised permanent grassland	Hedgerow	0.29
	Increased grass species richness	0.29
	Broadleaved woodland / tree strips	0.29
Unfertilised grassland	Marshy grassland	2.93
Peatlands	UK peatlands — natural accumulation	0.73

The values displayed in Table 2.4 are mean accumulation values for the duration of the period studied. Smith et al. (2000) derive regression equations for one sample site that increases the rate of SOC in response to the presence of increased SOC. These values have been modified with annual accumulation rates that account for a broader range of sample sites and more recent studies (Dawson et al., 2007; Ostle et al., 2009). The slow rate of C accumulation and necessity for monitoring over several decades renders it impractical to monitor SOC on an annual basis and measurements are frequently taken at intervals of five or 10 years. A linear approach (IPCC, 2006) where land use specific times to equilibrium are calculated based on a known baseline SOC and known potential SOC at equilibrium for the new land management practice or use at a known fixed annual rate of SOC accumulation (e.g. those in Table 2.3) has been undertaken. This is summarised in Equation 1.

Equation 1.

$$T = (SOCeqb_{(new)} - SOCeqb_{(baseline)}) / R(SOC)$$

where: T = Time to establish new SOC equilibrium

$SOCeqb_{(new)}$ = *potential SOC at equilibrium (t CO_2e ha^{-1}) of the new land use*

$SOCeqb_{(baseline)}$ = *SOC at equilibrium (t CO_2e ha^{-1}) of the baseline scenario (current land use)*

$R_{(SOC)}$ = *SOC accumulation rate (t CO_2e ha^{-1} $year^{-1}$) for a given change in land management*

As discussed in sections 2.2.2.2 and 2.2.2.3 the C balance for peat restoration is dictated by the emission of CO_2 and CH_4, it is also a result of losses of Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC). Studies such as Worrall et al. (2003) examine the C balance in detail although it is restricted to a single sample site. More generic figures of the net C balance (all gains and losses inclusive) are provided by Dawson and Smith (2007) and Ostle et al. (2009). Where restoration permits accumulation of SOC (a net gain in C once all C inputs and outputs are accounted) the net C gain UK peatlands is cited as between 0.73 and 1.83 t CO_2e ha^{-1} $year^{-1}$ (Dawson and Smith, 2007) but more typically as 0.7 t CO_2e ha^{-1} $year^{-1}$ by Lindsay (2010). The lower value cited by Dawson and Smith (2007) and that of Lindsay (2010) corroborate one another closely and have been used in the calculations. Dawson and Smith (2007) also cite SOC accumulation where wetland habitats are created to vary between 2.93 and 14.3 ha^{-1} $year^{-1}$. The periodic wetting of dry permanent grassland at equilibrium offers potential to form organo-mineral soils and accumulate further SOC at equilibrium. Productive grassland such as water meadow has a greater rate of biomass growth and return of organic matter to the soil than habitats such as upland moorland. The accumulation of SOC proceeds at a greater rate in such habitats (2.93 t CO_2 e ha^{-1} $year^{-1}$) (Table 2.3).

The compaction of topsoils may reduce biomass accumulation and the return of organic matter to the soil by up to 13% (Louwagie *et al.*, 2008). Baselines where compacted soils are present have been calculated to have a rate of SOC accumulation (Table 2.3) reduced by 13%. Options where management that causes compaction (e.g. high stocking rates) are removed permit the further accumulation of SOC. The SOC contained within eroded soils has also been accounted for in order to account for the potential impact of selected soil protection options (section 3.2). Of the mean 0.22 t soil ha^{-1} lost as soil erosion (Dawson and Smith, 2007; Ostle *et al.*, 2009) a mean 5% is assumed as SOC (Bell and Worrall, 2010) and converted to CO_2e for use in calculation of the GHG balance where soil erosion is mitigated. It is acknowledged that the fate of C within eroded soil may result in its deposition within a watercourse and anaerobic conditions where oxidation will not occur. On cultivated land, this is countered by the equivalent amount that will now be exposed to disturbance by tillage where previously it would have remained below the depth of cultivation. The loss of C from soil erosion has therefore been designated as a loss.

2.2.4.3. Carbon storage potential above ground

A recent review of the mean C sequestration in woodland tree biomass within the UK (Ostle *et al.*, 2009) cites 140.0 t C ha^{-1} (513.3 t CO_2e ha^{-1}). The biomass C in scrub and hedges has been calculated as 1.0 t C per 0.1 m in height for a vertical stem (Falloon et al., 2004). A hedgerow 1.5 m in height contains 15.0 t C ha^{-1}.

2.2.4.4. Changes in biomass carbon

The accumulation of biomass C in hedgerows proceeds at 0.1 m per year (Falloon *et al.*, 2004). A newly planted hedge requires 15 years to reach an equilibrium with a mean height of 1.5 m. This rate of biomass growth is also calculated for scrub for which the period to reach equilibrium has been extended to 15 years for a mean height of 1.5 m at equilibrium.

2.2.5. Ammonia

A mean 1.0% of the NH_3 volatilised forms N_2O-N (Jackson *et al.*, 2009) therefore the impact of management change on NH_3 also requires consideration. The volatilisation of NH_3 is an issue of relevance mainly to liquid manure management where for example, surface application of slurry is made to grassland during the summer in combination with warm air temperatures (Chambers *et al.*, 1999) or anaerobic lagoons that are not covered. The baseline scenarios no longer include the use of slurry as a method of manure storage however it is included in the IPCC (2006) emission factors for each storage method considered.

2.2.6. Impact assessment

For each baseline land management scenario and ES options not eliminated during the scoping phase a GHG $balance_{(EDP)}$ has been calculated as t CO_2e $ha^{-1}year^{-1}$ to standardise all GHG emissions (IPCC, 2006; Jackson *et al*., 2009) minus the C sequestered relative to the specified baseline conditions for each option defined in section 2.3 (Equation 2).

Equation 2.

$$GHGbalance_{(EDP)} = (m + d + i + Ns + Gs + Cs + Nl + Gf + Gl) - (Seq_{(SOC)} + Seq_{(AGC)})$$

Where:

$GHGbalance_{(EDP)}$ = GHG balance, excluding displaced production, during year n (t CO_2 e ha^{-1} $year^{-1}$)

m = indirect emissions from the manufacture of agro-chemicals (fertilisers, pesticides)
d = direct emissions from the operation of machinery (application of agro-chemicals, tillage operations, harvest, drying)
i = indirect emissions associated with the manufacture of machinery taking account of machinery depreciation

Ns = emission of N_2O from soils
Gs = emission of CH_4 from soils
Cs = emission of CO_2 from soil
Nl = emission of N_2O from manures
Gf = emission of CH_4 from enteric fermentation
Gl = emission of CH_4 from manures

$Seq_{(SOC)}$ = C sequestered in soil during year n

$Seq_{(AGC)}$ = C sequestered in plant biomass during year n

The total CO_2e emissions (t CO_2e $ha^{-1} year^{-1}$) and the net direction (positive or negative) to the atmosphere for each ES option evaluated relative to the baseline set of conditions for a has then been calculated for a mean 5 years (Equation 3).

Equation 3.

$$dGHG_{flux} = GHGbalance_{(EDP)}option_{(n)} - GHGbalance_{(EDP)}baseline$$

where

$dGHG\ flux$ = change in net GHG balance$_{(EDP)}$ during year n (years 1 to 5)

$GHGbalance_{(EDP)}option_{(n)}$ = net GHG balance$_{(EDP)}$ of the option during year n (years 1 to 5)

$GHGbalance_{(EDP)}baseline$ = net GHG balance of the baseline scenario

The net change relative to the baseline (t CO_2e ha^{-1} $year^{-1}$) is equal to the CO_2e of the ES scenario minus the annual gain in SOC and biomass C for the specified year as a result of the management change minus the GHG emissions from the original baseline scenario.

2.2.7. Mitigation category

The calculation of GHG emission reduction excludes the impact of displaced production. The net GHG mitigation (achieved emissions reduction beyond production displacement), sub-divided as Category 1 and Category 2 options where relevant, has been estimated. Category 1 refers to options that reduce emissions without a reduction in productivity i.e. no displacement (e.g. winter cover crops). Category 2 refers to options where productivity is reduced but the equivalent production displacement elsewhere results in a likely net reduction in emissions (e.g. creation of fen on cultivated peat soils where the crop is transferred to mineral soils).

3.0. RESULTS

3.1. Revision of baseline scenarios and allocation to options

The effect of changes in land use and management from implementation of ES agreements on the GHG balance is quantified by comparison with the original land use (baseline). The baseline states all processes and includes application of crop protection products (product, active ingredient and application rate/ha), fertilisers (product, nutrient composition and rate ha^{-1}) and field operations (type of implement, depth of operation) (Defra, 2003; Lewis *et al*., 2010; Tzilivakis *et al*., 2005ab; Warner *et al*., 2008, 2010). It also takes account of environmental factors such as soil type and rainfall that may impact on loss of N to de-nitrification and N_2O emissions. The baseline scenarios (Warner *et al*., 2008) have been modified in response to more recent published literature and in consultation with Natural England officers. In particular, amendments have been made to baselines so that they are representative of land where the option will be implemented, rather than land typical of production as a whole as was the rationale used previously. The impact of changes to the baseline and option management on the net GHG balance$_{(EDP)}$ are described in the following sections.

3.1.1. Cultivated land

Options on cultivated land are applicable to mainly lowland areas. The scenarios on cultivated land have been revised in response to the updating of the Fertiliser Recommendations (RB209) and the withdrawal of certain pesticide active ingredients. A new set of simulations using SUNDIAL (Smith *et al*., 1996) to calculate soil N_2O emissions have been undertaken as necessary. Application of N fertiliser was simulated in the original baselines to coincide with optimal timing (split dressings during spring) and the new simulations where a maximum of 10 kg N ha^{-1} have been reduced from later applications (late April) have made negligible impact on the soil N_2O emissions for the relevant cultivated crop baselines. The creation of an additional scenario to represent cultivated land subject to soil erosion includes CO_2e emissions from SOC removed in surface run-off and increased indirect N_2O emissions (Figure 1). The baseline management of the scenario is the same as for non-eroded cultivated land, it differs in field topography. Implementation of an option with this scenario (for example selected soil protection options) removes the additional emissions associated with erosion.

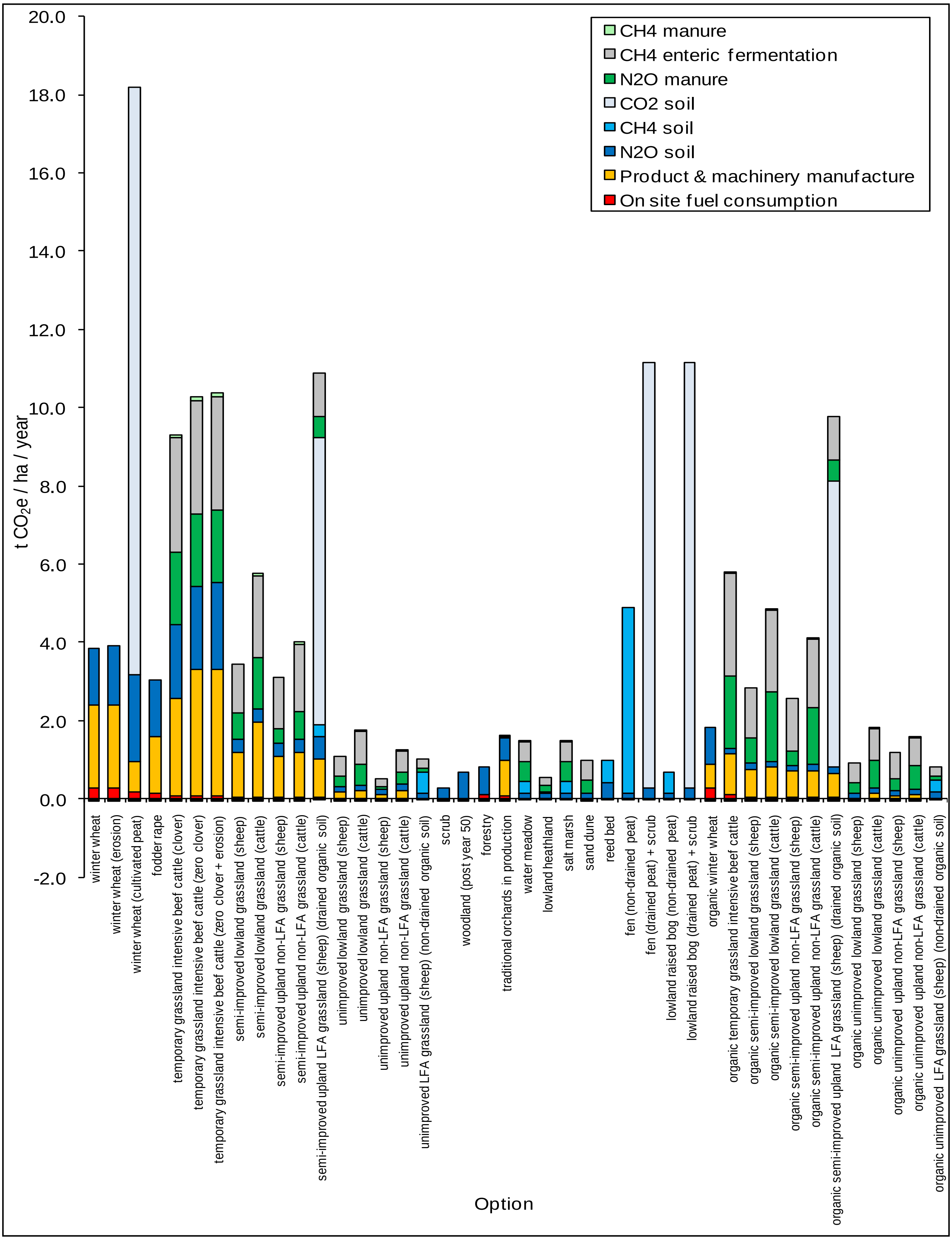

Figure 1. The GHG emissions (t CO_2e ha^{-1} $year^{-1}$) for each baseline scenario at equilibrium (no further accumulation of SOC or biomass C).

Certain options previously assumed implemented solely on cultivated land, for example option EC4, are deemed likely to be implemented on both cultivated land and permanent grassland. Where applicable, the impact per ha of option for both baselines has been calculated and ranked within the summary GHG balance$_{(EDP)}$ tables. Extrapolation to UK emissions as a whole by option area uptake (section 3.2.6) then calculates 50% as implemented on cultivated land and 50% on semi-improved grassland. Due to the high points total of 380, a proportional reduction in livestock has been calculated for the semi-improved grassland baseline scenario. The decrease in emissions during the initial five year period is smaller on permanent grassland as zero accumulation of additional SOC results. The hedgerow management options (EB1 – EB10) previously assumed with a 1.5 m width margin implemented on cultivated land (winter wheat baseline) have been amended to an existing hedgerow baseline and function as a maintenance option i.e the no cultivation to within two metres of the hedge centre (as per Cross Compliance requirements (Defra 2006, 2007)).

3.1.2. Temporary grassland

A generic baseline scenario has been constructed that aims to be applicable to the majority of land use where options relevant to temporary grassland are most likely to be implemented. These options are mainly on lowland grassland, although small areas of temporary grassland cut for silage in upland areas have also been entered into agreements. It is unlikely that high grade grassland for dairy production would be entered into agreements. The baseline has therefore been revised from temporary grassland grazed by dairy cattle to temporary grassland grazed by intensive beef cattle (TGIBC). The scenario is now complicit with NVZ rules that has required a reduction in stocking rates (LU ha^{-1}) in comparison to the previous dairy cattle scenario. The quantity of N excreted and associated emissions (Table 2.2) is therefore also lower. Enteric fermentation and the emission of CH_4 is lower from beef cattle per LU compared to dairy cows (IPCC, 2006; Williams *et al*., 2009) and this reduction is now coupled with a reduction in stocking rates. Emissions are lower overall for the TGIBC scenario however the dairy cattle scenario assumed clover was present within the sward. Three TGIBC scenarios have been created to reflect potential differences in inorganic N application rate on which the options applicable to temporary grassland may be implemented. Firstly, a scenario with up to 30% clover cover establishment. It is supplemented with a mean inorganic N application rate of 100 kg N ha^{-1} applied as a 50/50 split during spring and autumn to prevent the inhibition of N fixation by clover when temperatures increase (British Survey of Fertiliser Practice, 2010; RB209, 2010). A second scenario has negligible clover establishment and the majority of the recommended 210 kg N ha^{-1} (RB209, 2010) is supplied by manufactured inorganic N. The third TGIBC scenario does not have clover present and is subject to soil erosion and additional indirect N_2O emissions from run-off. Both baselines without clover apply 210 kg N ha^{-1} as inorganic N and are relevant to options on grassland where a minimum inorganic N application rate is required (grass buffer strips or the prevention of erosion or run-off from intensively managed grassland where a minimum of 100 and 200 kg N ha^{-1} respectively is stipulated). They are not necessarily representative of intensive grassland as a whole, rather intensive grassland on which specific options will be implemented. The GHG emissions associated with inorganic N application have increased in the two scenarios where a full rate of N is applied.

Table 3.1 lists options previously assigned temporary grassland baselines. They have been revised in response to the creation of three temporary grassland baselines, stipulation to be implemented on permanent grassland by the Management Handbook (2008) (option EE7 buffer zones around ponds) or identified as in need of revision to a permanent grassland baseline by Natural England experts. It was identified that buffer strips on grassland (options EE4 – 6) could be applicable to permanent grassland however the minimum stipulated N application rate of 100 kg N ha^{-1} was deemed more likely on temporary grassland.

Table 3.1. Revision of options previously assigned temporary grassland baselines.

Option	**Revised baseline**
EC / HC2 - Protection of in-field trees (grassland)	Semi-improved permanent
ED / HD5 - Archaeological features on grassland	Semi-improved permanent
EE / HE 4-6 - 2m buffer strips on intensive grassland	Temporary grassland
EE / HE7 - Buffering in-field ponds in improved grassland	Semi-improved permanent
EG / HG2 - Wild bird seed mixture in grassland areas	Temporary grassland (with clover)
EG3 / HG3 - Pollen and nectar seed mixtures in grassland areas	Temporary grassland (with clover)
EK1 / HK1 - Take field corners out of management	50% temporary grassland (with clover) / 50% semi-improved permanent grassland
HC6 - Ancient trees in intensively-managed grass fields	Semi-improved permanent
HE11 - Enhanced strips for target species on intensive grassland	Temporary grassland (with clover)
HJ6 - Preventing erosion or run-off from intensively managed grassland	Temporary grassland (erosion)
HJ7 - Seasonal livestock removal from intensively managed grassland	Temporary grassland (with clover)

3.1.3. Permanent semi-improved grassland

Permanent semi-improved grassland in lowland and upland areas (inside or outside Less Favoured Areas (LFAs)) includes grassland in receipt of inorganic fertilisers, lime and herbicide. Lowland semi-improved grassland has higher grass yields (higher productivity at lower altitudes) and is grazed by sheep with a greater body mass (higher livestock units per animal). The majority of grassland outside the LFA is classified within this category (*M. Edwards pers comm.*). Fertile grasslands subject to improvement such as periodically flooded water meadow and grasslands on organic soils where drainage has been undertaken are included within this category pre-entry into ES agreements. The main amendments to the semi-improved grassland scenarios have been a reduction in stocking rates. The SOC has been adjusted to incorporate values described by Dyson *et al*. (2009) for permanent grassland and now differentiates between grassland present of mineral, organo-mineral (where soils are periodically wet e.g. water meadow) and organic (drained formerly permanently wet) soils. An additional scenario to account for permanent grassland that may be cut for silage (lowland and upland) assumes livestock are removed in May (two months before the cut is taken) and then returned in late August. The number of cuts taken is fewer with an estimated 10% decrease in silage grass yield compared to temporary grassland. The manures produced during animal housing are applied as priority to any temporary grassland cut for silage on the farm (or to permanent grassland cut for silage as applicable). The semi-improved upland grassland grazed by cattle baseline scenario for options EL1 – EL4 has been replaced with semi-improved upland grassland within the LFA grazed by sheep.

3.1.4. Permanent unimproved grassland

Permanent unimproved grazing land does not receive NPK fertiliser but may be subject to occasional liming outside of LFA areas. Upon entry into ES agreements liming will cease. Unimproved grassland is present on both lowland and upland farms and additional scenarios have been created to differentiate baselines:

a) Outside LFA areas (upland and lowland)
b) Inside LFA areas (SDAs or very SDAs)
c) On mineral soils
d) On organo-mineral (<40 cm organic surface layer) soils (e.g. periodically flooded marshy grassland)
e) On deep (>40 cm organic surface layer) peat soils (drained or non-drained)

The SOC equilibrium for permanent grassland on mineral, organo-mineral or organic soils is described by Dyson *et al*. (2009) and assigned to each scenario as appropriate (Table 2.2).

3.1.5. HLS habitats

The following sections summarise amendments to the HLS specialist habitat baselines. Most modifications relate to stocking rate and the SOC equilibrium.

3.1.5.1. Wet grassland (HK9 – HK14)

Options on grassland (HK6 – HK19) are implemented both inside and outside the LFA albeit mainly outside on lowland grasslands. Two baseline scenarios have been applied (inside or outside the LFA) where the area within either classification on which an option is implemented is above 100 ha. Options that maintain or restore wet grassland

(HK9 – HK14) are located mainly outside the SDA (less than 50 ha within the SDA for most). The lowland cattle baseline scenarios remain unchanged. Wet grassland subject to period flooding uses an organo-mineral soil SOC equilibrium (Table 2.2).

3.1.5.2. Lowland Heathland (LH) (options HO1 – HO5)

Lowland heathlands are typically present on sandy soils where continued leaching of nutrients results in podsolisation (nutrient poor soils) (Catt, 2010). This restricts the growth of many plant species and, as a result, the return of plant biomass to the soil as organic matter proceeds slowly. A low soil pH prevents microbial decomposition of this plant biomass and allows the formation of a shallow organic layer on top of underlying sand soil (Plate 1a).

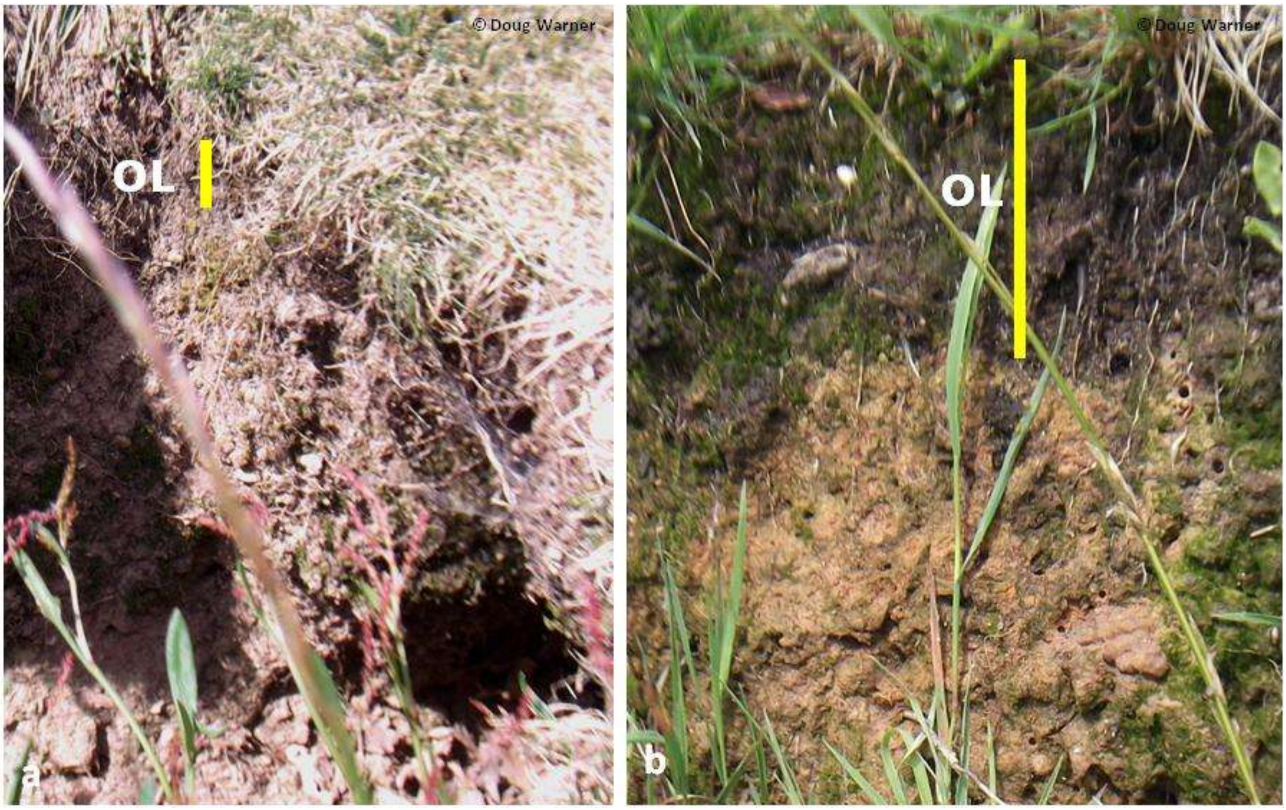

Plate 1. Soil profile of (a) dry and (b) wet lowland heathland. OL = Organic Layer.

This thin organic layer may be rich in SOC in contrast to the sand layer immediately beneath. Deeper organic layers within an organo-mineral soil exist where groundwater situated immediately below the soil profile periodically floods areas (groundwater gley soils) to form wet heathland (Plate 1b). Wet heathland is present on very low lying areas. Two lowland heathland baselines have been created to reflect implementation of options HO2, HO3 and HO4 on either dry heathland or wet heathland. Areas of wet heathland may be limited to a small proportion of the designated lowland heathland area. The calculations have assumed 20% of restored lowland heathland as being wet heathland.

3.1.5.3. Fen (F) (options HQ7 – HQ8)

The vegetation structure of the fen habitat has been modified to 5% standing water and 95% sedge, purple moor grass, reed, or sweet-grass dominated vegetation cover. They are grazed with sheep at 0.05 LU for 3 months from June – August. Stock are introduced from existing flocks with no net proportional increase in stocking numbers (no net gain in emissions from livestock due to fen restoration management).

3.1.5.4. Reedbeds (RB) (options HQ4 – HQ6)

Self *et al*. (1996) identify two distinct reed-dominated habitats. Firstly, reed swamp that is flooded all year and is mainly common reed. Secondly, reed fen where a permanent high water table exists but flooding is periodic. Where permanently flooded there is potential for the formation of deep organic soils. Periodic flooding may result in organo-mineral soils. The baseline assumes 50% of each habitat type.

3.1.5.5. Rough Grazing (RG) (options HL7 – HL8) and Sand Dunes (SD) (options HP1 – HP4).

Both baselines are of limited productivity and grazed by sheep at 0.1 LU ha^{-1} all year with no further inputs. Rough grazing includes bracken dominated areas with additional biomass C. Sand dunes have limited SOC and potential for its accumulation.

3.1.5.6. Salt Marsh (SM) (options HP5 – HP9).

Salt marsh is periodically flooded wet grassland grazed by sheep at 0.1 LU ha^{-1} all year with no other inputs. The livestock are not removed for any additional period during the winter compared to the baseline unless in combination with supplement HJ7 (Seasonal livestock removal on grassland).

3.1.5.7. Water Meadow (WM) (options HD10 – HD11).

Water meadows are typically productive grassland. The SOC equilibrium has been revised to organo-mineral, characteristic of periodically flooded habitats such as ‘marshy grassland’ (Carey *et al*., 2008; Dyson *et al*., 2009).

3.1.5.8. Hedgerow ($H_{(1.5m)}$ vertical stem) (options EB1 – EB10)

The creation of a baseline hedgerow scenario replaces the original 75% cultivated area. It assumes a mean height of 1.5 m vertical stems managed by mechanical flailing with a non-cultivated grass area 2 m either side of the hedge centre (Defra 2006, 2007). Options that potentially increase the height of the hedge (e.g. specify a minimum of 2.0 m) or the laying of stems (option UB14) at an angle (e.g. at 35° for a ‘Midland Bullock’ style increases the length of the stem to 2.6 m while maintaining an overall vertical height of 1.5 m) increase the biomass C content relative to a baseline 1.5 m vertical stem. A hedge with gaps contains 50% of the potential total hedge biomass.

3.1.5.9. Grazed Woodland (GW) (option HC8).

A grazed woodland scenario has been created to account for woodland where the presence of livestock may be 'accidental' (they have not been deliberately introduced) or deliberate if the woodland is grazed during the winter in upland areas. The baseline stocking rate for grazed woodland has been assigned as 0.08 LU ha^{-1} with 80% of the tree area at maturity (equilibrium) and the remaining 20% restricted by grazing.

3.2. Climate change mitigation$_{(EDP)}$ per unit of option per year

Management scenarios for land within each ELS, OELS and HLS ES option have been constructed using the same method as for the baseline scenarios. A comprehensive review of each option has been undertaken in consultation with Natural England. The management specifications of the 2005 Handbooks (Defra 2005abc) have been compared with those stated in the 2010 handbooks (Natural England 2010abc). Any differences in management with potential to impact the GHG balance are described in Appendix tables A1 and A2. Most changes are relatively subtle, for example reinforcement of Cross Compliance requirements not to cause compaction or poaching of soils, or risk pollution of watercourses. Some now specify a particular baseline e.g. EE7 (Buffering in-field ponds in improved permanent grassland) where previously it stated 'grassland' and had been calculated using a temporary grassland baseline. The temporary grassland baseline for this scenario has been amended to permanent grassland (section 3.1.2). Although the reduction in GHG emissions from implementation of the option is smaller, it is not the management of the option itself that has changed but the baseline.

3.2.1. Entry Level Scheme

3.2.1.1. Revision of management and baseline scenario

This section describes options where the baseline has been modified or because the stipulated management of the option itself has been modified. Selected current ELS options including new options and Upland ELS options per ha of option are displayed in Figure 2. All ELS options are ranked in Table 3.2.

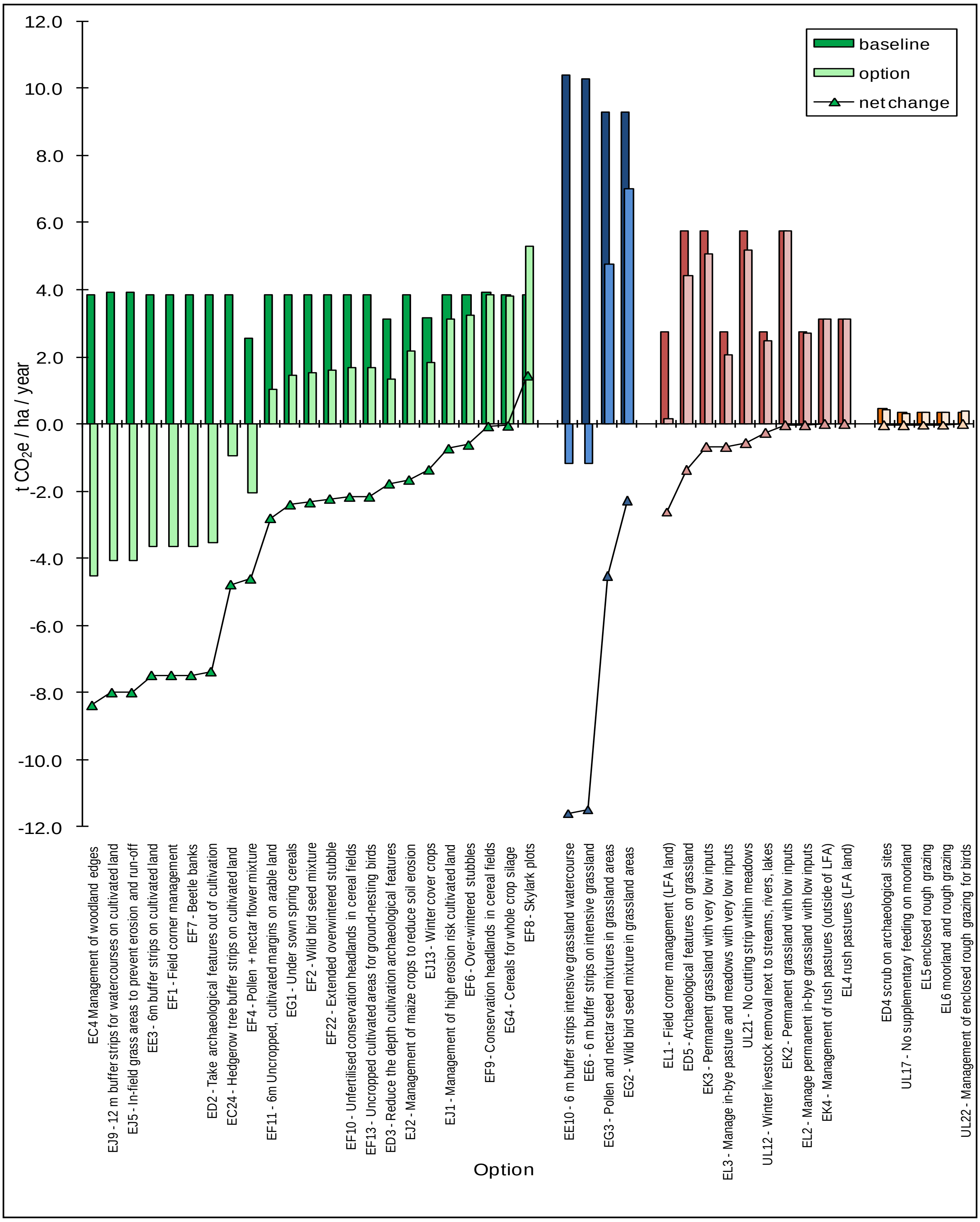

Figure 2. The GHG emissions (t CO_2e $ha^{-1}year^{-1}$) from land managed under the original baseline scenario (grouped by winter wheat (green), temporary grassland grazed by intensive beef cattle (blue), semi-improved grassland (red) and unimproved grassland (orange)), the mean per year after five years for selected ELS options and the resultant change in GHG emissions$_{(EDP)}$.

Table 3.2. Mean net GHG emissions$_{(EDP)}$ (t CO$_2$e ha^{-1} year^{-1} after five years) of ELS options relative to the baseline ranked by greatest reduction. New options are marked in blue, Uplands ELS options are marked in green. Displacement risk is indicated as high (H) (change in land use from a high productivity baseline to lower productivity; moderate (M) (change in a proportion of the land use of a high productivity baseline but not the overall land use or change in land use from medium productivity baseline to lower productivity land use; or low (L) (no change in land use or change in land use from a low productivity baseline). Category 1 options are marked (1), Category 2 as (2).

t CO$_2$e	Option	Disp^t risk
-11.59	EE10 - 6 m buffer strips on intensive grassland next to a watercourse	M
-11.48	EE4 - 2m buffer strips on intensive grassland	M
-11.48	EE5 - 4m buffer strips on intensive grassland	M
-11.48	EE6 - 6m buffer strips on intensive grassland	M
-8.65	EC1 - Protection of in-field trees (arable)	M
-8.38	EC4 - Management of woodland edges (arable)	M
-8.04	EK1 - Take field corners out of management	M
-8.00	EJ9 - 12 m buffer strips for watercourses on cultivated land	M(2)
-8.00	EJ5 - In-field grass areas to prevent erosion and run-off	M(2)
-7.48	EE9 - 6 m buffer strips on cultivated land next to a watercourse	M
-7.48	EE1 - 2m buffer strips on cultivated land	M
-7.48	EE2 - 4m buffer strips on cultivated land	M
-7.48	EE3 - 6m buffer strips on cultivated land	M
-7.48	EF1 - Field corner management	M
-7.48	EF7 - Beetle banks	M
-7.48	EE8 - Buffering in-field ponds in arable land	M
-7.33	EC24 - Hedgerow tree buffer strips on cultivated land	M
-7.25	EC2 - Protection of in-field trees (grassland)	M
-6.54	EC4 - Management of woodland edges (semi-improved grassland)	M
-6.21	EC25 - Hedgerow tree buffer strips on grassland	M
-6.19	EE7 - Buffering in-field ponds in improved grassland	M
-4.61	EF4 - Pollen + nectar flower mixture	M
-4.61	EF5 - Pollen + nectar flower mixture on set-aside land	M
-4.53	EG3 - Pollen and nectar seed mixtures in grassland areas	M
-3.90	ED2 - Take archaeological features out of cultivation	H
-3.75	EF4 - Nectar flower mixture (grassland)	M
-3.67	UB14 - Hedgerow restoration - laying	L(1)
-2.80	EF11 - 6m Uncropped, cultivated margins on arable land	M
-2.61	EL1 - Field corner management (LFA land)	M
-2.40	EG1 - Under sown spring cereals	L(1)
-2.33	EF2 - Wild bird seed mixture	M
-2.33	EF3 - Wild bird seed mixture on set-aside land	M
-2.29	EG2 - Wild bird seed mixture in grassland areas	M
-2.22	EF22 - Extended overwintered stubble	M
-2.17	EF10 - Unfertilised conservation headlands in cereal fields	M
-2.16	EF13 - Uncropped cultivated areas for ground-nesting birds on arable land	M
-2.05	UC5 - Sheep fencing around small woodlands	L(1)
-1.83	UB14 - Hedgerow restoration - gapping up	L(1)
-1.66	EJ2 - Management of maize crops to reduce soil erosion	L(1)
-1.66	EJ10 - Enhanced management of maize crops to reduce soil erosion and run-off	L(1)

-1.64	EC23 - Establishment of hedgerow trees by tagging	L(1)
-1.36	ED5 - Archaeological features on grassland	M/L
-1.36	EJ13 - Winter cover crops	L(1)
-0.97	ED3 - Reduce the depth of cultivation on archaeological features	L
-0.92	EB3 - Enhanced hedgerow management	L(1)
-0.72	EJ1 - Management of high erosion risk cultivated land	L(1)
-0.70	EL3 - Manage in-bye pasture and meadows with very low inputs	L
-0.70	EK3 - Permanent grassland with very low inputs	L
-0.67	EG5 - Brassica fodder crops followed by over-wintered stubbles	L
-0.62	EF6 - Over-wintered stubbles	L
-0.58	UL21 - No cutting strip within meadows	M
-0.27	UJ12 - Winter livestock removal next to streams, rivers and lakes	L(1)
-0.11	UJ3 - Post and wire fencing along watercourses	L(2)
-0.06	EF9 - Conservation headlands in cereal fields	M
-0.05	ED4 - Management of scrub on archaeological sites	L
-0.05	EG4 - Cereals for whole crop silage followed by over-wintered stubbles	L
-0.04	UL17 - No supplementary feeding on moorland	L(1)
-0.03	EF15 - Reduced herbicide cereal crops followed by overwintered stubble	L
-0.03	EK2 - Permanent grassland with low inputs	L
-0.03	EL2 - Manage permanent in-bye grassland with low inputs	L
-0.02	EL5 - Enclosed rough grazing	L
-0.02	EL6 - Moorland and rough Grazing	L
0.00	EB6 - Ditch management	L
0.00	EB7 - Half ditch management	L
0.00	EB10 - Combined hedge and ditch management (incorporating EB3)	L
0.00	EB1 - Hedgerow management (on both sides of hedge)	L
0.00	EB4 - Stone faced hedge bank management on both sides	L
0.00	EB8 - Combined hedge and ditch management (incorporating EB1)	L
0.00	EB2 - Hedgerow management (on one side of hedge)	L
0.00	EB5 - Stone faced hedge bank management on one side	L
0.00	EB9 - Combined hedge and ditch management (incorporating EB2)	L
0.01	UL22 - Management of enclosed rough grazing for birds	L
0.01	UL23 - Management of upland grassland for birds	L
0.01	EK4 - Management of rush pastures (outside of LFA)	L
0.01	EL4 - Management of rush pastures (LFA land)	L
1.45	EF8 - Skylark plots	M

The main impact on the GHG balance results from modifications to options implemented on temporary grassland baseline scenarios (for example replacement of temporary with permanent grassland), rather than to the stipulated management of the options themselves. The impact of changes to option management specifications are relatively minor. Overwintered stubble (option EF6) stipulates the subsoiling (deeper cultivation relative to the baseline) of additional field areas in addition to solely the tramlines. Additional fuel consumption results in additional CO_2 emissions. The use of herbicide to remove the crop to permit bare ground for skylark plots incurs emissions associated with the seed but without the biomass of the crop where previously the drill was turned off. The mowing of grass strips for up to two years instead of one potentially requires additional mowing operations but on most land, the management would not change.

The ranking of options after five years (Table 3.2) has not altered significantly with the exception of hedgerows, where the impact is now assigned to Cross Compliance, and the options in Table 3.1 previously on temporary grassland. The hedgerow options (EB1 to EB10) previously calculated that the 1.5 m adjacent to the hedge was removed from cultivation. This has now been incorporated within Cross Compliance requirements not to cultivate within 2 m of a hedge centre or watercourse, or 1 m from the top of a watercourse bank (Defra 2006, 2007). Option EB3 (Enhanced hedgerow management) is calculated to increase the mean hedgerow height from 1.5 m to 2.0 m over a period of five years. The hedge occupies 0.5 m width per 2.0 m wide strip. Where the baseline has been modified to permanent grassland from temporary grassland there is a smaller reduction in stocking rate and negligible impact on SOC accumulation. Inputs to grazing land are calculated as a proportion of one ha i.e. as the component of one forage ha (that also includes silage land). Certain options may be applicable to a particular component of a forage ha (for example, either the grazing land only or the area devoted to silage production only, but not both) and that individual component alone is impacted by the area in agreement. Buffer strips on grassland (EE4-6) remove a single component (most likely grazing land) and a proportional reduction in grazing overall was considered likely and calculated. In contrast, the Protection of in-field trees on grassland (EC2) is applicable to the grazed area but no longer reduces the stocking rate proportionally. Only fertiliser inputs and field operations associated with the specified proportion of grazing land are removed. The area applicable is now within a 12 m radius of the tree.

3.2.1.2. New ELS options and options not previously included

Options that prevent soil erosion and run-off are now included. Option EJ2 (Management of maize crops to reduce soil erosion) reduces the loss of SOC and the use of inorganic fertiliser from the undersowing of the crop with clover (Table 3.3). New ELS options and their mean impact on GHG emissions per year after 5 years are summarised in Table 3.2. A scoping exercise removed options deemed to have negligible impact GHG emissions (e.g. options EB12 and EB13 Earth bank management).

Table 3.3. Summary of baseline scenarios and management of new ELS options.

Code	Option	Baseline	Management
EC23	Establishment of hedgerow trees by tagging	Hedge$_{(1.5\ m)}$	Two trees per 100 m length; equivalent 2 m width per strip
EC24	Hedgerow tree buffer strips on cultivated land	WW	Establish permanent grass strips (sowing); 4 cuts per year; no cutting post year 1; no fertilisers or manures; spot treat with herbicides
EC25	Hedgerow tree buffer strips on grassland	SIG(cut)	4 cuts per year; no cutting post year 1; no fertilisers or manures; spot treat with herbicides
EE9	6 m buffer strips on cultivated land next to a watercourse	WW	4 cuts per year; no cutting post year 1; no fertilisers or manures; spot treat with herbicides
EE10	6 m buffer strips on intensive grassland next to a watercourse	TGIBC	4 cuts per year; no cutting post year 1; no fertilisers or manures; spot treat with herbicides
EF12	Uncropped cultivated areas for ground-nesting birds on arable land	WW	Plough (20cm), 1 pass with tines, 1 herbicide application (blackgrass)
EF15	Reduced herbicide cereal crops followed by overwintered stubble	WW & SB (2 years)	As WW but no insecticides post 15th March, no broad spectrum herbicide post harvest; stubble preceding spring barley
EF22	Extended overwintered stubble	WW	Light cultivation (spike toothed harrow (4m) in September; herbicide (blackgrass control) May, broad spectrum herbicide August, no crop biomass
EJ5	In-field grass areas to prevent erosion and run-off	WW	Establish permanent grass strips (sowing); 4 cuts per year; no cutting post year 1; no fertilisers or manures; spot treat with herbicides
EJ9	12 m buffer strips for watercourses on cultivated land	WW	Establish permanent grass strips (sowing); 4 cuts per year; no cutting post year 1; no fertilisers or manures; spot treat with herbicides
EJ10	Enhanced management of maize crops to reduce soil erosion and run-off	MZ	Prevention of soil erosion and additional indirect N_2O from run-off
EJ11	Maintenance of watercourse fencing	UIG	Maintain existing fencing and existing prevention of damage by stock to soil and increased deposition in watercourses
EJ13	Winter cover crops	SB	SB preceded by sown grass cover crop, removed with light cultivation (shallow cultivation 5 cm (spike toothed harrow (4m))

The calculations now account for soil erosion and include an estimate of additional indirect N_2O emissions due to increased surface run-off in a scenario where erosion is a risk. The grass buffer strips achieve the greatest reduction$_{(EDP)}$ on both grassland and cultivated land respectively. Options with the greatest deductions in GHG emissions implement grass buffer strips with additional benefit via prevention of surface run-off and erosion. The new ELS option EE10 uses an intensive grassland baseline subject to erosion. In addition to a decrease in GHG emissions$_{(EDP)}$ the presence of theses strips prohibits overgrazing and poaching within areas immediately adjacent to a watercourse but beyond the 1 m required by Cross Compliance. It reduces the likelihood of N deposition close to the watercourse and potential surface run-off where a steeper gradient may be present. The new ELS soil protection options EJ9 (12 m buffer strips for watercourses on cultivated land) and EJ5 (In-field grass areas to prevent erosion and run-off) offer the greatest potential to reduce GHG emissions on cultivated land. The risk of soil erosion or surface run-off into watercourses is reduced. Options EJ2 and EJ10 reduce erosion risk in maize crops and supply N via undersowing with clover, substituting a proportion (up to 180 kg N ha^{-1} per 30% clover composition (RB209, 2010)) of the manufactured inorganic N requirement. Winter cover crops (option EJ13) reduce indirect N_2O emissions from decreased NO_3 leaching, coupled with the incorporation of additional biomass into the soil to enhance levels of SOC. The latter three options have the added benefit that they do not remove land from production (low displacement risk).

Options EE9 (6 m buffer strips on cultivated land next to a watercourse), EE10 (6 m buffer strips on intensive grassland next to a watercourse) and EC24 (Hedgerow tree buffer strips) are calculated as similar in impact to the existing grass buffer strip options on cultivated and temporary grassland respectively. The Establishment of hedgerow trees by tagging (option EC23) encourages the growth of two trees per 100 m hedge length and increased biomass C within the additional height.

Option EF13 (Uncropped cultivated areas for ground-nesting birds on arable land) does not differ greatly to EF11 (Uncropped cultivated margins for rare plants) except for additional herbicide applications, that have minimal impact on GHG emissions (Warner *et al*., 2008). EF13 also assumes relocation annually. The decrease in N_2O emissions that results from the continual non-application of N fertiliser where the option is maintained continually in the same place each year (as for EF11) does not occur. Seasonal livestock removal on grassland with no input restriction (option EJ7) reduces the quantity on N deposited onto wet soils at risk of leaching and surface run-off. Part of the benefit is eliminated because of potentially increased methane emissions due to manure storage.

3.2.1.3. Uplands ELS options

The baseline scenario and management of relevance to GHG emissions of the new Uplands ELS strand of options are summarised in Table 3.4. The impact on net GHG emissions$_{(EDP)}$ are ranked in Table 3.2.

Table 3.4. Summary of baseline scenarios and management of the new Uplands ELS options of relevance to GHG emissions.

Code	**Option**	**Baseline**	**Comments**
UX1	Moorland commons and shared grazing requirements	UIGsh(up) inside LFA	Encourages grazing with hefted (self-maintained) flocks in order to prevent cross-breeding. Negligible impact on GHG emissions
UX2	Upland grassland and arable requirements	UIGsh(up) inside LFA	Discourages supplementary feeding of livestock and application of supplementary nutrients. Baseline assumes existing limited application but prevents any increase.
UX3	Moorland requirements	UIGsh(up) inside LFA	Specifies a minimum level of grazing the same as the baseline. Management stipulates no new land drainage, maintenance of existing drainage except where peat >0.5 m and to avoid supplementary feeding on bogs.
UB14	Hedgerow restoration - laying	$H_{(1.5m)}$not laid	Increased stem length for 1.5 m height - midland (35° degree angle), 2.62 m equivalent (requires initial pre-laid hedge height to be above 1.5 m)
UB14	Hedgerow restoration - gapping up	50% $H_{(1.5m)}$not laid	Additional plant biomass where gapped up (assumed 50% as gap)
UC5	Sheep fencing around small woodlands	WD(grazed)	Small woodland, no reduction in overall numbers of stock, allows 20% increase in woodland biomass.
UC22	Woodland livestock exclusion	WD(grazed) With UC5	For use with option above.
UJ3	Post and wire fencing along watercourses	Grazed watercourse edge	Stock access to watercourses causing bank erosion prevented for 1 m from the bank edge.
UJ22	Winter livestock removal next to streams, rivers and lakes	Grazed watercourse edge	Stock access to watercourses causing bank erosion during the winter prevented for 1 m from the bank edge.
UL17	No supplementary feeding on moorland	UIGsh(up) inside LFA	Numbers of stock on moorland reduced during the winter, not reduced in overall number (relocated off moorland on non-organic soils less vulnerable to waterlogging, decreased N deposition onto wet organic soils).
UL18	Cattle grazing on upland grassland and moorland	UIGsh(up) inside LFA	Graze cattle (minimum 30%) where existing cattle (i.e. no increase in cattle numbers) but increase in area grazed by cattle either on alternate years or as mixed grazing with sheep; allows supplementary feeding; housed during the winter
UL20	Haymaking	SIGup(cut) – neutral grassland	Cutting dates later than for silage; limited use of fertiliser.
UL21	No cutting strip within meadows	SIGup(cut)	No cutting; graze along with remainder of field after final cut.
UL22	Management of enclosed rough grazing for birds	UIGsh(up) inside LFA	No supplementary feeding with silage (concentrates used instead); cut rushes

UL23	Management of upland grassland for birds	UIGsh(up) outside LFA (below moorland line)	Establish different sward height (7 – 20 cm) (potential increase in sward species diversity); reduce stock between 1 April and 30 June (decrease stock to 0.6 LU but no net reduction in stock numbers); allow supplementary feeding; cut one third rushes;

Option UL23 is most likely to be implemented on grazing land where existing stocking rates are low (i.e. equal to the option requirement) so there is no equivalent reduction in stock numbers. If implemented on semi-improved permanent grassland then although a decrease in stock would be required the stock would be grazed elsewhere on farm during this period with no overall reduction in stocking rates.

Option UB14 (Hedgerow restoration) is dependent on whether the hedge is laid or 'gapped up'. Gapping up potentially accumulates greater biomass owing to new hedge planting although it will be subject to the proportion of the hedge line where new planting occurs. Hedges that are laid may accumulate additional biomass in the greater equivalent stem length when the stem (pleacher) is laid at an angle compared to a vertical stem. Sheep fencing around small woodlands (UC5) does not reduce the number of stock, they are located elsewhere on the farm. Relocation to existing semi-improved grassland allows the regeneration of an estimated 20% of woodland biomass previously grazed.

Post and wire fencing along watercourses (UJ3) and UJ4 (Winter livestock removal next to streams, rivers and lakes) both have a 'Grazed watercourse edge' baseline. Implementation of these options prevents access by stock to areas of potentially wet ground during the winter and decreases the risk of soil erosion and poaching in areas adjacent to watercourses. It reduces deposition of N onto wet and potentially compacted ground and emission of N_2O from denitrification. Indirect N_2O emissions are reduced through decreased surface run-off that may have been heightened by loss of surface biomass and direct exposure of bare soil to rainfall. Option UL17 (No supplementary feeding on moorland) reduces the number of stock present on wet organic soils above the moorland line during the winter. Stocking rates themselves are not reduced overall but stock are grazed below the moorland line where deposition onto wet organic soils has been calculated not to occur.

Option UL21 (No cutting strip within meadows) increases the equivalent grass biomass equilibrium during year one only. A small quantity of fuel may saved however this will be negligible as most of the field will be cut anyway and the machinery moved from the farm buildings. Options UL22 (Management of enclosed rough grazing for birds) and UL23 (Management of upland grassland for birds) specify the cutting of one third of the area of rushes. A small increase in emissions results because of additional cutting on one third of the area.

3.2.2. Higher Level Scheme

The ranked mean net change in GHG balance for HLS options per ha of option during years 1 – 5 are summarised in Figure 3. All HLS options are listed and ranked in decreasing reduction in net GHG emissions in Table 3.5.

On cultivated land, options that prevent erosion (options HJ3 and HJ4 Arable reversion to unfertilised grassland to prevent erosion or run-off) use a winter wheat with erosion baseline. The additional GHG emissions$_{(EDP)}$ from run-off and loss of SOC are eliminated when converted to permanent grassland. A reduction in the net GHG reduction$_{(EDP)}$ is evident where temporary grassland baselines have been replaced by permanent grassland (Table 3.1), such as Option HC6 (Ancient trees in intensively managed grass fields). The temporary grassland grazed by intensive beef cattle baseline has been adapted to include the presence or absence of clover within the sward (the latter scenario utilises solely inorganic N as a source of nitrogen), and the presence of soil erosion. Option HJ6 (Preventing erosion or run-off from intensively managed improved grassland) has emissions reduction$_{(EDP)}$ associated with a decrease in stocking rates. It requires a reduction in N fertiliser application of grassland receiving in excess of 200 kg N ha^{-1} to 100 kg N ha^{-1}. Silage yield (310 kg N ha^{-1} yielding 9.5 t ha^{-1} DM) has been adjusted using the Reid (1985) equation:

$$y = a - b\, exp(-cX^{d})$$

where y is yield (kg DM ha^{-1}),
X is the N applied (kg N ha^{-1})
a, b and c are constants.

Reid (1985) calculates that application of 100 kg N ha^{-1} yields 42% DM relative to 310 kg N ha^{-1} to give 4.0 t ha^{-1} DM that supports a stocking rate of 0.7 LU ha^{-1} when supplemented with 0.4 t concentrates (RB209, 2010 Table 8.4). A further reduction in the GHG balance is calculated from the prevention of erosion and run-off when the grassland is converted to permanent grassland, coupled with accumulation of SOC.

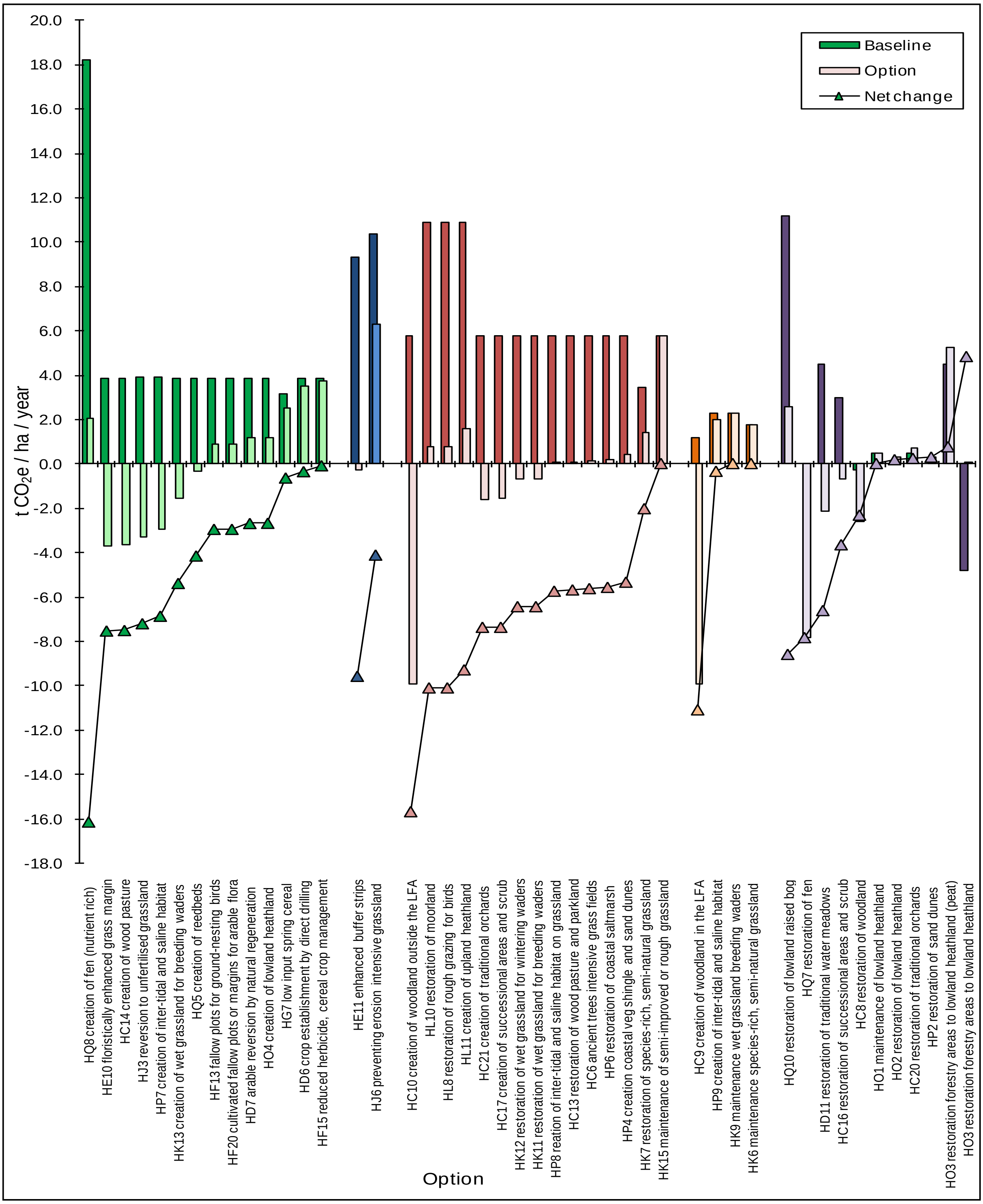

Figure 3. The GHG emissions (t CO$_2$e ha^{-1}year^{-1}) from land managed under the original baseline scenario (grouped by winter wheat (green), temporary grassland grazed by intensive beef cattle (blue), semi-improved grassland (red), unimproved grassland (orange) and other land use such as degraded semi-natural habitat (purple)), the mean per year after five years for selected HLS options and the resultant change in GHG emissions$_{(EDP)}$.

Table 3.5. Mean net GHG emissions$_{(EDP)}$ (t CO_2e ha^{-1} year^{-1} after five years) of HLS options relative to the baseline ranked by greatest reduction. Displacement risk is indicated as high (H) (change in land use from a high productivity baseline to lower productivity; moderate (M) (change in a proportion of the land use of a high productivity baseline but not the overall land use or change in land use from medium productivity baseline to lower productivity land use; or low (L) (no change in land use or change in land use from a low productivity baseline). Category 1 options are marked (1), Category 2 as (2).

t CO_2e	**Option**	**Disp^t risk**
-16.15	HQ8 - Creation of fen	H(2)
-15.66	HC10 - Creation of woodland outside of the LFA	H
-11.08	HC9 - Creation of woodland in the LFA	L/M
-10.13	HL10 - Restoration of moorland with HL15 Seasonal livestock exclusion supplement	M/L(1)(2)
-10.13	HL8 - Restoration of rough grazing for birds with HL15 Seasonal livestock exclusion supplement	M/L(1)(2)
-10.09	HL10 - Restoration of moorland	M/L(2)
-10.09	HL8 - Restoration of rough grazing for birds	M/L(2)
-9.55	HE11 - Enhanced strips for target species on intensive grassland	M
-9.31	HL11 - Creation of upland heathland	H(2)
-8.60	HQ10 - Restoration of lowland raised bog	L(2)
-7.53	HE10 - Floristically enhanced grass margin	M
-7.53	HQ7 - Restoration of fen	L/M(2)
-7.51	HC14 - Creation of wood pasture	M/H
-7.36	HC21 - Creation of traditional orchards	H/M
-7.34	HC17 - Creation of successional areas and scrub	H
-7.28	HO4 - Creation of lowland heathland from arable or **improved grassland** (on wet heathland)	H
-7.20	HJ3 - Reversion to unfertilised grassland to prevent erosion/run-off	H(2)
-7.16	HQ1 - Maintenance of ponds of high wildlife value < 100 sq m	M
-7.16	HQ2 - Maintenance of ponds of high wildlife value > 100 sq m	M
-6.86	HP7 - Creation of inter-tidal and saline habitat on arable land	H
-6.75	HO4 - Creation of lowland heathland from **arable** or improved grassland (on wet heathland)	H
-6.61	HD11 - Restoration of traditional water meadows	H/M
-6.42	HK11 - Restoration of wet grassland for breeding waders.	H/M
-6.42	HK12 - Restoration of wet grassland for wintering waders and wildfowl	H/M
-5.92	HK8 - Creation of species-rich, semi-natural grassland	H
-5.72	HP8 - Creation of inter-tidal and saline habitat on grassland	H
-5.66	HC13 - Restoration of wood pasture and parkland	L/M
-5.62	HP6 - Restoration of coastal saltmarsh with HP11 Saltmarsh livestock exclusion supplement	H/M(1)
-5.58	HP6 - Restoration of coastal saltmarsh	H/M
-5.38	HK13 - Creation of wet grassland for breeding waders	H
-5.38	HK14 - Creation of wet grassland for wintering waders and wildfowl	H
-5.35	HP4 - Creation of coastal vegetated shingle and sand dunes on grassland	H
-4.96	HJ4 - Reversion to low input grassland to prevent erosion/run-off	H
-4.15	HQ5 - Creation of reedbeds	M
-4.11	HJ6 - Preventing erosion or run-off from intensively managed grassland	H/M(2)
-4.02	HK16 - Restoration of valuable semi-improved or rough grassland	H/M
-3.67	HC16 - Restoration of successional areas and scrub	H

-3.58	HP3 - Creation of coastal vegetated shingle and sand dunes on arable land	H
-3.38	HF14 - Unharvested, fertiliser-free conservation headlands	M
-3.30	HF12 - Enhanced wild bird seed mix plots	M
-3.05	HK16 - Restoration of valuable semi-improved or rough grassland (SDA)	H/M
-2.94	HF16 - Cultivated plot or margin for arable flora - enhanced setaside	M
-2.94	HF17 - Fallow plots for ground-nesting birds - enhanced setaside	M
-2.94	HF20 - Cultivated fallow plots or margins for arable flora	M
-2.80	HF11 - 6m cultivated strip on arable land	M
-2.68	HD7 - Arable reversion by natural regeneration	H
-2.67	HO4 - Creation of lowland heathland from **arable** or improved grassland (on dry heathland)	H
-2.63	HK17 - Creation of valuable semi-improved or rough grassland	H
-2.40	HO4 - Creation of lowland heathland from arable or **improved grassland** (on dry heathland)	H
-2.05	HC8 - Restoration of woodland	L
-2.16	HK7 - Restoration of species-rich, semi-natural grassland (SDA)	M
-2.00	HK7 - Restoration of species-rich, semi-natural grassland	H/M
-1.85	HO2 - Restoration of heathland from neglected sites	L
-0.67	HG6 - Fodder crop management to retain or re-create an arable mosaic	L
-0.62	HG7 - Low input spring cereal to retain or re-create an arable mosaic	M
-0.48	HC5 - Ancient trees in arable fields	M
-0.41	HJ8 - Nil fertiliser supplement	M
-0.40	HC6 - Ancient trees in intensively-managed grass fields	M
-0.34	HP9 - Creation of inter-tidal and saline habitat by unmanaged breach or regular inundation with HP11 Saltmarsh livestock exclusion supplement	L(1)
-0.34	HD6 - Crop establishment by direct drilling (non-rotational)	L
-0.30	HP9 - Creation of inter-tidal and saline habitat by unmanaged breach or regular inundation	M
-0.20	HO5 - Creation of lowland heathland on worked mineral sites	L(1)
-0.18	HQ4 - Restoration of reedbeds	L
-0.09	HJ7 - Seasonal livestock removal from intensively managed grassland	L(1)
-0.07	HF15 - Low herbicide cereal preceding winter stubble and a spring crop	M
-0.04	HL7 - Maintenance of rough grazing for birds with HL15 Seasonal livestock exclusion supplement	L(1)
-0.04	HL9 - Maintenance of moorland with HL15 Seasonal livestock exclusion supplement	L(1)
-0.01	HC12 - Maintenance of wood pasture and parkland	L
0.00	HC15 - Maintenance of successional areas and scrub	L
0.00	HC18 - Maintenance of high value traditional orchards	L
0.00	HC19 - Maintenance of traditional orchards in production	L
0.00	HC7 - Maintenance of woodland	L
0.00	HD10 - Maintenance of traditional water meadows	L
0.00	HK10 - Maintenance of wet grassland for wintering waders and wildfowl	L
0.00	HK15 - Maintenance of valuable semi-improved or rough grassland	L
0.00	HK15 - Maintenance of valuable semi-improved or rough grassland (SDA)	L
0.00	HK6 - Maintenance of species-rich, semi-natural grassland	L
0.00	HK6 - Maintenance of species-rich, semi-natural grassland (SDA)	L
0.00	HK9 - Maintenance of wet grassland for breeding waders	L
0.00	HL7 - Maintenance of rough grazing for birds	L
0.00	HL9 - Maintenance of moorland	L
0.00	HO1 - Maintenance of lowland heathland	L
0.00	HP5 - Maintenance of coastal saltmarsh	L
0.00	HQ3 - Maintenance of reedbeds	L

0.00	HQ6 - Maintenance of fen	L
0.00	HP1 - Maintenance of sand dunes	L
0.00	HQ9 - Maintenance of lowland raised bog	L
0.00	HD8 - Maintaining high water levels to protect archaeology	L
0.23	HC20 - Restoration of traditional orchards	L
0.29	HP2 - Restoration of sand dune systems	L
0.78	HO3 - Restoration of forestry areas to lowland heathland (on wet heathland)	H
1.45	HF8 - Skylark plots	M
4.86	HO3 - Restoration of forestry areas to lowland heathland (on dry heathland)	H

The grassland options are implemented both inside and outside the SDA albeit mainly outside (Defra Statistics, *pers comm.*). Two baseline scenarios (inside and outside the SDA) have been used where significant (above 500 ha) are present in either category. Option HK6 (Maintenance of species-rich, semi-natural grassland) does not alter current management for either category. Option HK7 (Restoration of species-rich, semi-natural grassland) alters management from a semi-improved grassland grazed by sheep (inside or outside the SDA) to unimproved grassland grazed by cattle (inside or outside the SDA respectively). Additional SOC is accumulated in response to increased species diversity. The net reduction in stocking rate and reduction in emissions$_{(EDP)}$ is smaller within the SDA. The valuable semi-improved or rough grassland options do not alter emissions where maintenance is undertaken (HK15). A reduction in stocking rates and emissions occurs in option HK16 if rough grassland is restored from semi-improved grassland. The restoration of semi-improved grassland on existing semi-improved grassland are likely to be small as subtle alterations only are made to management (e.g. fertiliser or grazing regime) to enhance target species. The creation of valuable semi-improved or rough grassland on cultivated land decreases GHG emissions$_{(EDP)}$ via similar mechanisms to arable reversion.

The baseline for the restoration of water meadow (option HD11) has been modified to a semi-improved lowland grassland baseline due to the relatively high productivity of this habitat. On wet grassland habitats that include reinstating the periodic flooding of grassland for restoration purposes (also options HK11 and HK12) 2.93 t CO_2e accumulates as SOC up to a potential 634.3 t CO_2e (marshy grassland with organo-mineral soil). Option HK12 stipulates no grazing during the winter however on most land cattle are likely to be housed during the winter already. Where land is grazed by sheep their removal from wet grassland may be necessary but winter grazing will be elsewhere on the farm (on semi-improved grassland) and not subject to an additional housing period through entry into an ES agreement.

The maintenance of moorland or rough grazing (options HL7 and HL9) do not change the existing management and therefore no change in GHG emissions are calculated. The maintenance of, and restoration of moorland options remain grazed all year at rates equivalent to upland LFA unimproved grassland. The restriction of grazing to two or three months during the summer is employed only where bogs are present (*M. Edwards, pers comm.*). This is representative of a proportion of moorland which has been estimated using the area assigned to the shepherding supplement (HL16), frequently used to facilitate the maintenance of or rewetting of bogs. All options for Moorland and Upland Rough Grazing (HL7 – HL10) may be undertaken with supplement HL15 (Seasonal livestock exclusion). It is applied as necessary where winter exclusion (November – April) will benefit the restoration process (in conjunction with option HL10 Restoration of moorland) as sheep show a preference for grazing *Calluna vulgaris* during the winter (Grant and Armstrong, 1993). The impact of supplements that exclude livestock at particular times of the year, or allow management of sensitive habitat features, are calculated as the impact of the option and supplement combined. For example, the option HL10 (Restoration of moorland) alone allows grazing all year. The option and supplement HL15 (Seasonal livestock exclusion supplement) excludes livestock during the winter. Two sets of calculations have been made: sheep on moorland grazed for 12 months or sheep on moorland grazed for 7 months and removed during the winter with Supplement HL15 (Table 3.5). Where stock are removed during the winter, the quantity of N deposited onto wet organic soils is reduced, coupled with a reduction in N_2O emissions from denitrification (Table 2.1). An immediate emissions reduction results from decreased stocking rates and the prevention of CO_2 emission from drained organic soils. The creation of upland heathland (HL11) is no longer grazed for the first five years of the process. The stipulation that there should be no supplementary feeding in option EL5 (Enclosed rough grazing) may potentially reduce stocking rates but, in reality, it is unlikely that land would be entered into this option if an actual reduction in the overall level of stock on the farm resulted. No reduction in overall stocking has therefore been calculated for this option. Option EL6 (Unenclosed moorland rough grazing) specifies no supplementary feeding of silage but permits the feeding of hay and concentrates. Additional concentrates in the diet were calculated previously (Warner *et al*., 2008) and this has not been changed because hay requires a period of dry weather to achieve optimal dry matter content which may be difficult during some seasons. The modification to the calculation of enteric methane allows for differences in feed type to be accounted for. The feeding of silage on open moorland does not occur as standard (*M. Edwards, pers comm.*) and implementation of this option therefore is unlikely to change the management on many farms. There would be no change in the overall level of stocking. The restoration of species-rich, semi-natural grassland (HK7) in upland areas substitutes sheep grazing with cattle. The cattle would most likely be relocated from other areas of the farm with no net impact on stock numbers.

The impact of the restoration or creation of lowland heathland (options HO2 – HO4) depends on whether previously wet or dry heathland and the depth of the organic soil layer. On previously dry heathland where the organic layer is likely to be shallow the removal of trees has negligible impact on soil CO_2 emissions. Where wet heathland was present the emission of CO_2 from soil may potentially be reduced where the rewetting of the area is permitted. The net increase in GHG emissions that results from the removal of tree biomass during the restoration process in option HO3 is reduced where wet heathland is restored. The creation of lowland heathland (HO4) on agricultural land that was historically heathland is impacted by whether permanent grassland or cultivated land, and if recently wet heathland where organic soil remains within the profile. The net reduction in emissions is greatest where the cultivation of previously wet heathland is prevented.

The Intertidal and Coastal Options (HP5 – HP9) maintain or permit land to become periodically wet with saline water such as salt marsh. Sheep are grazed all year. Where restoration or creation occurs stocking rates are reduced however grazing deposition onto dry soils during the winter is replaced by deposition onto waterlogged soils. This is mitigated by application of supplement HP11 (Saltmarsh livestock exclusion supplement). Livestock are not removed by the implementation of the HLS options alone, only where the supplement is used with the option. This supplement is used mainly in conjunction with options HP6 (Restoration of coastal saltmarsh) and HP9 (Creation of inter-tidal and saline habitat by unmanaged breach or regular inundation). The periodic flooding of grassland creates anaerobic soil conditions allowing the accumulation of SOC and an increase in the equilibrium to that attained for ‘marshy grassland’ (Carey *et al*., 2008).

The impact of Wetland Options remains largely unchanged. The creation of reedbeds has been modified to calculate the potential for accumulation of high SOC peat fen soils. Creation requires the diversion of watercourses and the flooding of the area. Akers and Allcorn (2006) provide an example on dry permanent grassland. The cultivated land baseline has been replaced with unimproved grassland grazed by sheep. Initial excavation of sites may be required to lower the level of the soil surface to below that of the water table. The soil removed forms a bund around the perimeter to hold the water but is not disturbed further.

The removal of stock grazing large woodlands (>3ha) during the winter (e.g. within areas of moorland or rough grazing) necessitates a decrease in stock numbers both on the wider parcel of land and the overall stocking of the farm. Where stock are removed from small woodlands (<3 ha) (option UC5 - Sheep fencing around small woodlands in section 3.2.1.3) they are grazed on land elsewhere on the farm with no net reduction in stock numbers. Environmental Stewardship is applicable in most cases to woodlands <3 ha, option HC8 (Restoration of woodland) is assumed applied to woodlands of less than 3 ha that does not require an equivalent reduction in overall stock numbers.

3.2.3. Organic Entry / Higher Level Scheme

No significant modifications have been made to the organic baseline scenarios or option management scenarios (Figure 4).

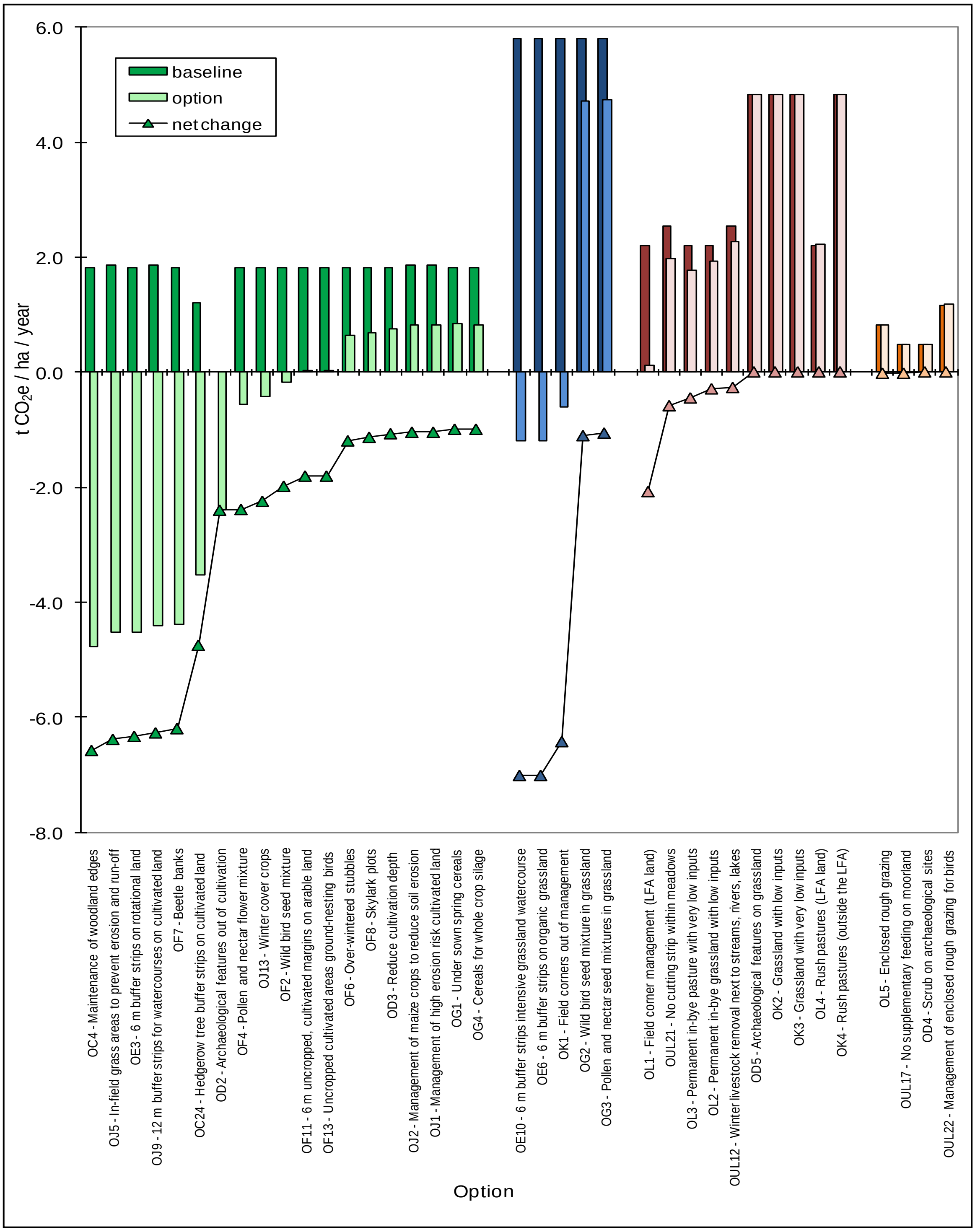

Figure 4. The GHG emissions (t CO_2e $ha^{-1}year^{-1}$) from land managed under the original baseline scenario (grouped by winter wheat (green), temporary grassland grazed by intensive beef cattle (blue), semi-improved grassland (red) and unimproved grassland (orange)), the mean per year after five years for selected OELS options and the resultant change in GHG emissions$_{(EDP)}$.

Existing stocking rates lower than the ELS or HLS baselines were complicit with NVZ rules. The temporary grassland scenario grazed by dairy cows has been replaced by intensive beef production grazed at 1.5 LU ha^{-1} (Lampkin, 2004). A total of 152 kg N ha^{-1} is produced. The N on grazed land is provided by clover and composted FYM (35.4 kg N ha^{-1}) that remains after application to silage land (below the equivalent 170 kg N ha^{-1}). Baselines have been adjusted where temporary grassland is a requisite. The mean net reduction in GHG $emissions_{(EDP)}$ after five years per ha of OELS options are ranked in Table 3.6. Options on rotational organic land include a two year grass-clover ley and accumulate 0.99 t CO_2e as SOC (Dawson and Smith, 2007).

Table 3.6. Mean net GHG $emissions_{(EDP)}$ (t CO_2e ha^{-1} $year^{-1}$ after five years) of OELS options relative to the baseline ranked by greatest reduction. New options are marked in blue, Uplands OELS options are marked in green. Displacement risk is indicated as high (H) (change in land use from a high productivity baseline to lower productivity; moderate (M) (change in a proportion of the land use of a high productivity baseline but not the overall land use or change in land use from medium productivity baseline to lower productivity land use; or low (L) (no change in land use or change in land use from a low productivity baseline). Category 1 options are marked (1), Category 2 as (2).

t CO_2e	Option	$Disp^t$ risk
-10.93	OC1 - Protection of in field trees - rotational land	M
-10.63	OC2 - Protection of in field trees - grassland	M
-7.01	OE10 - 6m buffer strip on organic grassland next to a watercourse	M
-7.00	OE4 - 2m buffer strip on organic grassland	M
-7.00	OE5 - 4m buffer strip on organic grassland	M
-7.00	OE6 - 6m buffer strip on organic grassland	M
-6.58	OC4 - Management of woodland edges (cultivated land)	M
-6.42	OK1 - Take field corners out of management (temporary grassland)	M
-6.38	OJ5 - In-field grass areas to prevent erosion or run-off	M(2)
-6.33	OE1 - 2m buffer strips on rotational land	M
-6.33	OE2 - 4m buffer strips on rotational land	M
-6.33	OE3 - 6m buffer strips on rotational land	M
-6.33	OE8 - Buffering in-field ponds in rotational land	M
-6.33	OE9 - 6m buffer strips on rotational land next to a watercourse	M
-6.33	OF1 - Field corner management	M
-6.27	OJ9 - 12m buffer strips for watercourses on rotational land	M(2)
-6.20	OF7 - Beetle banks	M
-5.72	OC25 - Hedgerow tree buffer strips on organic grassland	M
-5.61	OC4 - Maintenance of woodland edges (permanent semi-improved grassland)	M
-5.27	OE7 - Buffering in-field ponds in organic grassland	M
-4.75	OC24 - Hedgerow tree buffer strips on rotational land	M
-4.70	OK1 - Take field corners out of management (permanent grassland)	M
-3.67	OUB14 - Hedgerow restoration (laying)	L(1)
-2.40	OD2 - Take archaeological features out of cultivation	H
-2.39	OF4 - Pollen + nectar flower mixture	M
-2.24	OJ13 - Winter cover crops	L(1)
-2.09	OL1 - Field corner management (LFA land)	M

-2.05	OUC5 - Sheep fencing around small woodlands	L(1)
-1.98	OF2 - Wild bird seed mixture	M
-1.83	OUB14 - Hedgerow restoration (gapping up)	L(1)
-1.81	OF11 - 6 m uncropped, cultivated margins on arable land	M
-1.81	OF13 - Uncropped cultivated areas for ground-nesting birds - rotational	M
-1.64	OC23 - Establishment of hedgerow trees by tagging	L(1)
-1.19	OF6 - Over-wintered stubbles	L
-1.13	OF8 - Skylark plots	M
-1.09	OG2 - Wild bird seed mixture in grassland areas	M
-1.07	OD3 - Reduce the depth of cultivation on archaeological features	L
-1.07	OG5 - Brassica fodder crops followed by over-wintered stubbles	L
-1.07	OG3 - Pollen + nectar flower mixture in grassland areas	M
-1.04	OJ1 - Management of high erosion risk cultivated land	L(1)
-1.04	OJ2 - Management of maize crops to reduce soil erosion	L(1)
-0.99	OG1 - Under sown spring cereals	L(1)
-0.99	OG4 - Cereals for whole crop silage followed by over-wintered stubbles	L
-0.92	OB3 - Enhanced Hedgerow management	L(1)
-0.57	OUL21 - No cutting strip within meadows	M
-0.44	OL3 - Manage in-bye pasture and meadows with very low inputs	L
-0.29	OL2 - Manage permanent in-bye grassland with low inputs	L
-0.27	OUJ3 - Post and wire fencing along watercourses	L(1)
-0.27	OUJ12 - Winter livestock removal next to streams, rivers and lakes	L(1)
-0.01	OL5 - Enclosed rough grazing	L
-0.01	OUL17 - No supplementary feeding on moorland	L(1)
0.00	OD5 - Archaeological features on grassland	M/L
0.00	OB1 - Hedgerow management on both sides of hedge	L
0.00	OB10 - Combined hedge and ditch management (incorporating OB3)	L
0.00	OB2 - Hedgerow management on one side of hedge	L
0.00	OB4 - Stone faced Hedge bank management on both sides	L
0.00	OB5 - Stone faced Hedge bank management on one side	L
0.00	OB6 - Ditch management	L
0.00	OB7 - Half ditch management	L
0.00	OB8 - Combined hedge and ditch management (incorporating OB1)	L
0.00	OB9 - Combined hedge and ditch management (incorporating OB2)	L
0.00	OD4 - Management of scrub on archaeological sites	L
0.00	OK2 - Permanent grassland with low inputs	L
0.00	OK3 - Permanent grassland with very low inputs	L
0.01	OL4 - Management of rush pastures (LFA land)	L
0.01	OK4 - Management of rush pastures (outside the LFA)	L

3.2.4. Review of options with the largest reduction of GHG emissions$_{(EDP)}$

Table 3.7 lists the 10 options that per ha made the largest contribution to GHG emission reduction$_{(EDP)}$. Each has been reviewed and where changes considered necessary, they have been stated in the table. The main impacts are to option EB1 that has become classed as maintenance of an existing baseline (negligible change) and the alteration of temporary grass baselines to permanent grass baselines (described previously).

Table 3.7. Summary of revision to management scenarios of the 10 options with the highest net GHG reduction$_{(EDP)}$.

Code	Option	BD2302 Baseline	Changes made in BD5007
EB1	Hedgerow management (on both sides of hedge)	75% cultivated land; 25% hedge	Impact of not cultivating within 2 m of a hedge assigned to Cross Compliance requirements
EC4	Management of woodland edges	Cultivated land	Baseline changed to 50% cultivated land and 50% permanent semi-improved grassland
ED5	Management of archaeological features on grassland	Temporary grassland grazed by dairy cattle	Baseline changed to permanent semi-improved grassland
EE3	6 m buffer strips on cultivated land	Cultivated land	No change
EE6	6 m buffer strips on intensive grassland	Temporary grassland grazed by dairy cattle	Baseline changed to temporary grassland grazed by intensive beef cattle without clover
EF1	Field corner management	Cultivated land	No change
EK1	Take field corners out of management: outside SDA & ML	Temporary grassland grazed by dairy cattle	Baseline changed to 50% temporary grassland grazed by intensive beef cattle and 50% permanent semi-improved grassland
HC10	Creation of woodland outside of the SDA & ML	SIGC(low)	No change
HC9	Creation of woodland in the SDA	UIGSh inside LFA	No change
HE11	Enhanced strips for target species on intensive grassland	Temporary grassland grazed by dairy cattle	Baseline changed to temporary grassland grazed by intensive beef cattle without clover
HJ6	Preventing erosion or run-off from intensively managed grassland	Temporary grassland grazed by dairy cattle	Baseline changed to temporary grassland (with erosion) grazed by intensive beef cattle. Maximum 100 kg total N manures or 50 kg N inorganic (grass yield and stocking rate adjusted accordingly)
HK7	Restoration of species-rich, semi-natural grassland	SIGC	Baseline changed to permanent semi-improved grassland grazed by sheep
HL10	Restoration of moorland	SIGSh(up)drained peat	Initial increase in CH_4 emissions year 1
HL11	Creation of upland heathland	SIGSh(up)drained peat	Initial increase in CH_4 emissions year 1, no grazing during years 1 to 5
HL8	Restoration of rough grazing for birds	SIGSh(up)drained peat	Initial increase in CH_4 emissions year 1
HQ7	Restoration of fen	Scrub (lowland drained organic soil)	Increase in CH_4 emissions of fen habitat scenario
HQ8	Creation of fen	Cultivated (lowland) drained cultivated organic soil	Increase in CH_4 emissions of fen habitat scenario

3.2.5. Trends in option uptake

Most options have increased in uptake since 2007. Notable increases (>1000 ha) are evident for the key ELS options 4 and 6 m buffer strips on cultivated land and the removal of field corners from management on lowland grassland. Over 408,500 m of new hedgerows have been planted and an additional 3,100 and 17,600 trees protected on arable and grassland respectively. The Management of woodland edges (EC4) decreased by 4,100 ha.

An increase of between 300 and 500 ha has occurred for the key HLS options Creation of fen (HQ8) and Creation of woodland inside or outside the SDA (HC9 and HC10). Significant areas are now under agreement within the moorland restoration options (an increase of over 220,000 ha in comparison to 2007) and Restoration of rough grazing for birds (an additional 11,000 ha). This represents a transfer from previous ESA and CSS agreements now expired. The area within option HQ9 (Maintenance of lowland raised bog) has decreased by almost 5,000 ha. This option itself is not calculated as responsible for a decrease in GHG emissions however it does ensure preservation of high SOC stores.

The organic options have increased in area in most cases. Increases of above 100 ha are present for key options 4 m and 6 m buffer strips on rotational land (OE2, OE3 and OHE3) and Field corner management (OF1).

3.2.6. Revision of BD2302 ES scheme impact, calculation of and comparison with current impact of ES scheme on UK agricultural GHG emissions

The area (ha) devoted to each evaluated ES option provided by Natural England enabled the impact of ES options relative to the Quantified Emission Limitation or Reduction Commitments (QELRC), the 5.2% GHG emissions reduction target that industrialised nations are committed to between 2008 and 2012 under The Kyoto Treaty, on a national scale to be calculated (Warner *et al*., 2008). This figure has been recalculated using the revised emission factors and, where relevant, modified baseline and option management scenarios. It has been compared with UK agricultural GHG emissions for 1990 (Table 3.8) and the Low Carbon Transition Plan (LCTP) (DECC, 2009) that targets a 3 Mt CO_2e reduction in England by 2020. In the previous assessment (Warner *et al*., 2008) Natural England advisors matched ESA and CSS options to an ES equivalent option to allow their inclusion within the calculations. These ESA and CSS agreements have, in most cases, now ended and, where agreements renewed, will have continued as the equivalent ES option. The area devoted to these renewed agreements is included in the 2010 ES uptake data provided by Natural England. The Fourth Carbon Budget Report (Committee on Climate Change, 2010a) calculates the potential reduction in GHG emissions via strategies that do not displace production. They include (but are not limited to) optimal application of N fertiliser, the manipulation of ruminant diet to reduce enteric fermentation and manure storage. The contribution to the 2020 agricultural GHG reduction for England (DECC, 2009) by ES options that do not displace production, further sub-divided as Category 1 and Category 2 mitigation, has been estimated. The Category 2 is a 'best case' estimate, it does not assume transfer of production overseas or a significant change in land use to absorb the displaced production, but emissions associated with the baseline production remain, the CO_2 emissions from the degradation of organic soils are removed. The UK inventory for agriculture currently excludes CO_2 emissions from degraded upland peat soils (Natural England, 2010c). Category 2 emission reductions from options implemented on upland peat / organo-mineral soils, where applicable, have been excluded from the percent reduction estimate in Table 3.8.

Table 3.8. Mean annual (five year average) C mitigation$_{(EDP)}$ potential of ES (t CO_2e) and estimated total percent reduction of annual UK agricultural GHG emissions (excluding CO_2 emissions from upland soils), 2020 target (total and where financial cost applicable) and percent reduction from Category 1 and Category 2 mitigation.

	t CO_2e year^{-1}
ELS	-850,000
[1]HLS	-3,200,000
OELS	-40,000
Total mean per year	-4,000,000
[2]UK 1990 agricultural GHG emissions	61,000,000
[2]%UK 1990 agricultural GHG emissions$_{(EDP)}$	-3.6%
% UK 1990 agricultural GHG emissions Category 1	-0.1%
[2]% UK 1990 agricultural GHG emissions Category 2	-0.03%
[2]England target reduction agricultural GHG emissions by 2020	3,000,000
% ES Category 1	-2.3%
[2]% ES Category 2	-0.6%
[2,3]Estimated England target reduction agricultural GHG emissions by 2020 incurring a cost of up to £40 t^{-1} CO_2e ha^{-1}	750,000
% ES Category 1	-9.0%
[2]% ES Category 2	-2.6%

[1] including estimate for HL15 Seasonal livestock exclusion supplement + 'other' (not specified) options
[2] excluding emissions from degraded upland soils
[3] estimate (25%) based on ratio 2 Mt CO_2e achievable at cost of <£40 tCO_2e to 6 Mt CO_2e achievable at zero cost for first agricultural Marginal Abatement Cost Curve (MACC) of 8 Mt CO_2e target reduction (Committee on Climate Change, 2010b).

The 3 Mt CO_2e target for 2020 includes strategies that do not incur an additional cost i.e. zero income foregone, that would not qualify under ES. The first agricultural Marginal Abatement Cost Curve (MACC) (Committee on Climate Change, 2010b) estimated that such strategies contributed to 75% of this target. The remaining 25%

of reductions therefore, could potentially qualify under ES. This percentage has been applied to the 3 Mt CO2e target for 2020 against which mitigation achieved by Category 1 and Category 2 options has been calculated. Category 1 options contribute an estimated 9% to the target for emissions reduction that incurs an additional cost and 11.6% in total for Category 1 and 2. The range in uptake is between 640 ha (EJ13 Winter cover crops), almost 8,000 ha (EJ2 Management of maize crops to reduce soil erosion) and 610,000 ha (HL15 Seasonal livestock exclusion supplement + 'other' (not specified) options). A decrease in area has not been observed for most ES options although the Category 1 option EJ10 (Management of maize crops to reduce soil erosion) decreased by just over 4,000 ha since 2007. Relative to the overall area devoted to ES, most options comprise a relatively small proportion of the area.

4.0. DISCUSSION

Environmental Stewardship continues to reduce UK GHG emissions$_{(EDP)}$. An increase in area of key options has meant this reduction$_{(EDP)}$ is greater in comparison to the previous assessment by Warner *et al*. (2008). A comprehensive review of all option management specifications has not identified any significant increase in GHG emissions as a result of stipulated changes to management (Natural England, 2010ab). Where changes have been identified, the impact is minimal (e.g. an additional years mowing permitted results in additional fuel consumption but in practice mowing for one year remains sufficient). The discussion has focused on the impact of new options and options not previously included by Warner *et al*. (2008), and the impact on agricultural production and displacement risk where possible, although it has not been quantified in the analysis. The displacement of production, the impact of producing and importing the same agricultural commodity from another country to replace any commodity where production has been reduced, has been identified as a potential issue where land is removed from production as a consequence of converting the land into an ES agreement. A number of ES options reduce GHG emissions but do not require the removal of land from production. This, in essence, is true GHG mitigation.

On cultivated land the new ES option E/HJ13 allows payment for the growing of a winter cover crop preceding spring sown crops on sandy soils. The mitigation of NO_3^- leaching include winter cover crops, reported to reduce N leaching by between 25 and 50 kg N ha^{-1} (Silgram and Harrison, 1998) equivalent to 0.25 – 0.5 kg N_2O-N ha^{-1} (IPCC, 2006; Jackson *et al*., 2009). The precise impact is dependent on field specific variables such as winter rainfall, the soil N content (Soil Nitrogen Supply index) and soil type (RB209, 2010). At current levels of option uptake (641 ha), this equates to between 0.16 and 0.32 t CO2e ha^{-1} year^{-1}. An additional benefit of cover crops is the prevention of soil loss by wind erosion (Duncan, 2008) and the nutrients and soil organic carbon (SOC) contained within that soil. Removal of the cover crop with a light cultivation also adds further biomass C to the soil (Freibauer *et al*., 2004).

Soil protection options on cultivated land e.g. E/HJ2 (Management of maize crops to reduce run off and erosion) also do not remove land from production. Where soil erosion occurs, the removal of C within that eroded soil may not necessarily result in its mineralisation to CO_2, for example, if it is washed into a watercourse where anaerobic conditions prevent its oxidation. The layer of soil equivalent to the depth that is eroded that was not previously disturbed by tillage will however, then become exposed to cultivation and risk of accelerated SOC oxidation and increased CO_2 emissions (Dawson and Smith, 2007). Where soil erosion is prevalent, increased surface run-off on land subject to continual N fertilisation increases the indirect emission of N_2O from soils (IPCC, 2006; Jackson *et al*., 2009). The prevention of erosion is coupled with reduced indirect soil N_2O emissions. The undersowing of cereal or maize crops with clover, also a requisite of option E/HJ2, provides N to the crop with the potential to substitute part of the inorganic N fertiliser requirement. Inorganic N fertiliser is identified by several Life-cycle Assessments of agricultural production as a chief contributor to GHG emissions (Tzilivakis et al., 2004; Williams *et al*., 2009). A 20 – 30% clover composition within grassland supplies up to 180 kg N ha^{-1} (RB209, 2010) however sole dependency on clover as a source of N may not be viable because its growth and capacity to fix N is temperature dependent. Application of inorganic N is a requirement during early spring when lower temperatures inhibit N fixation by the clover plant (RB209, 2010).

Certain ES management specifications on grassland reinforce the requirements of Cross Compliance (Defra, 2006) (e.g. avoidance of soil compaction via movement of ring feeders, avoidance of poaching and not entering the field when wet to prevent soil compaction). The grazing of livestock on wet soils also risks soil compaction. This in turn inhibits grass growth and biomass formation by up to 13% and 35% for topsoil and subsoil compaction respectively (Louwagie *et al*., 2008). Excessive grazing by livestock on wet soils may cause topsoil compaction. A decrease in grass growth equates to a reduction in potential SOC accumulation and the SOC at equilibrium of the specified area of grassland. The housing of livestock during the winter has been cited as a potential GHG mitigation strategy (Moorby et al., 2007). It does not necessarily require a reduction in stocking rates or a change of dominant land use. The removal of stock from grassland during the winter when there is negligible active grass growth prevents the deposition of N onto grass that will not utilise it immediately. Removal of N deposition during periods of greater daily rainfall in the winter reduce the risk of leaching and surface run-off of that N (Moorby *et al*., 2007, Schils *et al*., 2008). Environmental Stewardship options that permit winter stock removal are most likely to be applicable to sheep since cattle tend to be housed during the winter as standard procedure. The housing of livestock increases the quantity of manure produced, with associated GHG emissions that must be accounted for, the magnitude of which critically are dependent on the method of manure storage. The FYM has been assumed stored in unconfined piles or stacks which has been calculated to produce greater quantities of N_2O than storage as a liquid (slurry). For the full benefit of winter housing to be realised, manure storage strategies that minimise N_2O and CH_4 emissions need to be employed. For example, the Fourth Carbon Budget Report (Committee on Climate Change, 2010a) stipulates the covering of lagoons & slurry tanks as a means of agricultural GHG mitigation. Emissions of N_2O may be reduced from solid manures by the covering of manure heaps (Chadwick, 2005).

Option supplements HL15 (Seasonal livestock exclusion) and HP11 (Saltmarsh livestock exclusion supplement) allow the removal of stock (mainly sheep) from certain habitats e.g. moorland, during the winter but they are not necessarily housed. Again, no net reduction in stocking rate and therefore production is required. The impact on the net GHG balance depends on where the stock are grazed during the winter. Their removal from habitats dominated by organic soils e.g. moorland may be beneficial if they are grazed where firstly, waterlogging is not such a risk and secondly, dominated by mineral soils as opposed to organic soils. Deposition of N onto waterlogged soils (e.g. water meadow or salt marsh) during the winter increases the risk of denitrifcation (Machefert *et al*., 2002) although rates are unlikely to increase until soil temperatures rise during the spring. Relocation of stock during the winter onto fields less susceptible to flooding reduces the N deposited and present where anaerobic soil conditions will persist for longer after soil temperatures increase. Deposition of N onto organic soils increases the proportion of N that is denitrified (DeVries *et al*., 2003). While denitrification will be an inevitable consequence on all soils, it may be reduced where grazing during the winter on habitats dominated by organic soils prone to waterlogging is substituted with grazing on land dominated by mineral soils. It is acknowledged that this is location dependent and may not be a viable option on all farms.

The second category of options that achieve an element of 'true' mitigation remove land from production but their impact on GHG emission reduction$_{(EDP)}$ is enhanced due to site specific variables (i.e. if the displaced production is sited elsewhere there remains a net decrease in emissions in comparison). The preservation of peat soils as a means to mitigate GHG emissions is identified as a priority by several authors (Dawson and Smith, 2007; Dyson *et al*., 2009; Schils *et al*., 2008; Ostle *et al*., 2009). Their removal from cultivation, where CO_2 emissions may be significant (Freibauer, 2003; Ostle *et al*., 2009; Schils *et al*., 2008) due to drainage and loss of the anaerobic soil conditions conducive with peat formation is targeted. It is acknowledged that the rewetting of organic rich soils may initially increase CH_4 emissions (Worrall *et al*., 2003; Lindsay, 2010). This initial increase does not persist on peat bogs (Mojeremane *et al*., 2010) because of the greater proliferation of desirable vegetation such as *Sphagnum* species in response to the restoration process (Lindsay, 2010). The HLS option HQ8 typically recreates fen on land that is cultivated. Fen contains deep layers of highly organic C rich soils (Carey *et al*., 2008). Although this option effectively displaces any production on land elsewhere, if that production were to be taken up on non-organic soils, the inhibition of additional CO_2 emissions from the accelerated mineralisation of the organic soil layers results in a net mitigation effect. A relatively small area (374 ha) is currently under management within this option but has increased in comparison to 2007. The area designated as restoration of moorland within HLS has increased in area significantly, mostly because of transfer from previous ESA agreements. Restoration occurs on semi-improved grassland where improvements, notably drainage, have been undertaken. Restoration reverses the drainage process and the release of CO_2 from drained organic soils.

Other options that remove land from production but reduce GHG emissions in addition to those solely production related include the soil protection options E/HJ5 (In-field grass areas to prevent erosion or run-off) on cultivated land that prevent the loss of SOC and additional N_2O emissions from run-off. The introduction of 12 m width grass buffer strips on cultivated land (E/HJ9) carries an additional filtering capacity compared to smaller widths to prevent surface run-off entering watercourses. The NO_3^- within the run-off is utilised by the grass within the buffer strip.

New options for implementation on the field peripheries have the potential to enhance biomass but with a negligible impact on agricultural production. Option UB14 allows the 'gapping up' of hedgerows or the laying of stems at an angle, both of which increase the hedge biomass for a given hedge height. Option EC23 permits additional tree biomass within the hedge line.

A small number of options risk increased GHG emissions$_{(EDP)}$. Skylark plots (option EF8) necessitate the creation of bare ground that continues to receive inputs of agro-chemicals (associated with the baseline winter wheat scenario in this case). Due to practicalities associated with the small plot size, management is identical to the surrounding cereal crop. Use of precision application techniques may allow the removal of unnecessary agro-chemical application (N fertiliser would be the priority) to the uncropped plots with an associated decrease in emissions, although it is acknowledged that the technology is not available to all farms. Bare ground inevitably eliminates the C associated with crop biomass and increases the net GHG emissions. An alteration to the management stipulation prefers removal of the crop with a herbicide, as opposed to the turning off of the seed drill, has increased the net GHG emissions further. Plot sizes are however small (36 m^2) and do not represent large areas overall. The use of precision application techniques would help reduce the emission increase associated with this option. On organic land the inclusion of a grass ley within the rotation accumulates SOC and nullifies the loss of biomass. Option HC20 (Restoration of traditional orchards) assumes a 'worse case' scenario where scrub is removed and the number of stock are increased (to allow grazing of the area where scrub is removed) albeit only slightly. Alternative management could include removal of a proportion (but not all) scrub, for example, allow 5% of the area to remain, and the planting new trees where scrub clearance has occurred. The Restoration of sand dunes (HC29) introduces light grazing by sheep. Although this results in a net increase in emissions, the restored land supports a small amount of agricultural productivity in combination with the desired habitat outcome.

The restoration of lowland heathland also risks increased net GHG emissions$_{(EDP)}$ although this is variable and dependent on the land use from which it is restored, and the topography of that land. Lowland heathland may be classed as wet or dry. Wet heathland is present where the soil surface is just above the level of the groundwater and may be periodically flooded (groundwater gley soils). Dry heathland exists on more elevated areas that remain dry throughout the year. Both are present on organo-mineral soils (Catt, 2010) but are distinguished by the depth of the organic soil layer above the mineral layer. The periodic flooding of wet heathland allows the formation of a deeper organic layer above the mineral soil layer. The removal of this periodic flooding will result in the drying of the organic layer, the oxidation of the SOC and emission of CO_2. On cultivated land, frequent tillage will accelerate this process further while forestry potentially lowers the water table and creates drier soil conditions for most of the year, and risks oxidation of this deeper organic layer and increased emissions of CO_2. The restoration of lowland heathland, specifically former wet heathland, on cultivated land, grassland or forestry land presents the opportunity to reduce CO_2 emissions from the soil. On dry heathland the impact of afforestation on SOC is likely to have been negligible because the existing soil conditions were dry and further drying of the soil will not have occurred. Restoration via deforestation replaces tree biomass with dwarf shrub plant communities and has a corresponding loss of biomass C. This is partially compensated for by a reduction in soil CO_2 emissions on wet heathland but for both wet and dry heathland, a net increase in CO_2 emissions results which is unavoidable. Restoration management that prompts more rapid establishment of heathland vegetation (for example reseeding) or, on wet heathland, an increase in appropriate water depth (for example removal of any drainage) will minimise this inevitable increase.

The UK GHG inventory for agriculture calculates GHG emissions based on factors such as numbers of livestock or quantity of N applied. Identification of emission reduction is limited to an associated reduction in livestock numbers (displaced production risk) or quantity of N applied, and a proportional reduction in GHG emissions from N deposition and enteric fermentation. The Category 1 reductions identified in this report (e.g. Winter livestock removal) would be overlooked. A comparable situation exists for cultivated cropping where GHG emissions are calculated as a direct proportion of N fertiliser applied, but do not account for the timing of application or management interventions such as winter cover crops on N leaching. The Fourth Carbon Budget Report (Committee on Climate Change, 2010) calculates that Category 1 equivalent mitigation has the potential to reduce UK agricultural GHG emissions by between 8.6 and 18.9 Mt CO_2e by 2022. Strategies include more efficient use of nutrients, modification of livestock diets, and alteration to methods of manure management. These strategies specifically, are not currently included within ES. Environmental Stewardship has a potentially important role where compensation permits crop or livestock management with Category 1 mitigation potential but incurs additional costs to the land manager (for example, winter cover crops). Payment for the modification to livestock diets or purchase of nitrification inhibitors, identified by the Committee on Climate Change (2010) and Lewis et al. (2010), where there is associated income foregone, could also be included within ES.

Environmental Stewardship is also pivotal in the restoration and maintenance of high C containing organic soils (Category 2), identified throughout Europe as a key GHG mitigation strategy (Schils *et al*., 2008). Greenhouse gas reductions achieved via carbon sequestration in soils is not permanent, that is, the benefit may be reversed if reversion to the original management occurs. Large areas of moorland are included within ES agreements and, although upland soils are not currently included in the UK agricultural GHG emissions inventory (Committee on Climate Change, 2010), CO_2 emissions from degraded upland soils could be significant if managed inappropriately. Environmental Stewardship agreements ensure sympathetic management of these large areas. Further, the potential risk posed to degraded organic soils by changes in climate (alteration to precipitation and temperature) that risks accelerated degradation of non-pristine areas reinforces the importance of their continued sympathetic management.

5.0. REFERENCES

Abberton, M.T., Marshall, A.H., Humphreys, M.W., Macduff, J.H. Collins, R.P. and Marley, C.L. (2008) Genetic Improvement of Forage Species to Reduce the Environmental Impact of Temperate Livestock Grazing Systems. Advances in Agronomy, 98, 311-355.

ADAS (2007a) Rationale for the proposed NVZ Action Programme measures. ADAS report to Defra – supporting paper D4 for the consultation on implementation of the Nitrates Directive in England. July 2007.

Akers P., Allcorn R.I. (2006). Reedbed creation through excavation of dry grassland and infilling of former gravel workings at Dungeness RSPB reserve, Kent, England. Conservation Evidence, 3, 94-95.

Bell, M. J. and Worrall, F. (2009). Estimating a region's soil organic carbon baseline: The undervalued role of land management. Geoderma 152, 74-84.

Bradley, R.I., Milne, R., Bell, J., Lilly, A., Jordan, C. and Higgins, A. (2005) A soil carbon and land use database for the United Kingdom. Soil Use and Management, 21, 363–369.

BSI (2008). PAS 2050:2008. Specification for the assessment of the life cycle greenhouse gas emissions of goods and services. Publicly Available Specification. British Standards Institute, Carbon Trust, Department for Environment, Food and Rural Affairs (Defra). ISBN 978 0 580 50978 0.

Cannell, M.G.R., Milne, R., Hargreaves, K.J., Brown, T.A.W., Cruickshank, M.M., Bradley, R.I., Spencer, T., Hope, D., Billet, M.F., Adger, W.N., Subak, S. (1999). National inventories of terrestrial carbon sources and sinks: the UK experience. Climatic Change 42, 505-530.

Carey, P.D., Wallis, S., Chamberlain, P.M., Cooper, A., Emmett, B.A., Maskell, L.C., McCann, T., Murphy, J., Norton, L.R., Reynolds, B., Scott, W.A., Simpson, I.C., Smart, S.M. and Ullyett, J.M. (2008) Countryside Survey: UK Results from 2007. NERC/Centre for Ecology & Hydrology, 105pp. CEH Project Number: C03259.

Catt, J. (2010). Hertfordshire Geology and Landscape. Hertfordshire Natural History Society with Hertfordshire Geological Society. ISBN 978-0-9521685-9-1.

Committee on Climate Change (2010a). The Fourth Carbon Budget. Reducing emissions through the 2020s.

Committee on Climate Change (2010b). Meeting Carbon Budgets – ensuring a low-carbon recovery. 2nd Progress Report to Parliament.

Chadwick, D.R. (2005) Emissions of ammonia, nitrous oxide and methane from cattle manure heaps: effect of compaction and covering. Atmospheric Environment, 39, 787–799.

Chambers, B.J., Lord, E.I., Nicholson, F.A. and Smith, K.A. (1999) Predicting nitrogen availability and losses following application of organic manure to arable land: MANNER. Soil Use and Management, 15, 137-143.

Conant, R.T., Paustian, K. and Elliott, E.T. (2001) Grassland Management and Conversion into Grassland: Effects on Soil Carbon. Ecological Applications, 11, 343-355.

Dawson, J.J.C. and Smith, P. (2007) Carbon losses from soil and its consequences for land-use management. Science of the Total Environment, 382, 165–190.

Department of Energy and Climate Change (DECC) (2009). Low Carbon Transition Plan (LCTP). The Stationary Office, UK.

Department for Environment, Food and Rural Affairs (Defra). 2003. Investigation of varietal characteristics required for sustainable agriculture. Final Report for project VSO128 undertaken by the National Institute of Agricultural Botany (NIAB) and the University of Hertfordshire.

Department for Environment, Food and Rural Affairs (Defra), 2005a. Entry Level Stewardship Handbook. PB10355. February 2005.

Department for Environment, Food and Rural Affairs (Defra), 2005a. Higher Level Stewardship Handbook. PB10382. February 2005.

Department for Environment, Food and Rural Affairs (Defra), 2005a. Organic Entry Level Stewardship Handbook. PB10381. February 2005.

Department for Environment, Food and Rural Affairs (Defra) (2006). Single Payment Scheme Cross Compliance Handbook for England 2006 edition. PB 11305. Crown copyright 2005.

Department for Environment, Food and Rural Affairs (Defra) (2007). Single Payment Scheme Cross Compliance Handbook for England Supplement for 2007. PB 12276. Crown copyright 2006.

Department for Environment, Food and Rural Affairs (Defra), (2009). Guidance for Farmers in Nitrate Vulnerable Zones. Standard values, manure sampling protocol and glossary. Leaflet 3. PB12736c. April 2009.

Department for Environment, Food and Rural Affairs (Defra) (2009). Guidance for Farmers in Nitrate Vulnerable Zones. Leaflet 3. Standard values, manure sampling protocol and glossary. PB12736c. Crown copyright 2009.

Department for Environment, Food and Rural Affairs (Defra) (2010). Fertiliser Manual (RB209) 8th Edition. PB13381. TSO (The Stationery Office)

Dyson, K.E., Thomson, A.M., Mobbs, D.C., Milne, R., Skiba, U., Clark, A., Levy, P.E., Jones, S.K., Billett, M.F., Dinsmore, K.J., van Oijen, M., Ostle, N., Foereid, B., Smith, P., Matthews, R.W., Mackie, E., Bellamy, P., Rivas-Casado, M., Jordan, C., Higgins, A., Tomlinson, R. W., Grace, J., Parrish, P., Williams, M., Clement, R., Moncrieff, J. and Manning, A. (2009) Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry. Ed: K.E. Dyson. Annual Report, July 2009. Department for the Environment, Food and Rural Affairs Climate, Energy and Ozone: Science and Analysis Division Contract GA01088.

Falloon, P., Powlson D. and Smith, P. (2004) Managing field margins for biodiversity and carbon sequestration: a Great Britain case study. Soil Use and Management, 20, 240-247.

Follett, R.F., Kimble, J.M. and Lal, R. (2001) The potential of U.S. grazing lands to sequester soil carbon. pp 401-430 in R. F. Follett, J. M. Kimble and R. Lal (eds). The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. Lewis Publishers, Boca Raton, FL.

Freibauer, A. (2003) Regionalised inventory of biogenic greenhouse gas emissions from European agriculture. European Journal of Agronomy, 19, 135-160.

Grant, S.A., Armstrong, H.M. (1993). Grazing ecology and the conservation of heather moorland: the development of models as aids to management. Biodiversity and Conservation 2, 79-94.

Hensen A, Groot TT, van den Bulk WCM, Vermeulen AT, Olesen JE, Schelde K. 2006. Dairy farm CH_4 and N_2O emissions, from one square metre to the full farm scale. Agriculture Ecosystems & Environment 112. 146-152.

IPCC (2006) 2006 Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa.

ISO 14040 Environmental management - Life cycle assessment (Principles and Framework). 1997. International Organization for Standardization.

ISO 14041 Environmental management - Life cycle assessment (Goal, Scope and Inventory Analysis). 1998. International Organization for Standardization.

ISO 14042 Environmental management - Life cycle assessment (Life Cycle, Impact Assessment). 2000. International Organization for Standardization.

ISO 14043 Environmental management - Life cycle assessment (Life Cycle Interpretation). 2000. International Organization for Standardization.

Jackson, J., Choudrie, S., Thistlethwaite, G., Passant, N., Murrells, T., Watterson, J., Mobbs, D., Cardenas, L., Thomson, A. and Leech, A. (2009) UK Greenhouse Gas Inventory, 1990 to 2007: Annual Report for submission under the Framework Convention on Climate Change. ISBN 0-9554823-8-0. http://www.airquality.co.uk/reports/cat07/0905131425_ukghgi-90 07_main_chapters_Issue2_UNFCCC_CA_v5_Final.pdf.

King, J.A., Bradley, R.I., Harrison, R. and Carter, A.D. (2004) Carbon sequestration and saving potential associated with changes to the management of agricultural soils in England. Soil Use and Management, 20, 394-402.

Lampkin, N., Measures, M. and Padel, S., 2004. 2004 Organic farm management handbook 6th Edition. Organic Farming Research Unit, Institute of Rural Sciences, University of Wales, Aberystwyth UK and Organic Advisory Service, Elm Farm Research Centre.

Lewis, K. A., Tzilivakis, J., Green, A. and Warner, D.J. (2010). The climate change mitigation potential of an EU farm: towards a farm-based integrated assessment. ENV.B.1/ETU/2009/0052. Final Report for DG Environment, European Commission.

Lindsay, R. (2010). Peatbogs and carbon. A critical synthesis. University of East London.

Machefert, S.E., Dise, N.B., Goulding, K.W.T. and Whitehead, P.G. (2002). Nitrous oxide emission from a range of land uses across Europe. Hydrology and Earth System Sciences, 6, 325-337.

Monteny, G., Bannink, A. and Chadwick, D. (2006). Greenhouse gas abatement strategies for animal husbandry. Agriculture, Ecosystems and Environment, 112, 163-170.

Moorby, J.M., Chadwick, D.R., Scholefield, D., Chambers, B.J. and Williams, J.R. (2007). A review of best practice for reducing greenhouse gases. Defra project report AC0206.

Mojeremane, W., Rees, R.M., Mencuccini, M. (2010). Effects of site preparation for afforestation on methane fluxes at Harwood Forest, NE England. Biogeochemistry 97, 89-107.

Natural England (2010a). HLS Handbook 3rd edition 2010.
Natural England (2010b). ELS Handbook 3rd edition 2010.
Natural England (2010c). England’s peatlands: Carbon storage and greenhouse gases.

Oenema, O., Wrage, N., Velthof, G.L., van Groenigen, J.W., Dolfing, J. and Kuikman, P.J. (2005) Trends in global nitrous oxide emissions from animal production systems. Nutrient Cycling in Agroecosystems, 72, 51–65.

Ogle, S.M., Breidt, F.J., Eve, M.D. and Paustian, K. (2003) Uncertainty in estimating land-use and management impacts on soil organic carbon storage for U.S. agricultural lands between 1982 and 1997. Global Change Biology, 9, 1521-1542.

Ostle, N.J., Levy, P.E., Evans, C.D. and Smith, P. (2009) UK land use and soil carbon sequestration. Land Use Policy, 26, S274-S283.

Schils, R.L.M., Oleson, J.E., del Prado, A. and Soussana, J.F. (2008) A review of farm level modelling approaches for mitigating greenhouse gas emissions from ruminant livestock systems. Livestock Science, 112, 240-251.

Self, M, Hawke, C, José, P (1996). Reedbed enhancement and creation at RSPB nature reserves. RSPB Conservation Review 10, 45-53

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. and Smith, J. (2008) Greenhouse gas mitigation in agriculture. Philosophical Transactions Royal Society of London Biological Sciences, 363, 789-813.

Smith, P., Powlson, D. S., Smith, J.U., Falloon, P. and Coleman, K. (2000a) Meeting the UK's climate change commitments: options for carbon mitigation on agricultural land. Soil Use and Management, 16, 1-11

Smith, P., Powlson, D. S., Smith, J.U., Falloon, P. and Coleman, K. (2000b) Meeting Europe's climate change commitments: quantitative estimates of the potential for carbon mitigation by agriculture. Global Change Biology, 6, 525-539.

Smith, P., Milne, R., Powlson, D. S., Smith, J. U., Falloon, P. and Coleman, K. (2000c) Revised estimates of the carbon mitigation potential of UK agricultural land. Soil Use and Management, 16, 293-295

Smith, J.U., Bradbury, N.J. and Addiscott, T.M. (1996) SUNDIAL: A PC-based system for simulating nitrogen dynamics in arable land. Agronomy Journal, 88, 38-43.

Smith, K. A. and Conen, F. (2004) Impacts of land management on fluxes of trace greenhouse gases. Soil Use Management, 20, 255–263.

Sommer, S.G., Petersen, S.O., Sørensen, P., Poulsen, H.D. and Møller, H.D. (2007) Methane and carbon dioxide emissions and nitrogen turnover during liquid manure storage. Nutrient Cycling in Agroecosystems, 78, 27-36.

Soussana, J.F., Loiseau, P., Viuchard, N., Ceschia, E., Balesdent, J., Chevallier, T., Arrouays, D. (2004) Carbon cycling and sequestration opportunities in temperate grasslands. Soil Use Management, 20, 219–230.

Svensson, B.H. and Sundh, I. (1992). Factors affecting methane production in peat soils. SUO – Mires and Peat 43, 183-190.

Thomas, C. (2004) Feed into Milk (FiM): a New Applied Feeding System for Dairy Cows. Nottingham University Press, UK.

Tuittilla, E.S., Komulainen, V.M., Vasander, H., Nykanen, H., Martikainen, P.J. and Laine, J. (2000). Methane dynamics of a restored cut-away peatland. Global Change Biology 6, 569-581.

Tzilivakis, J., Warner, D. J., May, M., Lewis, K. A. and. Jaggard, K., 2005a. An Assessment of the Energy Input for Sugar Beet (Beta vulgaris) Production in the UK. Agricultural Systems, 85, 101-119. .

Tzilivakis, J., Jaggard, K., Lewis, K.A., May, M., Warner, D.J., 2005b. Environmental impact and economic assessment for UK sugar beet production systems. Agriculture Ecosystems & Environment, 107, 341-358.

Warner, D.J., Tzilivakis, J., Lewis, K.A. (2008). Research into the current and potential climate change mitigation impacts of environmental stewardship. Final Report for Department for Environment, Food and Rural Affairs (Defra) Project BD2302.

Warner, D.J. Davies, M., Hipps, N., Osborne, N., Tzilivakis, J. and Lewis, K.A. (2010) Greenhouse gas emissions and energy use in UK grown short-day strawberry (*Fragaria xananassa*) crops. Journal of Agricultural Science, 148, 667-681.

Williams, A.G., Audsley, E. and Sandars, D.L. (2009) Environmental Burdens of Agricultural and Horticultural Commodity Production - LCA (IS0205) version 3. Cranfield University, UK.

Williams, A.G., Audsley, E. and Sandars, D.L. (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.

Worrall, F., Reed, M.S., Warburton, J., Burt, T.P. (2003). Carbon budget for a British upland peat catchment. Science of the Total Environment 312, 133–146.

Worrall, F., Bel, M., Bhogal, A. (2010). Assessing the probability of carbon and greenhouse gas benefit from the management of peat soils. Science of the Total Environment 408, 2657–2666.

6.0. APPENDICES

6.1. Revisions to existing management scenarios

Tables A1 and A2 highlight where changes in management have been specified within the ES handbooks, or review of the original BD2302 scenarios has highlighted a need to change the management. Where 'comment' is stated it is proposed that the potential impact on GHG emissions is commented on rather than included in the calculations. This may be where there is potential uncertainty associated with the impact to allow quantification with confidence, or where the impact does not occur on all areas where the option is implemented. For example, the statement 'avoid poaching by livestock' does not assume that where the option is implemented, poaching will necessarily occur but the potential impact of poaching, should it be allowed, could be commented on.

Table A1. Revised options (from handbooks).

Code	Option	Baseline	Change in management
EC1	Protection of in-field trees on arable land	WW	Specifies a 10 m radius from the base of the tree' must be used as a minimum where the prescription refers to 'the tree canopy' and management must not occur within 2m of the canopy. Altered to a 12 m radius.
EC2	Protection of in-field trees on grassland	Temporary grassland	Altered to a 12 m radius, no reduction stocking rate
OC1	Protection of in-field trees on rotational land	OWW	Altered to a 12 m radius.
OC2	Protection of in-field trees on organic grassland	Organic temporary grassland	Altered to a 12 m radius.

Table A2. Modified option management (from BD2302 management scenarios) due to change in wording of option specifications / review of original option management scenarios.

Code	Option	Baseline	Change to management specifications
EB1 & EB2	Hedgerow management	WW	Addition of text to avoid poaching and run-off (re-enforces)
EC4	Management of woodland edges	WW	Specification to not cultivate within 6 m of woodland edge (adjusted from 2 m); allow scrub growth of up to 50% (previously calculated as one third of the area and cut every 3 years)
ED2	Take out of cultivation archaeological features	WW	Reseeding by slot seeding (no cultivation during reseed operation)

	currently on cultivated land		
ED5	Archaeological features on grassland	Permanent instead of temporary grassland	Mainly applicable to areas of ridge and furrow
EE1-3	Buffer strips on cultivated land	WW	Establishment mainly by sowing; regular cutting for weed control up to 24 months (was 12 which should remain sufficient); control woody growth max every 2 years (was 5).
EE7	Buffering in-field ponds in improved permanent grassland	Permanent instead of temporary grassland	Now specifies on permanent grassland (scenario previously used temporary grassland); as for EE1-3
EE7	Buffering in-field ponds in cultivated land	WW	Specifies no areas of compaction, poaching or tracks from vehicles; as for EE1-3
EF1	Management of field corners	WW	as for EE1-3
EF2	Wild bird seed mixture	WW	Specifies that 'Large-seeded crops (such as maize) and game covers (such as giant sorghum or sweet clover) are not allowed'; allows limited use of insecticides (specific products)
EF4	Nectar flower mixture	WW / temporary grassland	Specifies on both cultivated land or temporary grassland (previously cultivated land only)
EF6	Overwintered stubble	WW	Now specifies sub-soiling of headlands and 'other areas' of compaction in addition to tramlines (increase proportion of field subsoiled)
EF8	Skylark plots	WW	Gives option to 'sow the crop as normal and spray out the plots by 31 December with an appropriate herbicide' as an alternative to turning off drill (almost 100% switch to herbicide spraying)
EF9	Unfertilised cereal headlands	WW	Zero application of fertilisers and manures to headland; application of pinoxadin permitted; pre-harvest desiccant permitted if weed problem
EF10	Unharvested cereal headlands	WW (autumn) / SB (spring)	Option to sow in autumn or spring (specifies no bare ground during winter); 3-6m headland (previously up to 24m); specifies sow at reduced seed rate; vary depth of cultivation
EF11	Uncropped cultivated margins for rare plants	WW	Cultivate to 15 cm (not 20 cm)
EG1	Undersown spring cereal	WW	10 - 30% by weight clover
EG4	Cereals for whole-crop silage followed by overwintered stubble	WW	Pinoxaden permitted; light cultivation before end of September to stimulate weed growth (where absent); removal of compaction on sloping fields (comment); no agro-chemicals or grazing to stubble
EK1	Take field corners out of management	TGDC	Specifies no application of lime (already assumed in scenarios); no cutting 1 March – 31 August
EK2	Permanent grassland with low inputs	SIG(low)	Manure application permitted in spring but not where birds are nesting and ground conditions dry (manure assumed not applied in scenarios)

EK3	Permanent grassland with very low inputs	SIG(low)	Maintain structurally diverse sward (prohibit 'recreational topping' i.e. cut only areas where injurious weeds); scrub control by grazing, mowing or topping; application of lime permitted (if already undertaken); manure application permitted in spring but not where birds are nesting
EK4	Management of rush pastures	SIG(low)	No application of inorganic fertiliser permitted (previously up to 50 kg N ha^{-1}); application of lime permitted (if already undertaken); manure application permitted in spring but not where birds are nesting
EL1	Take field corners out of management in SDAs	SIG(upLFA)	Specifies no application of lime (already assumed in scenario); no cutting 1 March – 31 August; no grazing
EL2	Permanent grassland with low inputs in SDAs	SIG(upLFA)	Manure application permitted in spring but not where birds are nesting and ground conditions dry (manure assumed not applied in scenarios)
EL3	Permanent grassland with very low inputs in SDAs	SIG(upLFA)	Maintain structurally diverse sward; scrub control by grazing, mowing or topping; application of lime permitted (if already undertaken); manure application permitted in spring but not where birds are nesting
EL4	Management of rush pastures in SDAs	SIG(upLFA)	No application of inorganic fertiliser permitted (previously up to 50 kg N ha^{-1}); application of lime permitted (if already undertaken); manure application permitted in spring but not where birds are nesting
EL5	Enclosed rough grazing	UIG(upLFA non-drained)	Prevent spread of invasive species; no reseeding (already assumed in scenario)
EL6	Unenclosed moorland rough grazing	UIG(upLFA non-drained)	No reseeding (already assumed in scenario)

Table A3 summarises options no longer included in the analysis (no further change in management).

Table A3. Discontinued ES options. Option HF13 is now Option EF12 within ELS.

Code	**Option**
HF13	Fallow plots for ground-nesting birds (rotational or non-rotational)
HF15	Reduced herbicide, cereal crop management preceding over-wintered stubble and a spring crop
HF16	Cultivated fallow plots or margins for arable flora as an enhanced setaside option
HF17	Fallow plots for ground-nesting birds as an enhanced set-aside option
HF18	Reduced herbicide, cereal crop management preceding enhanced set-aside
HF19	Unharvested, fertiliser-free conservation headlands preceding enhanced set-aside
HJ5	In-field grass areas to prevent erosion or run-off (now ELS)
OG5	Brassica fodder crops followed by over-wintered stubbles
OJ1	Management of high erosion risk cultivated land

6.2. Baseline scenarios

6.2.1. Temporary Grassland with Intensive Beef Cattle within an NVZ TGIBC(NVZ) (excluding Grassland Derogation).

The total organic N applied to one forage ha does not exceed the equivalent of 170 kg N ha^{-1} farm limit for organic N (or 250 kg N ha^{-1} field limit). For an average grass growth class (RB209, 2010), to be eligible for options such as HJ7 (specifies intensive grassland) an 'intensive' lowland beef system of 1.7 LU ha^{-1} has been assumed. At a stocking rate of 1.7 LU forage ha^{-1} a total of 170 kg organic N ha^{-1} is produced (including grazing deposition) (Defra 2009 NVZ Guidance Leaflet 3). For 1.7 LU of beef cattle a total of 2.70 t DM as silage is required and occupies 0.28 ha (for a total yield of 9.5 t ha^{-1} DM (RB209, 2010)). A housing period of 151 days produces 70 kg N as FYM and 100 kg N as grazing deposition (41% N as FYM, 59% N as grazing deposition). Where clover is assumed not present (i.e. not representative of typical farm but representative of a scenario for which the option criteria are met) the required N not supplied by manures is provided by inorganic N.

Table A4. Grazing land within an NVZ: total N requirement for average growth class, average SNS, limited clover present, 210 kg N ha^{-1} in total applied in five applications of inorganic N. A soil P and K index of 2 requires an application of 20 kg P_2O_5 ha^{-1}. Nitrogen applications in italics are removed where clover (30%) is present.

	Date	**Activity**	**Product / active ingredient (equivalent per ha^{-1})**
Rotation	every 4 years	lime	ground limestone 3 t
	every 8 years	plough (20 cm)	
		power harrow	
		drill	25 kg seed
Year		stocking rate	Beef cattle 1.7 LU forage ha^{-1} (2.8 head average herd)
	Mar	P & K fertiliser	20 kg P_2O_5
	Mar	N fertiliser	50 kg N as AN
	Mar	herbicide (weedwipe)	2 l Tomahawk (fluroxypyr) (200 g l^{-1})
	Apr	chain harrow	
	May	*N fertiliser*	*40 kg N as AN*
	June	*N fertiliser*	*40 kg N as AN*
	July	*N fertiliser*	*30 kg N as AN*
	August	N fertiliser	50 kg N as AN
	winter	feed concentrates	300 kg per 0.6 LU
	winter	silage (grass)	954 kg DM per 0.6 LU

Table A5. Grass silage: N requirement for a stocking rate of 1.7 LU, 9.5 t DM ha^{-1} (38 t ha^{-1} fresh weight as wilted silage 25% DM when carted to a silage clamp) is 310 kg N ha^{-1} (Table 8.4 RB209, 2010). The British Survey of Fertiliser Practice (2010) cites a mean 130 kg inorganic N ha^{-1} applied to silage land (includes adjustment for N supplied by manures and clover) the figure used in this scenario. An area of 0.3 ha supplies 2.85 t DM (total yield 9.5 t ha^{-1}) (includes 280 kg DM silage in addition to total livestock requirement) to which 70.3 kg N ha^{-1} total N from FYM is applied (equivalent to 234 kg N ha^{-1}), equivalent to 23.4 kg available N; 75 kg available P_2O_5; 281 kg available K_2O ha^{-1} (surface applied during spring, 10% available N). An additional 0.3 t per head is supplied as concentrates.

	Date	**Activity**	**Product / active ingredient (ha^{-1})**
rotation	every 4 years	lime	ground limestone 3 t
	every 8 years	plough (20 cm)	
		power harrow	
		drill	25 kg seed
year		rolling	
	Mar	N fertiliser (ammonium nitrate)	20 kg N
	Mar	FYM	equivalent 41.2 t, 24.7 kg N; 84 kg P_2O_5; 297 kg K_2O available
	Apr	N fertiliser (ammonium nitrate)	30 kg N
	Mar	herbicide (weedwipe)	2 l Tomahawk (fluroxypyr) (200 g l^{-1})
	Apr	1st cut	
	Apr	bale	
	May	N fertiliser (ammonium nitrate)	30 kg N
	Jun	N fertiliser (ammonium nitrate)	30 kg N
	late June	2nd cut	
		bale	
	July	N fertiliser (ammonium nitrate)	20 kg N
	late July	3rd cut	
		bale	
		transport to on farm storage (2 km)	