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Spatial and temporal variability of greenhouse gas emissions from rural development land use operations

Authors: Tzilivakis, J., Warner, D.J., Green, A. and Lewis, K.A.

Affiliations: Agriculture and Environment Research Unit (AERU), School of Life and Medical Sciences, University of Hertfordshire, United Kingdom.

Address for correspondence: Dr John Tzilivakis, Agriculture and Environment Research Unit (AERU), School of Life and Medical Sciences, University of Hertfordshire, United Kingdom. AL10 9AB. Tel: +44 (0)1707 285259; Email: J.Tzilivakis@herts.ac.uk.

Abstract

Climate change objectives of mitigation and adaptation are being mainstreamed into many policies and strategies around the world. In Europe, this has included the Rural Development Programme, which aims to tackle multiple social, economic and environmental objectives in rural areas, and the integration of climate change objectives adds another strand of complexity to the decision making process. When formulating policies determining the likely effectiveness of any particular measure can be challenging, especially with respect to the spatial and temporal variability of greenhouse gas emissions. This is a challenge faced by all countries and regions around the world. This study uses Europe as an example to explore this issue. It highlights the variability in emissions from land use operations that may be encountered under different conditions and time horizons and considers this in the context of policy formulation. The Optimal Strategies for Climate change Action in Rural Areas software has been adapted to derive net greenhouse gas emissions for rural development operations for all regions in Europe. Operations have been classified into five categories based on their benefit/burden over different time horizons. The analysis shows that it is important to understand the time period over which benefits or burdens are realised and determine how this fits with policy instruments, such as land management agreements and the permanency of actions. It also shows that in some regions an operation can have benefits, but in other regions it has burdens, thus location can be critical. Finally, in the context of developing operations to meet multiple social, economic and environmental

objectives, it is important to acknowledge that seeking options that only reduce emissions may not always be practical or possible. In some instances we may have to accept an increase in emissions in order to meet other objectives. It is important that we evaluate the net greenhouse gas emissions of all operations, not just those aimed at climate change mitigation. We can then select those with the least burden in the process of developing optimal solutions to meet multiple objectives.

Keywords: greenhouse gas emissions; spatial and temporal variability; rural development; land use

1.0. Introduction

Climate change has steadily risen up the political agenda over the last 40 years and its objectives are now embedded in many policies and strategies, for example the Europe 2020 strategy (EC, 2010) is tackling climate change as one of its five headline targets. Mitigation and adaptation are two key climate change objectives. Mitigation involves actions to reduce emissions of greenhouse gases (GHGs), to reduce their concentration in the atmosphere, and adaptation involves actions to increase capacity to adapt to changes in climate. Globally 35.3 billion tonnes of carbon dioxide equivalents (tCO_2e) were emitted in 2013, with the European Union (EU) accounting for 11% (Olivier et al., 2014). Agriculture and land use change accounts for 9% of EU emissions (EC, 2009) and this figure increases to approximately 30% globally (Smith et al., 2014). In the last decade there have been efforts around the world to mainstream (integrate) mitigation and adaptation objectives into regional and national policies. For example, Asia and Africa have formed the Government Group Network for Climate Change Mainstreaming (IIED, 2014); in Europe the European Commission has been making efforts to mainstream climate change objectives into European policy (Berkhout et al., 2013); and there have been efforts to integrate climate change into national sustainable development strategies and plans in Latin America and the Caribbean (Raufer, 2013). The underlying principle of mainstreaming is that all policy sectors need to play a role in tackling climate change. In Europe this has included major policies such as the Common Agricultural Policy (CAP) including the second pillar of the CAP; the Rural Development Programme (RDP) via the European Agricultural Fund for Rural Development (EAFRD) (EC, 2013a).

The RDP, and its associated measures and operations, can be complex and attempt to tackle multiple social, economic and environmental objectives in the rural land use sector, and the addition of climate change objectives increases this complexity. Consequently, when formulating policies, determining the likely effectiveness of any particular measure or operation, with respect to any benefits or burdens for any objectives, including climate change, can be challenging (Donnellan et al., 2014; Glenk & Colombo, 2011; Plieninger et al., 2012; Van Der Ploeg et al., 2000). In particular, the potential effect of any operations in terms of net GHG emissions can be highly variable, spatially and temporally (Friedrich et al., 2003; Houghton et al., Imer et al., 2013; 2012; Schulp et al., 2008). Understanding this variability is crucial for the development and implementation of measures and operations in Europe and other countries and regions around the world, as it impacts upon potential effectiveness and, in some instances, can determine whether the impact is a benefit or a burden. This paper explores this variability using some example land use operations that have been implemented across Europe. It aims to highlight the variability in GHG emissions that may be encountered under different conditions and time horizons and provide this in a format that can be considered when formulating policies to address GHG emissions from the land use sector. In so doing, it aims to reveal a range of issues for tackling complex issues policy issues, especially where optimal solutions are required to meet multiple objectives. This has relevance for not only national and regional policies in Europe, but also for other regions and countries around the world and for global strategies and initiatives.

2.0. Methodology

2.1. Overview

Land use scenarios need to be defined and quantified in order to calculate GHG emissions. This involves defining RDP operation scenarios, i.e. where there is change from a baseline to a future scenario. This generates quantified changes in numerous land use activities and features, which can then be used to calculate the associated changes in GHG emissions for each activity and feature and thus the net GHG emissions for an operation. This process is embedded in a software tool that was developed for the European Commission. The tool, known as OSCAR (Optimal Strategies for Climate change Action in Rural Areas) (AERU, 2013 & 2014), was developed to help managing authorities across the EU to integrate climate change objectives into the RDP measures and operations post-2013. The OSCAR software was adapted for this study to generate the net GHG emissions for RDP operations for all NUTS (Nomenclature of Territorial Units for Statistics) 3 regions in the EU-27 (the 27 member states of the European Union prior to the 1 July 2013), thus facilitating the exploration of spatial and temporal variability in emissions. This involved developing automation routines to apply each RDP operation to each NUTS3 region in the EU-27 (166530 combinations); storing the output data (GHG emissions) in a database; exporting the data to Excel; and automatically generating charts (such as those shown in Section 3).

2.2. Defining RDP operations

Firstly, it is important to define what is meant by an RDP operation. The EU rural development regulation (EU, 2013) outlines around 20 broad measures that member states can select from to formulate their national or regional RDPs. The measures include investment in physical assets, afforestation, agri-environment-climate, animal welfare, knowledge transfer, etc. RDP operations are the activities that are encouraged within these measures and they are defined by member states. They are more specific and often have detailed prescriptions on how and where they should be implemented. This provides member states with the flexibility to tailor the RDP to a region to meet its specific requirements. As a consequence, there are many hundreds (with thousands of variations) of operations within RDPs across Europe, for example, a review of national and regional RDPs across the EU-27 revealed at least 2600 operations (AERU, 2013).

With regard to calculating GHG emissions from these operations, they can be grouped into the following broad categories of operations:

- Soft: for example training and education
- Maintenance: for example operations which seek to maintain specific land uses or habitats
- Management: where the land use remains the same, but there is a change in management or inputs either over the whole or part of an area
- Land use change: where the land use changes either over the whole or part of an area

- Infrastructure: improvements in farm infrastructure, for example capital input to support the purchase of new farm buildings or machinery

Modelling GHG emissions is currently only feasible for some of these operations. For example, it is difficult to model soft operations, such as training and education, as determining the impact of such activities is inherently difficult to quantify as it involves elements of behavioural change (Arneth et al., 2014; OECD, 2012; Rounsevell et al., 2012). For maintenance operations, there should be no net change in GHG emissions. However, emissions could be calculated from the perspective of what happens if there is no maintenance, as this could result in changes in emissions under some circumstances, but those circumstances need to be defined (essentially an anti-operation). However, for other operations GHG emissions can be calculated, particularly those where there are changes in management, land use or infrastructure.

Where there are quantifiable changes from a baseline to a future scenario, it becomes possible to calculate the net change in GHG emissions. This is a process of defining the RDP operation based on the changes it causes with respect to a range of activities and features. Table 1 gives an example where the RDP operation is implementing a buffer strip on cultivated land next to a watercourse. A delta (Δ) value (i.e. the change) can be derived for each activity and feature defining that RDP operation. The OSCAR software can then use this delta value to determine the GHG emissions for each activity and feature and thus the net value for the whole operation. The exact implementation of an RDP operation can vary from one location to another. Clearly it would not be feasible within the scope of this study to calculate all possible combinations of all the activities and features parameters (the example in Table 1 has 25 parameters, so the number of combinations would be vast). To overcome this, firstly values were used that were considered to be the most the typical; secondly in some instances the value was varied with spatial parameters (e.g. those marked with M in Table 1 have multiple values depending on soil type and rainfall); and thirdly where there were significantly different scenarios, variants of the operation were created as a new operation (for example, 10 buffer strip operations were created: 4 for arable land to account for different adjacent features and 6 for grassland to account for different types of grassland and livestock).

Table 1: RDP operation definition example: Buffer strips on cultivated land next to a watercourse

The example RDP operations presented herein were selected based on the results of the analysis, i.e. those which best highlight the different spatial and temporal variability scenarios that may be encountered. No other criteria were used to select them.

2.3. Summary of the OSCAR software

The OSCAR software tool was developed in 2012 (AERU, 2013 & 2014). Its development involved combining the techniques of Life Cycle Assessment (LCA) with Geographical Information Systems (GIS). ArcGIS® was used to generate Regional Variation Categories (RVCs) across Europe for spatial parameters that potentially impact upon GHG emissions (e.g. soil type and texture; soil organic carbon content; soil erosion and compaction; rainfall; climate zone; ecological zone; elevation; etc.). The RVCs are in the form of raster data containing RVC classes, where each class represents a combination of specific spatial parameters. The RVCs were then used to generate spatially variable emission factors (using a range of models (e.g. see Tzilivakis et al., 2014) which draw upon the spatial parameters in the RVCs) which were then used in an LCA for each RDP operation. For example, emissions of nitrous oxide (N_2O) from soil erosion on cultivated land (in Table 1) would be 0.000056 tonnes of carbon dioxide equivalents per hectare per year (tCO_2e ha^{-1} yr^{-1}) for a coarse textured soil with a moderate risk of soil erosion (5-10 tonnes per hectare per year (t ha^{-1} yr^{-1}) based on the Pan-European Soil Erosion Risk Assessment (PESERA) soil erosion risk assessment (Kirkby et al., 2003)), whereas for N_2O from erosion from permanent unimproved grass would be negligible. Therefore the using the delta values in Table 1, the reduction in emissions from this aspect in the operation would be 0.000056 tCO_2e ha^{-1} yr^{-1}. The OSCAR tool is essentially a meta-modelling approach, thus it has some limitations with respect to the accuracy of the emissions figures. However, it is deemed suitable for the purpose for which it was designed, albeit there is inevitably always scope for improvement, and thus it is fit for purpose for this study.

This enabled the calculation of net GHG emissions for an operation in any given location. On a more regional basis, the spatial distribution of RVCs was overlaid with NUTS3 regions, which, when combined with land use data (using the Coordination of Information on the Environment (CORINE) 2006 dataset (EEA, 2013)), allowed the calculation of potential benefits of any RDP operation in a region. Consequently, the OSCAR software provided managing authorities with a tool in which they could select their region(s) of interest, select RDP operations and set potential uptake rates, and the software provides a report on the net GHG emissions for each operation (it also provides a report on potential impacts on adaptation and production). GHG emissions are calculated for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) and are expressed as tCO_2e ha^{-1} yr^{-1} using Global Warming Potential values for the 100 year time horizon (GWP_{100}) of 1, 25 and 298 for CO_2, CH_4 and N_2O respectively. Additionally, net GHG emissions are calculated over 7 time horizons (1; 5; 10; 25; 50; 100 and 250 years), thus showing the time over which benefits (or burdens) might be attained. This enables accounting for, for example, carbon sequestration, where an equilibrium (in the soil and above-ground biomass) is reached over a certain period of time, and impacts upon the benefits in the longer term.

2.4. Generation of data on variability

The OSCAR software provides an assessment of GHG emissions for an RDP operation within a selected region. If a NUTS0, 1 or 2 region is selected then it is also possible to display the variability in emissions within the selected region, by showing the emissions for each NUTS3 region. To explore this variability further, this process has been undertaken for all NUTS3 regions across the EU-27 (1281 NUT3 regions).

The OSCAR software was adapted to batch process (calculate) the GHG emissions for each RDP operation for every NUTS3 region in the EU-27, using an uptake rate of 100%, i.e. the operation is applied to all the applicable land within a region (e.g. if the operation applies to arable land it is applied to 100% of the arable land). The uptake rate has no influence on the results of this study, it is simply a scaling factor and so it was set to the maximum. Once this data had been processed, the following were generated for each of the seven time horizons:

- The average tCO_2e ha^{-1} yr^{-1} for each operation for the whole of the EU-27, based on total emissions divided by the total applicable hectares.
- An XY scatter chart of tCO_2e ha^{-1} yr^{-1} versus total hectares. The XY scatter chart shows the relationship between the two sets of data by plotting each data set on the X and Y axes respectively. In this instance XY scatter chart reveals the emissions that are estimated to arise from different areas of land, highlighting

the variability in emission intensity and consequently the emissions that might typically be expected to arise.

- The average absolute variation from the average, positively and negatively, weighted by the number of hectares.
- A chart of the average tCO_2e ha^{-1} yr^{-1} over the 7 time horizons (as a line chart) with error bars (positive and negative) to display average absolute variation.

These outputs facilitate an analysis of the variation in GHG emissions spatially and temporally across the EU-27 at the NUTS3 level.

The OSCAR software currently has data for 130 RDP operations available. The analysis above was undertaken for all these operations, but it is beyond the scope of this paper to examine the results for each operation. Consequently, the general findings are presented in the results with a few operations explored in detail. Additionally, the focus of this paper is on land use, therefore infrastructure improvement operations such as manure stores or machinery have been excluded from this analysis. For reference, the operations that are explored in this paper are briefly outlined below:

- Arable reversion to lowland semi-improved grassland: This is where arable/cultivated land is converted back to grassland improved with fertiliser and then grazed by either cattle (*Bos Taurus*) or sheep (*Ovis aries*). This can be achieved by sowing grass species or allowing grass to grow via natural regeneration.
- Beetle banks: Tussocky grass strips, about two metres wide, which run through the middle of large arable fields. They provide important over-wintering habitat for many insects, including predatory beetles. Some of these insects these insects will move into the crop in spring and eat crop pests, such as aphids.
- Buffer strips: Strips of vegetation, such as grass strips, designed to reduce losses of soil, nutrients and pesticides from fields and thus protect watercourses. Table 1 provides a detailed definition of this operation.
- Fallow plots for ground nesting birds on arable land: Creation of bare/fallow plots within an arable field, about 20 square metres in size. These provide valuable habitat for ground-nesting birds such as the Skylark (*Alauda arvensis*).

- Heathland creation/restoration: Heathland is habitat dominated by dwarf shrubs and found mainly on free draining acidic soils.
- Hedgerow management and planting: Hedgerows consist of trees and shrubs, usually longer than 20 metres, no wider than 5 metres and 1.5 to 2 metres high, and usually constitute part of a field boundary.
- Lower input agricultural systems: Production systems with lower inputs of nutrients, including inorganic fertilisers, and pesticides.
- Pollen and nectar seed mixtures: Can be on arable land, grassland or fallow/set-aside land (land which has been taken temporarily out of production). A pollen and nectar flower mixture is typically a mixture containing legumes, and can include, for example, Clovers (*Trifolium spp*.), Birdsfoot trefoil (*Lotus corniculatus*), Sainfoin (*Onobrychis spp*.), Musk mallow (*Malva moschata*), Black knapweed (*Centaurea nigra*), and Vetches (*Viccia spp*.).
- Replacing sheep with cattle on upland grassland and moorland: Where grazing of upland (land typically above the limits of enclosed farmland) is changed from grazing by sheep to cattle.
- Traditional orchards: Creation of new traditional orchards (fruit and nut trees).
- Wet grassland for wintering waders and wildfowl: Wet grassland is pasture or meadow that is periodically inundated with water. Wintering waders and wildfowl consist numerous bird species, for example: Lapwing (*Vanellus vanellus*), Redshank (*Tringa tetanus*), Snipe (*Gallinago gallinago*), Curlew (*Numenius arquata*), and ducks, geese and swans (*Anatidae spp*.).
- Wild bird seed mixture: Can be on arable land, grassland or fallow/set-aside land. The mixture could include, for example, Barley (*Hordeum vulgare* L.), Triticale (*× Triticosecale*), Kale (*Brassica oleracea*), Quinoa (*Chenopodium quinoa*), Linseed (*Linum usitatissimum*), Millet (*Setaria italica*), Mustard (*Sinapis alba*), Fodder radish (*Raphanus sativus subsp. Oleiferus*), and Sunflower (*Helianthus annuus*).
- Woodland creation: Woodland is land covered by trees and can be coniferous (dominated by conifer tree species), broadleaved (dominated by deciduous tree species) or a mixture of the two.

3.0. Results

A number of findings on the GHG emissions profile of the operations emerged from the analysis. They have been grouped into the following categories relating to the respective benefits and burdens of the operations over different time horizons:

1. Long-term benefit: There is a net decrease in emissions across all time horizons.
2. Short-term burden, long-term benefit: There is a net increase in emissions in the first year, followed by a net decrease in subsequent years.
3. Medium-term burden, long-term benefit: There is a net increase in emissions over 50-100 years, followed by a net decrease in subsequent years.
4. Variable benefit/burden: Emissions depend on location and time horizon.
5. Long-term burden: There is only a net increase in emissions.

Each of these categories is explored below with some example operations within each category.

3.1. Long-term benefit

Many operations in addition to achieving other objectives also decrease GHG emissions. They include the creation of woodland, grassland, moorland, buffer strips and beetle banks; hedgerow management; and shifting to lower input agricultural systems.

The greatest spatial variations tend to occur with woodland creation operations, especially when they are replacing grassland and livestock. Figure 1 shows the average absolute variation in emissions over the 7 time horizons for the operation of creating coniferous forest on lowland unimproved grassland (cattle). It shows that the average net GHG emissions is always a net decrease, and the decrease tails off after 50-100 years as this is the point at which the above ground biomass reaches equilibrium and carbon sequestration no longer occurs. Figure 1 also shows that emissions can vary from -6 to -91 $tCO_2e\ ha^{-1}\ yr^{-1}$. There are more extremes, as shown in Figure 2, but these tend to be smaller areas.

Figure 1: Average absolute variation in emissions for: Woodland creation: Coniferous forest on lowland unimproved grassland (cattle)

Figure 2 XY Scatter for: Woodland creation: Coniferous forest on lowland unimproved grassland (cattle) over 100 years

This variation occurs due to a combination of potential for grass growth (and thus emissions arising from cattle) and the potential for carbon sequestration in coniferous trees (tree growth), based on the Intergovernmental Panel on Climate Change (IPCC) climate and ecological zones (IPCC, 2006). Consequently, areas such as the south and south-west of France have high potential for both, i.e. eliminating livestock emissions and maximising carbon sequestration (e.g. Ardèche with -84 tCO_2e ha^{-1} yr^{-1} in the south and Gironde and Landes in the south-west with -260 tCO_2e ha^{-1} yr^{-1}), whereas other areas, such as northern Germany (e.g. Wesermarsch) have a lower potential with only -7 tCO_2e ha^{-1} yr^{-1}.

The creation or moorland, grassland and buffer strips tend to have a lower net decrease in emissions (and associated variation), typically 3 to 8 (+/- 0.5) tCO_2e ha^{-1} yr^{-1}. Similarly lower input agricultural systems are 3 to 8 (+/- 1.5) tCO_2e ha^{-1} yr^{-1}.

3.2. Short-term burden, long-term benefit

It can take 1 to 5 years before a net decrease in emissions occurs for some operations. This includes the management of ancient trees and creation of traditional orchards on semi-improved grassland; creation/restoration of grassland, fallow plots for ground nesting birds on arable land, management of clover swards in lowland temporary grassland, hedgerow planting on arable land and pollen and nectar flower mixture on set-aside land.

Figure 3 shows an example of this for the operation: creation/restoration of heathland from arable land. It shows that in the first year there is a net increase in emissions, but by year 5 this becomes a net decrease. This is because it takes 2-5 years before the reduced emissions from, for example, the loss of inputs (such as fertilisers, pesticides and field operations) into the arable system, outweigh the emissions from the new system, i.e. heathland with sheep grazing in this instance. A similar scenario exists for the other operations that fall into this category.

Figure 3: Average absolute variation in emissions for: Creation/restoration of heathland from arable land

3.3. Medium-term burden, long-term benefit

The time taken before a net decrease in emissions occurs can be longer under some circumstances for some operations. For example, as shown in Figure 4, the operation of adding pollen and nectar seed mixtures in lowland unimproved grassland could take 50 to 150 years (depending if the land has cattle or sheep).

Figure 4: Average absolute variation in emissions for: Pollen and nectar seed mixtures in lowland unimproved grassland (cattle and sheep)

In this instance, the operation is taking some of the lowland unimproved grassland out of production to be replaced with a pollen and nectar seed mixture to enhance biodiversity (particularly pollinators). Although this reduces emissions due to the removal of livestock and inputs, there can be significant emissions that are incurred as a result of the new system. In particular there are emissions of CO_2 from soil (due to ploughing the grassland) from both oxidation of organic matter and soil erosion. As a consequence it takes longer before the benefit of livestock removal is achieved (more so with sheep due to their lower emissions compared to cattle). The issue of displacement should also be considered here, in that the removal of livestock by this operation may simply result in the livestock production, and associated emissions, being shifted elsewhere. Consequently a broader more strategic perspective may be required to determine the overall benefit of this operation on emissions reduction.

3.4. Variable benefit/burden

A number of regions showed net increases in emissions, when the average is a net decrease and this can vary over time for some operations. In some cases, using the average absolute variation, this should still typically be a net decrease, but in others there could be significant areas where there is a net increase in emissions. For example, Figure 5 shows the XY scatter chart for the operation of creating pollen and nectar flower mixture on set-aside land using the 100 year time horizon. It shows that over 100 years, although a large number of regions are producing a reduction in GHG emissions of around 0 to 1.5 $tCO_2e\ ha^{-1}\ yr^{-1}$, there are some generating a net increase in emissions of 0 to 4 $tCO_2e\ ha^{-1}\ yr^{-1}$ and some as high 9, 13 and 14 $tCO_2e\ ha^{-1}\ yr^{-1}$. Some of these extremes can be explained by variation in spatial parameters. For example, the region with a net increase of 9 $tCO_2e\ ha^{-1}\ yr^{-1}$ is Zuidoost-Drenthe in the Netherlands. The soils in this region have high organic carbon content and consequently any cultivation is likely to result in emissions of CO_2. Prior to being fallow, it is likely that this arable land would have been emitting CO_2 due to cultivation and this may have continued under set-aside. Consequently, the re-introduction of cultivation onto the land as part of the operation is exacerbating the loss of CO_2 from the soil. Across all regions, Figure 6 shows that although it starts with a net increase in emissions in year 1, this then drops to a net decrease in emissions after 5 years and it remains as a net decrease across the remaining time horizons even when accounting for the average absolute variation. But in regions with high organic matter soils, operations that introduce cultivation should perhaps be avoided as there will be little or no net benefit and more likely a net increase in emissions. In these regions there should be removal of cultivation activities and possibly remediation action such as rewetting to increase carbon sequestration in the soil.

Figure 5: XY Scatter for: Pollen and nectar flower mixture on set-aside land over 100 years

Figure 6: Average absolute variation in emissions for: Pollen and nectar flower mixture on set-aside land

Figure 7 shows the XY chart for the operation creation of wet for wintering waders and wildfowl from arable land, where again there are a large number of regions providing a decrease in emissions, but some resulting in a net increase. This is dependent on the balance between the emissions reduced from the loss of inputs into the arable system and increase in carbon sequestration versus the introduction of livestock into the grassland system. In many instances the loss of emissions from the arable system is larger than the increase in emissions from the livestock. But in a few instances, where the potential for grass growth is very high (and thus there is capacity for high stocking rates), this can significantly increase emissions due to increased CH_4 emissions from enteric fermentation and CH_4 and N_2O from manure. For example, Lincolnshire in the United Kingdom (UK) results in a net decrease of 2.4 $tCO_2e\ ha^{-1}\ yr^{-1}$, but Lochaber, Skye & Lochalsh, Arran & Cumbrae and Argyll & Bute on the west coast of Scotland has substantially higher grass growth potential and consequently results in a net increase in emissions of 133 $tCO_2e\ ha^{-1}\ yr^{-1}$ (if stocked at full potential). However, unlike pollen and nectar flower mixture on set-aside land, Figure 8 shows that this operation starts with a net decrease in emissions which then steadily declines and more so after 25 years, when carbon sequestration (from grassland) reaches equilibrium. Although the average remains as a net decrease, after 100 and 250 years the average absolution variation extends into a net increase in emissions. Thus it is likely that in some regions this operation will result in a net emission of GHGs (due to additional livestock at potentially high stocking rates).

Figure 7: XY Scatter for: Creation of wet grassland for wintering waders and wildfowl from arable land over 100 years

Figure 8: Average absolute variation in emissions for: Creation of wet grassland for wintering waders and wildfowl from arable land

Clearly, the time horizon for which an operation is in place could have a bearing on their potential benefit or burden. If the operation of creation of wet grassland for wintering waders and wildfowl from arable land is only in place for less than 50 years, then a net increase in emissions is less likely.

Similarly, Figure 9 shows the variation in emissions for arable reversion of semi-improved grassland (cattle) by natural regeneration, and it shows that generally there is a net increase in emissions. However, there is significant spatial variation in the emissions and in years 5 to 25 there can be a net decrease in emissions. Figure 10 shows the XY scatter of emissions for the 10 year time horizon. It shows that for a significant area within the EU-27, there can be a net decrease in emissions from this operation over a period of 10 years. For example, Badajoz and Cáceres in Spain have the potential for 4.5 tCO_2e ha^{-1} yr^{-1} net decrease in emissions over significant areas (e.g. up to 1.1m hectares for both Badajoz and Cáceres combined).

Figure 9: Average absolute variation in emissions for: Arable reversion to lowland semi-improved grassland (cattle) by natural regeneration

Figure 10: XY Scatter for: Arable reversion to lowland semi-improved grassland (cattle) by natural regeneration over 10 years

The benefit of this operation is the removal of arable inputs and carbon sequestration in the form of increased soil organic carbon under the grass. The latter of these reaches equilibrium after 10-25 years, consequently the increased emissions from livestock then starts to outweigh the initial benefits. Unfortunately, it is not simply a case of reverting back to arable after 10 years to repeat the process, as this would release the CO_2 sequestered in the soil, thus resulting in little net benefit.

3.5. Long-term burden

For many operations there is no net decrease in emissions. These tend to be operations that are implemented for fairly specific objectives, thus there is a trade-off with GHG emissions. They include forest management activities to improve woodland, conservation activities that involve cultivation of grassland, such as wild bird seed mixture, arable reversion to semi-improved grassland (subject to stocking rate), cattle replacing sheep on upland moorland and grassland, and creation/restoration of heathland from coniferous forest. These all have conservation or other environmental benefits, but result in increased GHG emissions due to activities requiring fuel, introduction or changes to livestock, or changes in soil N_2O emissions. Some of these have been explored in previous examples above, and there could be many more operations that fall into this category, but they have not been explored within the OSCAR software as there was no potential for emissions reduction. However, what this category of operations does reveal is the potential scale of any emissions increases, and thus these can be taken into account in any decision making processes. For example, where a number of operations could be implemented for biodiversity conservation, for example, those with the lowest net GHG emissions increase might be more preferential. Of the operations examined in this analysis, the net increase in emissions ranged from 0.1 to 25 tCO_2e ha^{-1} yr^{-1}, with many towards the lower end of this range.

4.0. Discussion

Agriculture and land use accounts for 9% of EU GHG emissions and 30% of global GHG emissions (EC, 2009; Smith et al., 2014), equating to 0.34 and 10.59 $GtCO_2e$ respectively (based on the data of Olivier et al., 2014). Although EU emissions are relatively small compared to other sectors, they are not insignificant and clearly at a global level they are substantial. Thus it is important efforts are put in place to reduce emissions where possible and preferably where there are also additional environmental and economic benefits to be gained.

As part of this process it is important to account for how emissions vary spatially and temporally in order to focus efforts and make them as cost-effective as possible.

The knowledge that GHG emissions from land use practices is highly variable spatially and temporally is not new. There have been many studies and scientific experiments (e.g. Dobbie et al., 1999; Dobbie & Smith, 2001 & 2003; Freibauer, 2003; Machefert et al., 2002; Smith & Conen, 2004) to establish quantities of CO_2, CH_4 and N_2O emitted from agricultural sources and on the sources and sinks of carbon sequestered in the soil and biomass (e.g. Bell & Worrall, 2004; Bradley et al., 2005; Cannell et al., 1999; Dawson & Smith, 2007, King et al., 2004; Ostle et al., 2009). What is new, and an ongoing challenge, is placing our understanding of spatial and temporal variation into the context of decision making at the global, European, national, regional and farm level. Empirical studies, such as those cited above, form the foundation of knowledge, but their precise scope and boundaries are not always conducive to the broad, strategic and holistic perspective that is needed for pragmatic decisions to address multiple objectives (Dilling & Lemos, 2011; Heller & Zavaleta, 2009; Olander et al., 2013; Rosen & Guenther, 2014). Information and knowledge needs to be collated and synthesised from a variety of sources to help paint the clearest picture possible and often this needs to be in the form of tools, indicators or meta-analyses to support the decision making process.

In recent years, one of the key strategies to tackle climate change has been to mainstream climate change objectives into all policy areas (Berkhout et al., 2013; Medarova-Bergstrom & Volkery, 2012). In so doing, by its very nature, this poses the challenge of finding solutions that meet multiple objectives. This in itself is not a new idea - the concept of multi-functional farming (Renting et al., 2009; Van Huylenbroeck and Durand, 2003) has existed for some time, and rural development programmes have a range of social, economic and environmental objectives. So the introduction of climate change objectives into the mix is just another strand of complexity among many for the decision making process to tackle.

This study has focused on GHG emissions from rural development land use operations in Europe, but the issues and concepts it has explored are equally applicable to other regions of the world, where it may be of greater importance due to higher emissions. The spatial data required to undertake such an analysis may not be available in all regions, but the principle remains the same, in that emissions will significant vary spatially and temporally. Additionally, taking the broader perspective of global trade, the EU imports a range of food products to meet consumer demand: the EU-27 imported 79.3 million tonnes of food and live animals and 3.4 million tonnes of beverages in 2010, with a high proportion imported from developing countries (Eurostat, 2011). Therefore Europe's footprint of GHG emissions from land use extends beyond its geographical boundaries. These emissions will also vary spatially and temporally, and thus perhaps should be accounted for when considering global trade policies, which should also be subject to the mainstreaming of climate change objectives.

The OSCAR software (AERU, 2013 & 2014) that was used for the analysis presented herein, has attempted to provide a holistic analysis for the potential GHG emissions of RDP operations to facilitate the incorporation of this information into the decision making process and thus support the process of identifying optimal solutions to meet multiple objectives. Although much of the spatial and temporal variability data has been derived from the original empirical studies cited above, this has inevitably involved broad classifications, generalisations and interpolation of data in order to develop a system that can be used for practical decision making and which draws upon readily available spatial data across Europe. Consequently the accuracy of the tCO_2e values quoted could be questioned in comparison to the original empirical studies. This may be an issue in the context of reporting emissions retrospectively, e.g. for national inventories, but in the context of planning interventions, it could be argued that the exact tCO_2e value is of less importance, compared to whether it is positive or negative, whether it is of a magnitude of 10s, 100s or 1000s and how it varies spatially and temporally.

There is always scope for further improvement with regard to calculating net GHG emissions. For example, generally the OSCAR software used winter wheat (*Triticum aestivum*) as the baseline for an RDP operation applicable to arable land. Clearly, winter wheat is not the only crop, thus the addition of other arable crop baselines would further improve the analysis, although this would be at the expense of making the application of the tool more complex and less practical, i.e. instead of just mapping arable land, individual crops would need to be mapped, which of course will vary from year to year as the rotation changes. There is also scope to improve the calculation of carbon sequestration rates and equilibriums. At the moment the calculation uses simple linear mean sequestration rates (Falloon et al., 2004). However, a sigmoidal relationship (IPCC, 2006) for sequestration rates would be more appropriate and as such this could impact upon the time horizon over which benefits might be achieved. However, despite the limitations outlined above, the analysis has highlighted a number of key issues.

Firstly, it is important to understand over what time horizon net decreases might be attained from any operation. In some instances benefits may be obtained within a few years, in other instances it may take longer, possibly 10, 25 or 50 years or more. This presents a number of issues for interventions, firstly with respect to the period of time over which agreements are made (in the context of land management schemes and agreements with land owners) and secondly regarding the permanency of any operation. For example, an operation that changes land use from arable to grass may result in a net decrease in emissions due to elimination of arable inputs and sequestration of carbon in the soil under grass. But if this reverts back to arable after 5 or 10 years, then many of these benefits will be lost as the sequestered carbon is then released back to the atmosphere.

Secondly, it is important to understand the spatial variation in emissions. For example, Figures 9 and 10 show that over a period of 100 to 250 years for the whole of Europe, the operation of arable reversion to lowland semi-improved grassland (cattle) by natural regeneration, provides a net increase in emissions. If this data is examined for different regions or countries, a slightly different perspective emerges. Figures 11 and 12 show the XY scatter data for the UK and Spain respectively for the 250 time horizon. In the UK this operation results in a net increase in emissions in all regions, but in Spain this operation results in a net decrease in emissions for a large number of regions. Therefore, as a means of reducing emissions this operation should not be considered in the UK, but in Spain there is scope to use it to contribute toward these objectives, albeit clearly it should be avoided in some regions.

Figure 11: XY Scatter for: Arable reversion to lowland semi-improved grassland (cattle) by natural regeneration for the UK over 250 years

Figure 12: XY Scatter for: Arable reversion to lowland semi-improved grassland (cattle) by natural regeneration for Spain over 250 years

The example operations explored in this paper show that the process of integrating climate change objectives into interventions is complex and variable. This paper has only explored the issue of mitigation and the addition of adaptation objectives further complicates the process. There is increasing recognition that the objectives of mitigation and adaptation need to be tackled together (EC, 2013b; IPCC, 2014; Klein et al., 2003; Klein et al., 2007; Tzilivakis et al., 2013; VijayaVenkataRaman et al., 2012), and in the context of RDPs this needs to be coupled with tackling other environmental, social and economic objectives. There is unlikely to be win-win-win situations for all operations, albeit where they do exist they should be utilised to their fullest extent. Thus decision makers will be faced with decisions to make regarding trade-offs between different objectives. In many instances there will be synergies between objectives. For example, operations that take land out of production or reduce inputs, generally (but not always) also result in a reduction in GHG emissions. However, there will also be situations where operations that target other environmental objectives will result in a net increase in GHG emissions. In those instances it will be important to develop a range of options to achieve the target objective, but which might have a range of GHG emissions under different circumstances. This information can then be taken into account in the decision making process and thus support the development of optimal solutions.

The majority of efforts to date have been on developing operations and activities that reduce GHG emissions, which is useful for planning interventions focused on climate change objectives. However, perhaps the efforts should be broadened to developing tools and techniques to assess all operations and activities with respect to their GHG emission profile. In the context of meeting multiple objectives, we need to be selecting those with least burden as well as those with the greatest benefits for climate change. To build on the analogy often used in the climate change literature, as well as picking the low hanging fruits we also need to be selecting the least bad apples. This would then be truly mainstreaming climate change into all decision making processes at local, regional, national, European and global levels.

Acknowledgements

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Figures

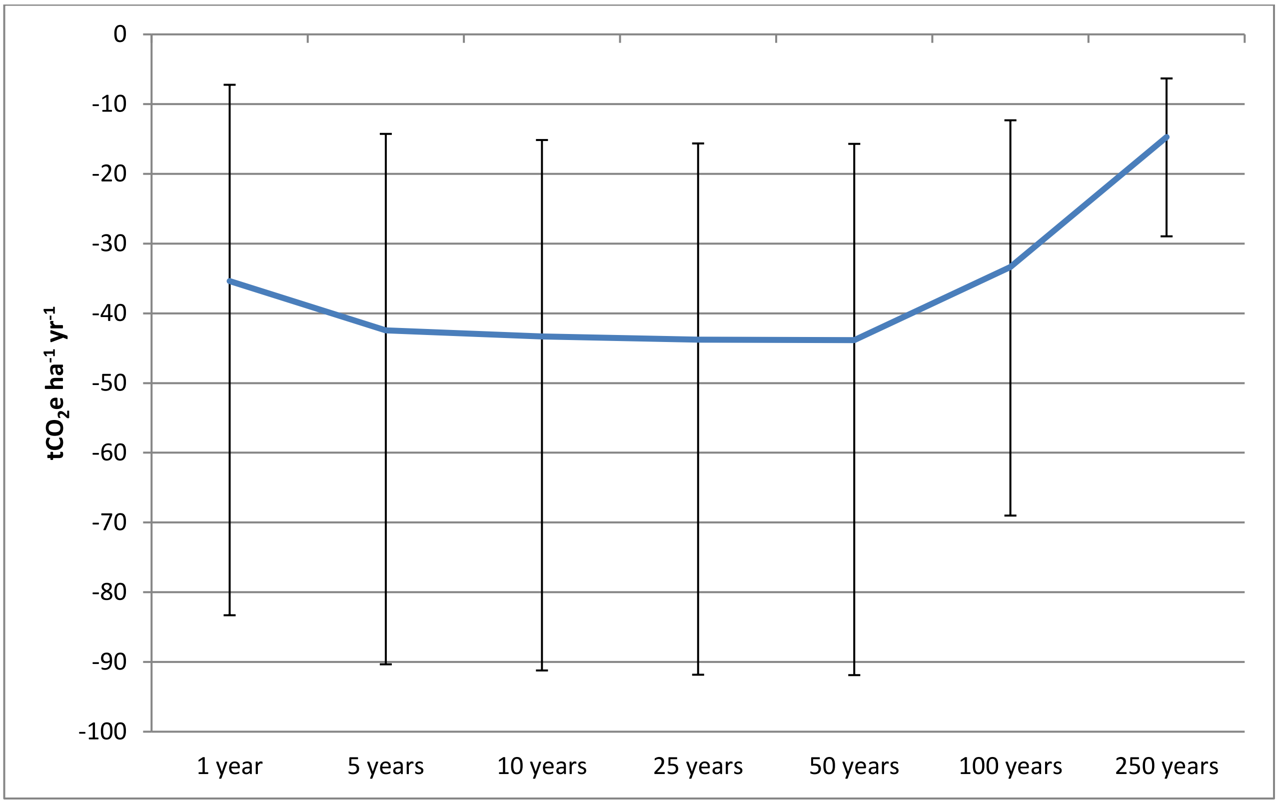

Figure 1: Average absolute variation in emissions for: Woodland creation: Coniferous forest on lowland unimproved grassland (cattle)

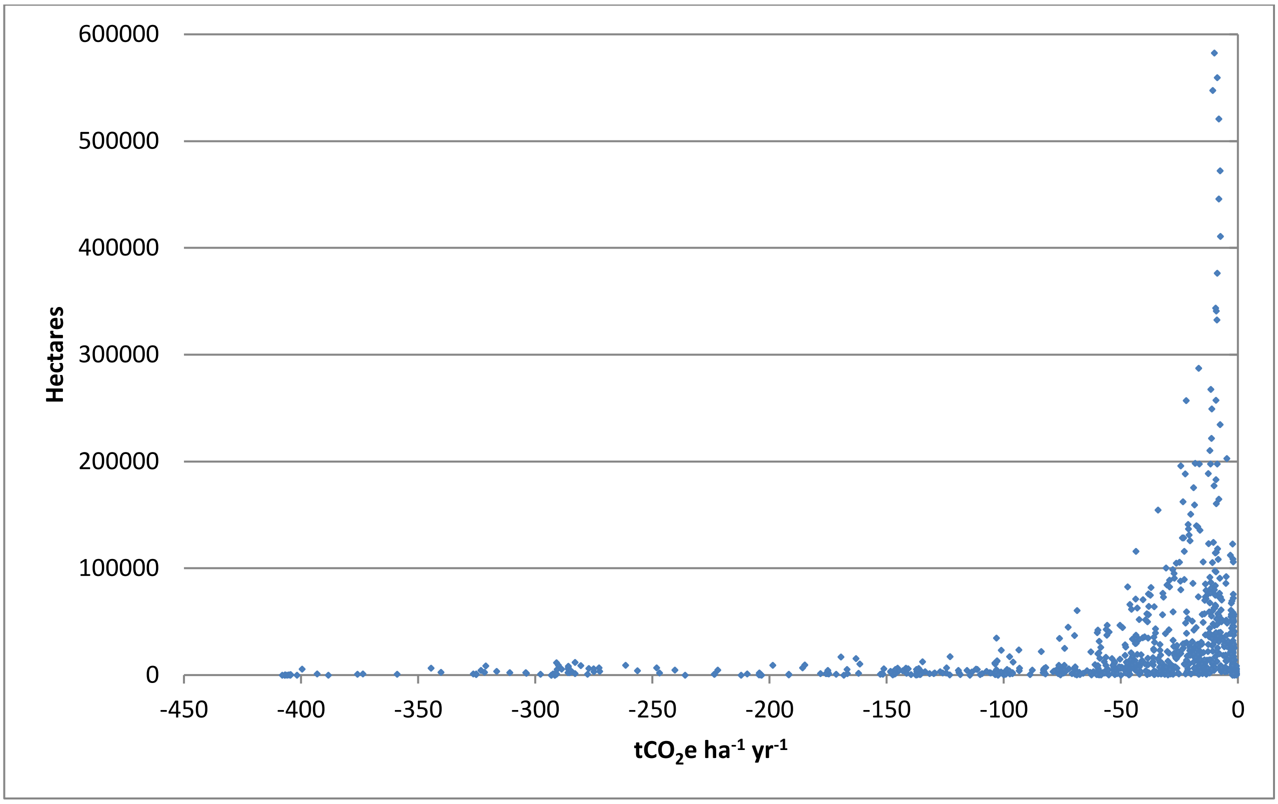

Figure 2 XY Scatter for: Woodland creation: Coniferous forest on lowland unimproved grassland (cattle) over 100 years

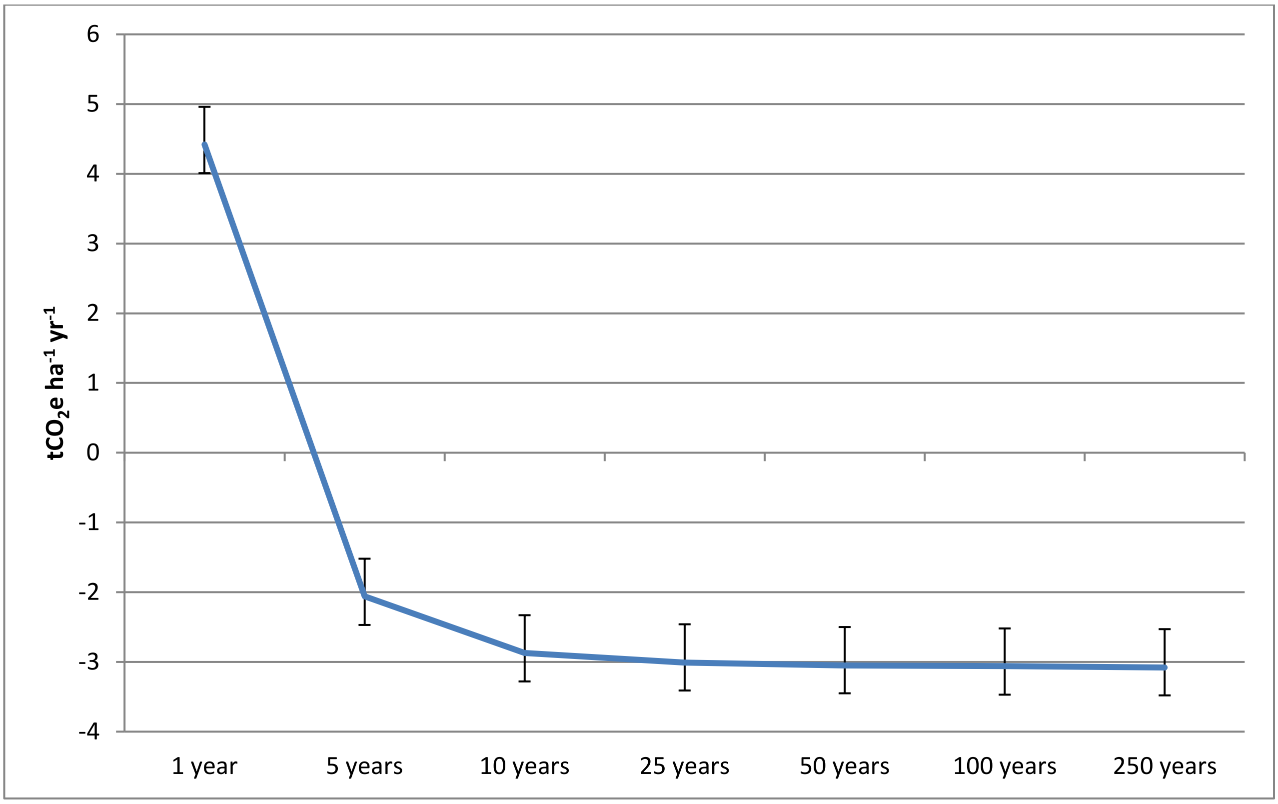

Figure 3: Average absolute variation in emissions for: Creation/restoration of heathland from arable land

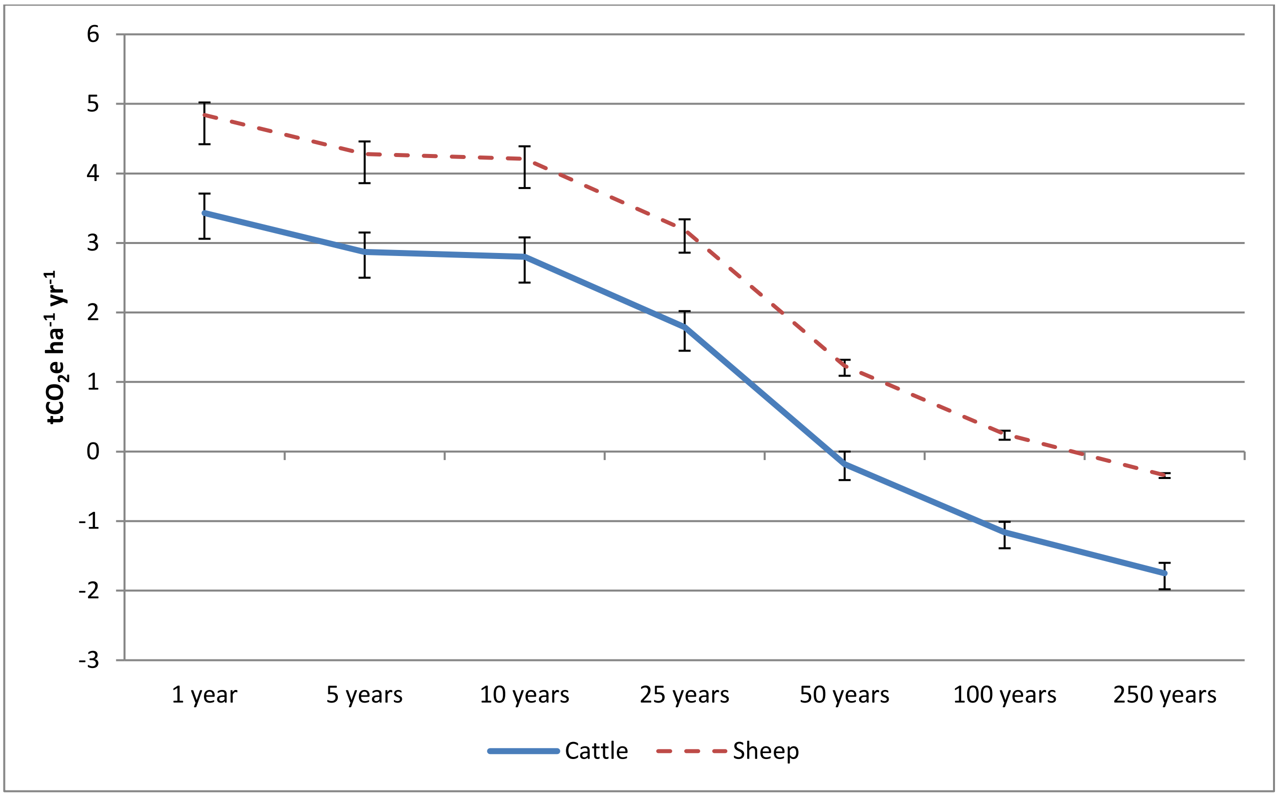

Figure 4: Average absolute variation in emissions for: Pollen and nectar seed mixtures in lowland unimproved grassland (cattle and sheep)

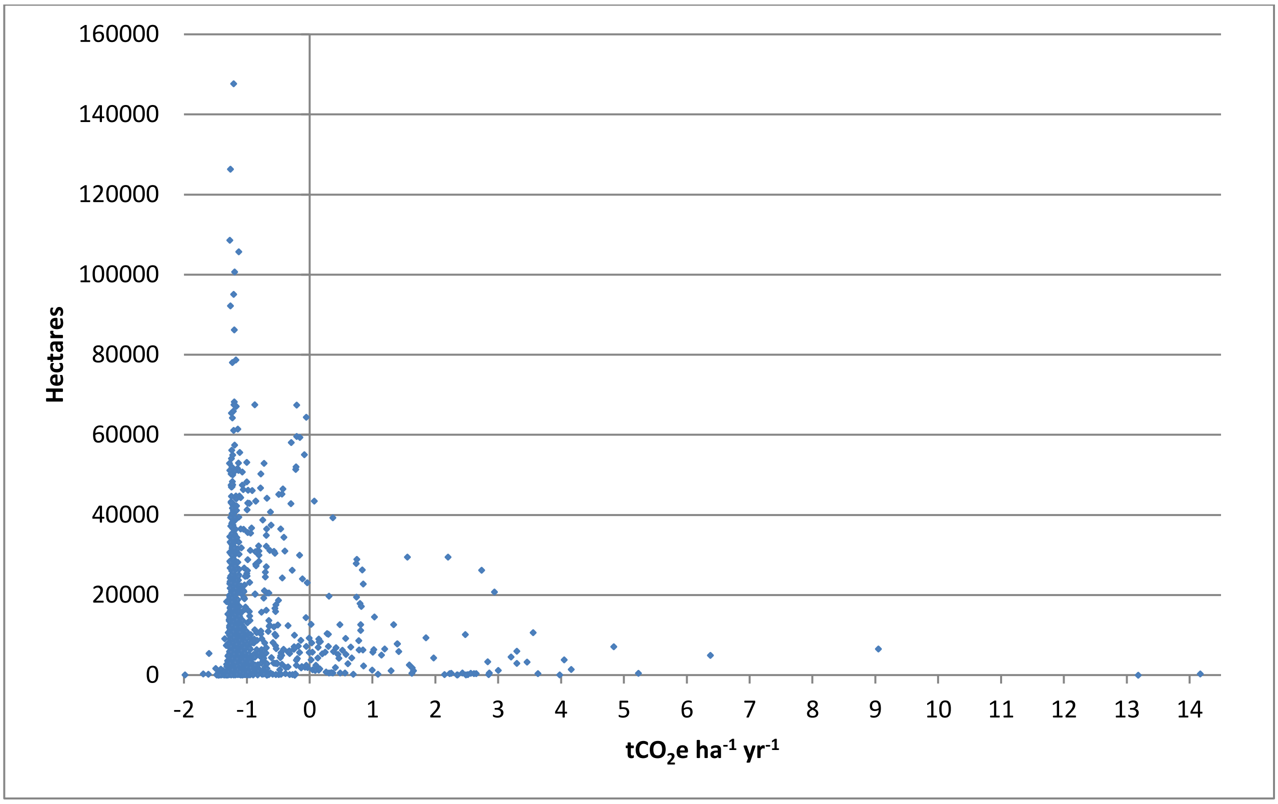

Figure 5: XY Scatter for: Pollen and nectar flower mixture on set-aside land over 100 years

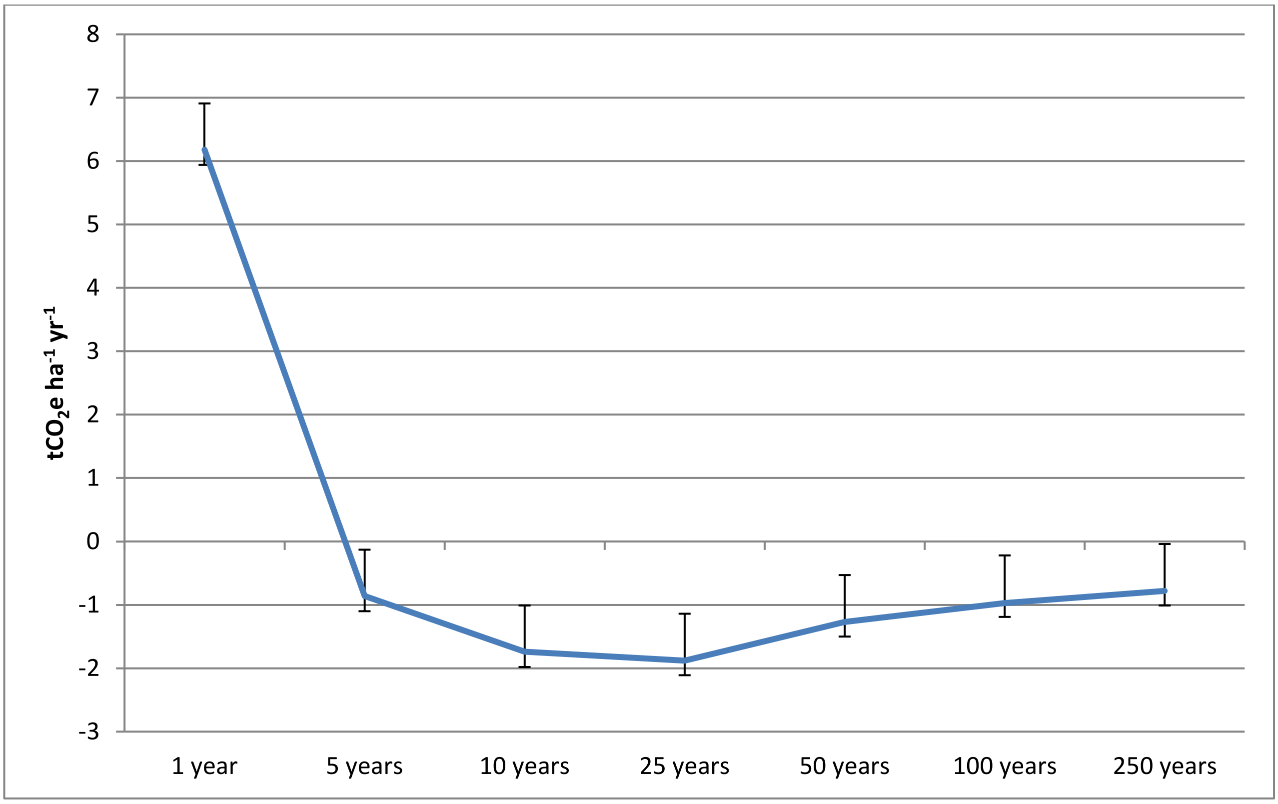

Figure 6: Average absolute variation in emissions for: Pollen and nectar flower mixture on set-aside land

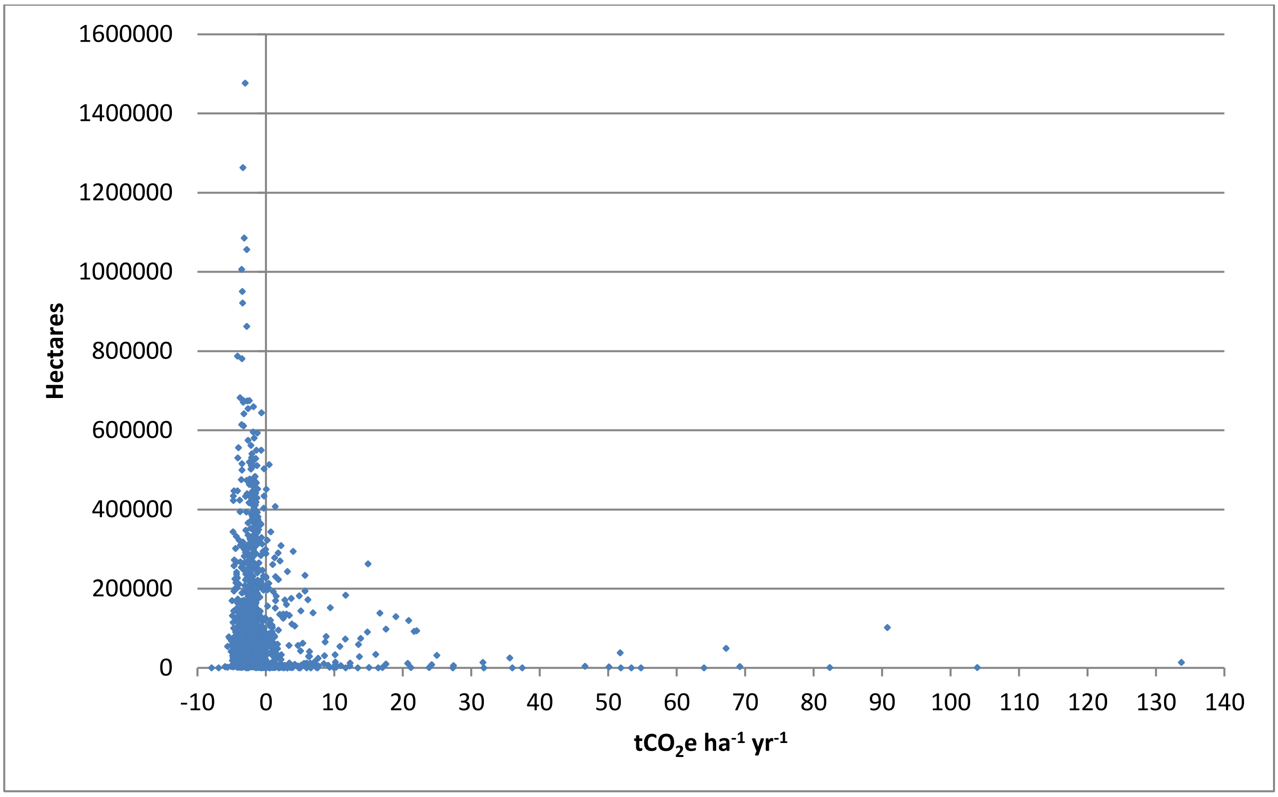

Figure 7: XY Scatter for: Creation of wet grassland for wintering waders and wildfowl from arable land over 100 years

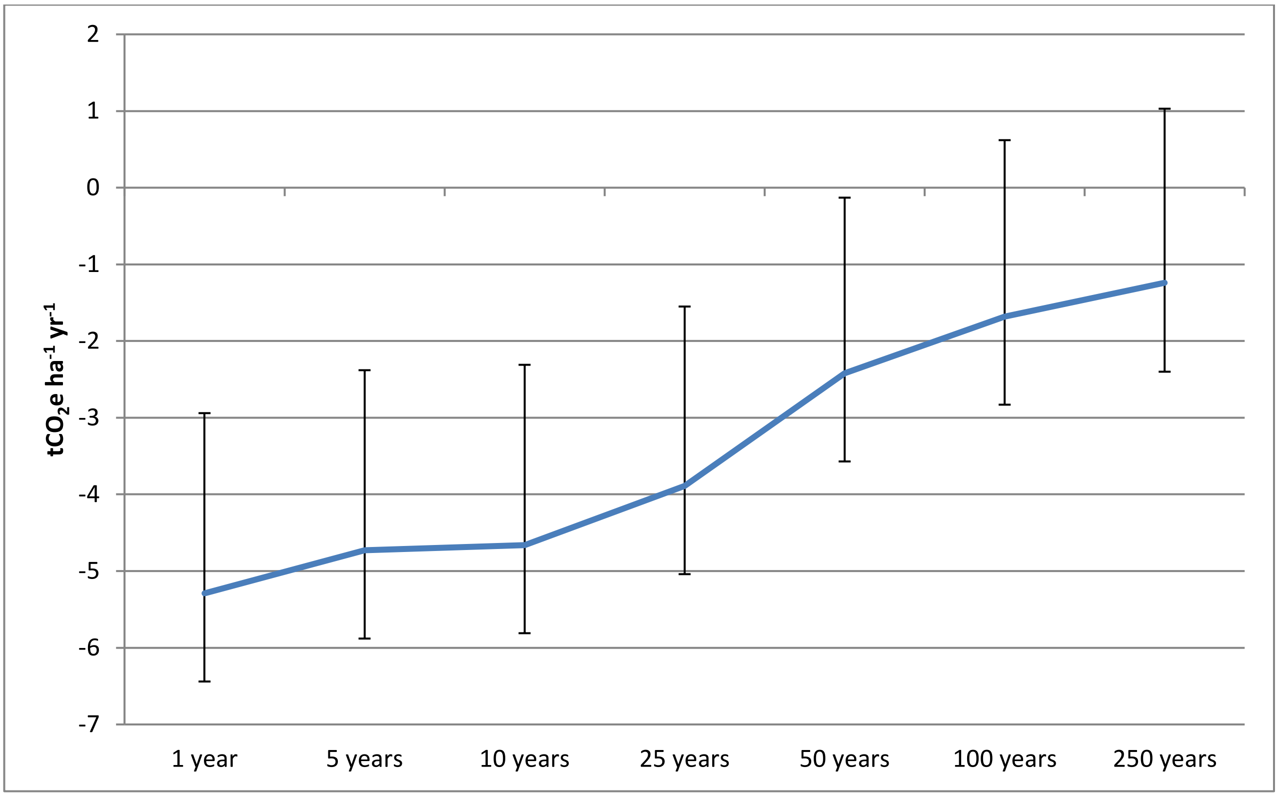

Figure 8: Average absolute variation in emissions for: Creation of wet grassland for wintering waders and wildfowl from arable land

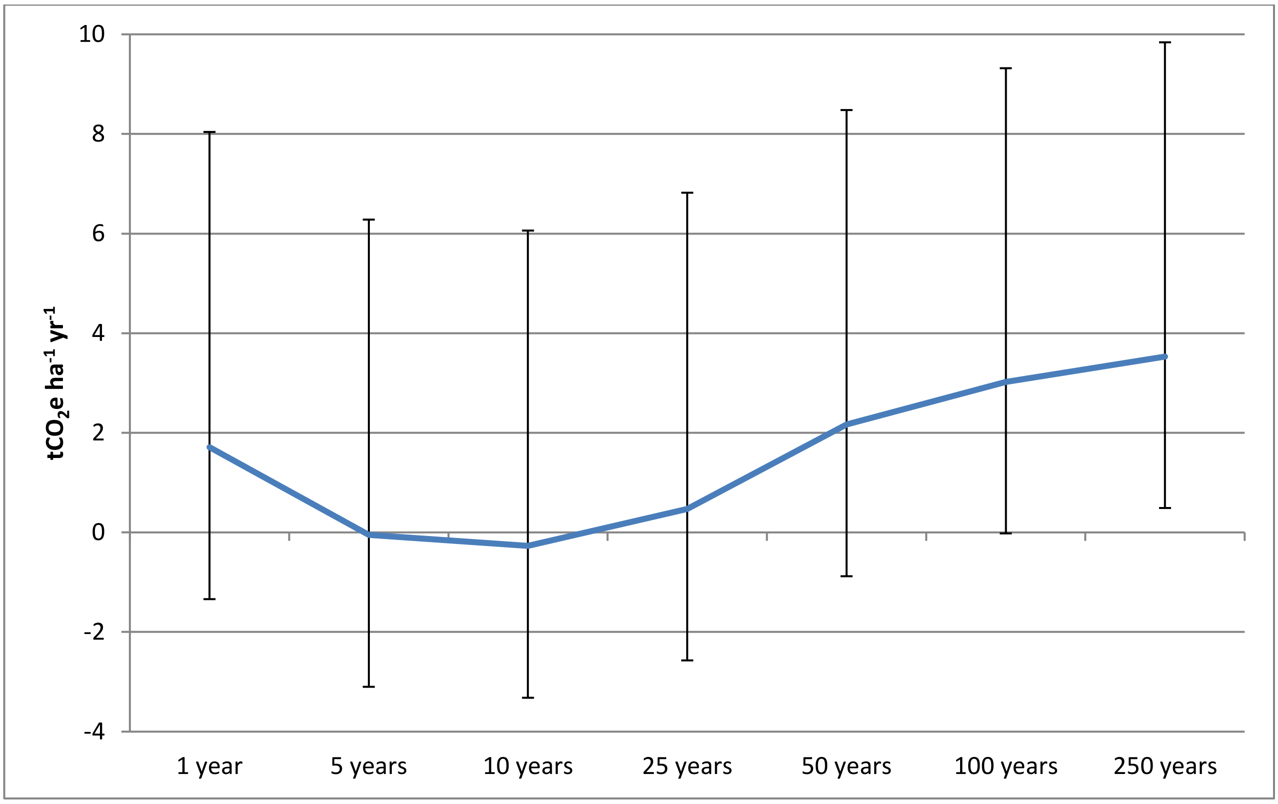

Figure 9: Average absolute variation in emissions for: Arable reversion to lowland semi-improved grassland (cattle) by natural regeneration

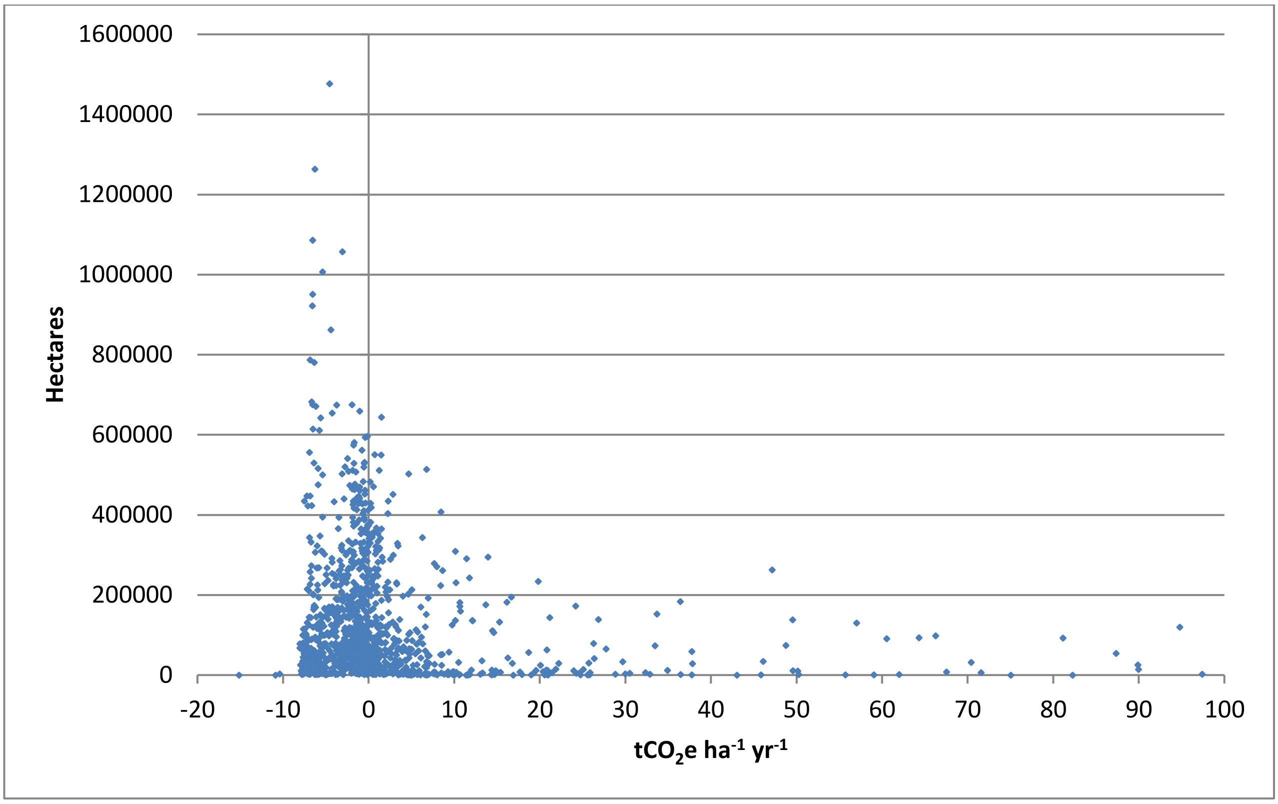

Figure 10: XY Scatter for: Arable reversion to lowland semi-improved grassland (cattle) by natural regeneration over 10 years

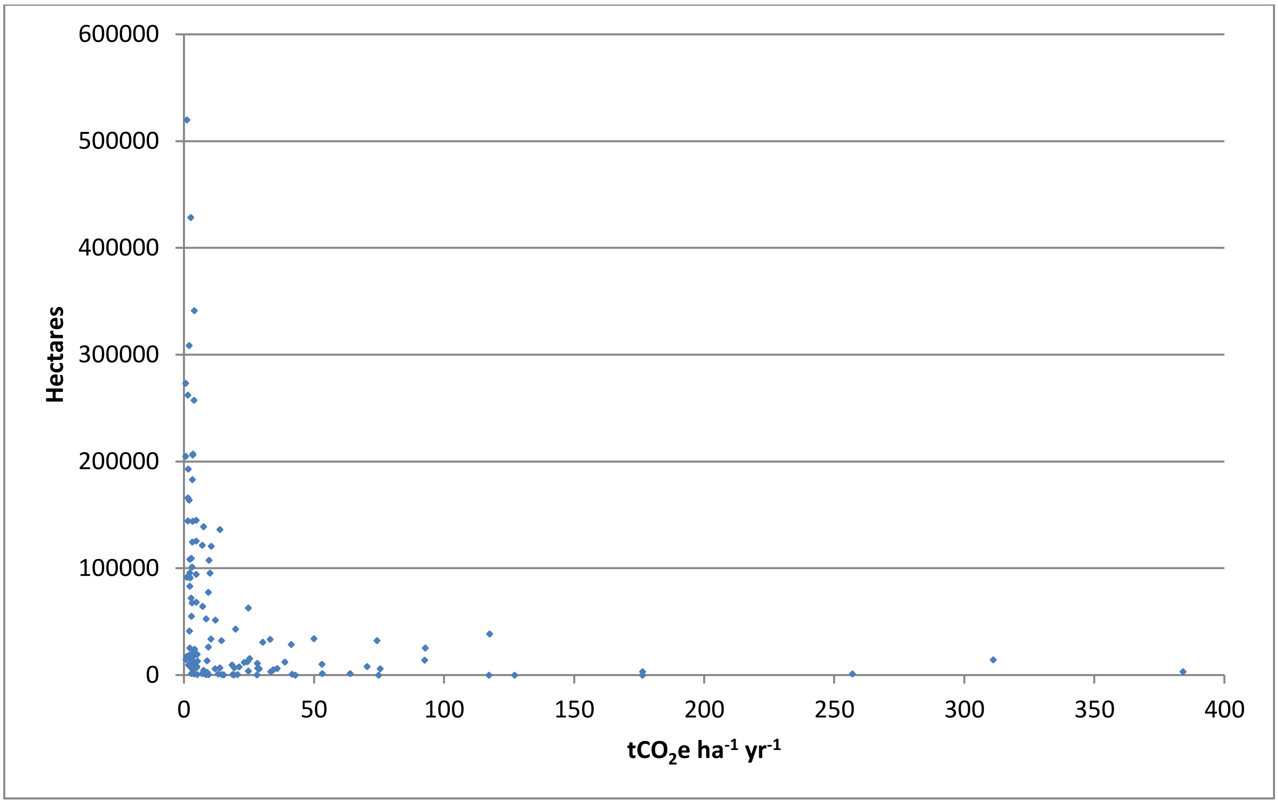

Figure 11: XY Scatter for: Arable reversion to lowland semi-improved grassland (cattle) by natural regeneration for the UK over 250 years

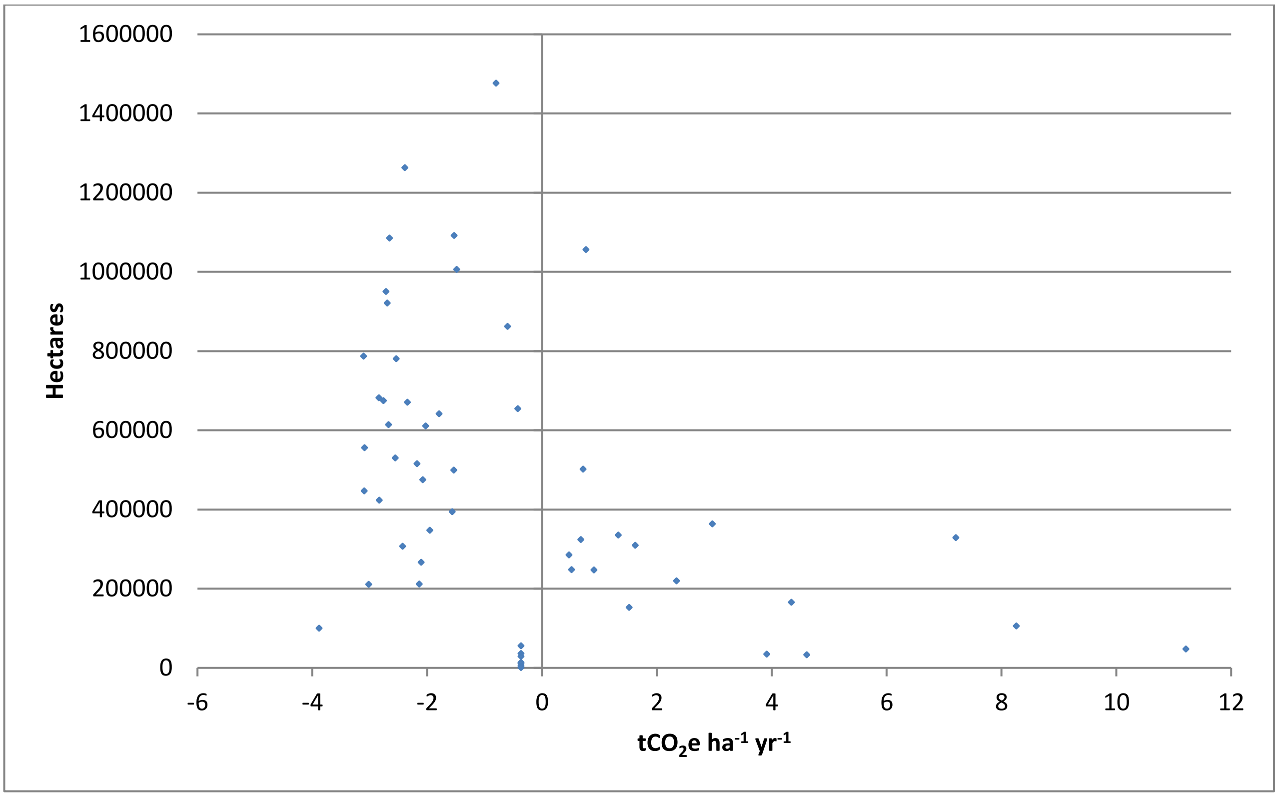

Figure 12: XY Scatter for: Arable reversion to lowland semi-improved grassland (cattle) by natural regeneration for Spain over 250 years

Tables

Table 1: RDP operation definition example: Buffer strips on cultivated land next to a watercourse

Activities and features (unit)	Baseline (winter wheat)	Buffer strips on cultivated land next to a watercourse	Δ
Seedbed preparation: Ploughing to 20 cm depth (number of field operations)	1	0	-1
Seedbed preparation: Power harrow - a harrow with a rotary system of bars driven from the tractor power take-off (number of field operations)	1	0	-1
Wheat seed (kg)	180	0	-180
Planting of seed: drilling (number of field operations)	1	0	-1
Ammonium nitrate (NH_4NO_3) manufacture (kg)	M*	0	-M*
Ammonium sulphate ($(NH_4)_2SO_4$) manufacture (kg)	30	0	-30
Phosphate fertiliser (P_2O_5) manufacture (kg)	63	0	-63
Potassium fertiliser (K_2O) manufacture (kg)	96	0	-96
Application of inorganic Nitrogen fertiliser (number of field operations)	4	0	-4
Application of lime (number of field operations)	1	0	-1
Pesticide application: spraying of liquids or broadcasting of solids (number of field operations)	5	1	-4
Biomass accumulation: annual cultivation (single action)	1	0	-1
Biomass accumulation: permanent unimproved grass (single action)	0	1	+1
Erosion: cultivated land: CO_2 emissions (single action)	1	0	-1

Activities and features (unit)	Baseline (winter wheat)	Buffer strips on cultivated land next to a watercourse	Δ
Erosion: cultivated land: N_2O emissions (single action)	1	0	-1
Erosion: permanent unimproved grass: CO_2 emissions (single action)	0	1	+1
Erosion: permanent unimproved grass: N_2O emissions (single action)	0	1	+1
Grain harvest: combine harvester (number of field operations)	1	0	-1
Transport or harvested grain 2 km from the field to on-farm storage (number of field operations)	1	0	-1
Drying harvested grain to 86% Dry Matter (number of operations)	1	0	-1
Soil: change in Soil Organic Carbon (SOC) as a result of changing from winter wheat to permanent unimproved grass (single action)	0	1	+1
Soil: unimproved grass: CH_4 emissions (single action)	0	1	+1
Soil: winter wheat: CH_4 emissions (single action)	1	0	-1
Soil: winter wheat: N_2O emissions (single action)	M*	0	-M*
Cutting of vegetation: mowing / strimming (number of field operations)	0	1	+1
*M = Multiple values: the baseline value will vary depending on location, e.g. fertiliser application rates will vary with soil texture and rainfall			