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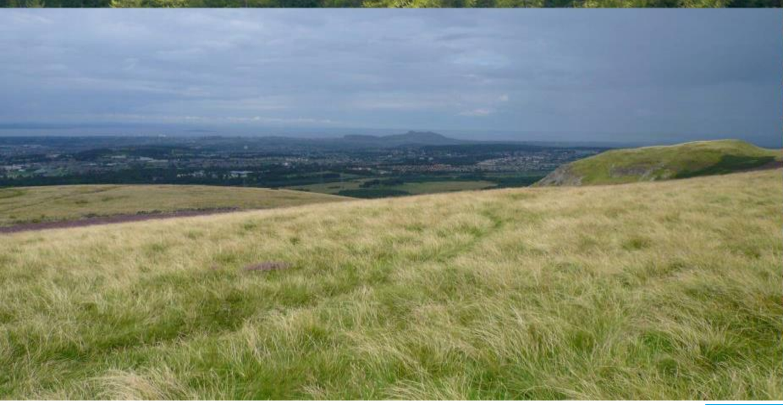
Estimating current CO_2 Emissions and Removals from Changes in Soil Organic Carbon Stocks

Based on statistical data on land use and land use change, 1970 - 2016

Roland Hiederer and Raúl Abad Viñas

2018



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Abstract

For the purpose of reporting GHG emissions and removals from anthropogenic activities in Agriculture, Forestry and Other Land Use (AFOLU) under the UNFCCC, the Intergovernmental Panel on Climate Change (IPCC) provides in the 2006 IPCC Guidelines that it is good practice to use managed land as a proxy for anthropogenic emissions and removals.

For the years 2013-2020 Decision No 529/2013/EU of the European Parliament and of the Council extended mandatory accounting for Greenhouse Gas (GHG) emissions and removals to the activities Cropland Management (CM) and Grazing Land Management (GM) for the Member States of the European Union.

The 2006 IPCC Guidelines distinguish three tiers of methods, of which Tier 1 is the most generic. Tier 1 uses general default values and national data for estimating carbon stock changes and non-CO_2 GHG emissions. For the purpose of accounting under the Kyoto Protocol land use conversions leading to GHG emissions from the soil should be spatially explicit (Approach 3).

A processing environment following the IPCC guidelines for a Tier 1 method and Approach 3 was developed at the JRC to estimate CO_2 emissions and removals from changes in soil organic carbon (SOC) stocks as a consequence of changes in land use, management practice and input level. The implementation uses statistical data to establish the annual status and a range of ancillary data to estimate transitions between years. A comparison between the results obtained and the trends related in the annual reports provided by EU Member States led to the conclusion that the data on land use was a major source of differences between the estimated and reported in the trends of CO_2 emissions and removals from the soil. These differences will decide the trend of any estimates, regardless of the IPCC Tier used.

As a consequence, the procedure implemented to generate a complete time-series of statistical data was investigated and revised. Particular attention was paid to the process of integrating data coming from different sources into a single set. The degree to which data from different sources agree varies from complete agreement to opposing trends. The procedure for generating a more consistent single time-series combines a hierarchical structure for combining data with a statistical analysis for detecting outliers, but not changing any trends.

The new input data was employed to re-process changes in soil organic carbon stocks from 1970 to the statistical data available on land use in 2018. Although all EU Member States are processed starting with 1970, the publicly available source data on land use would allow a 1990 baseline for reporting CO_2 emissions and removals for 18 countries using national data, but only 8 countries using data at NUTS Level 2. In the sources used 5 countries are reported with detailed data only for 2005 later years.

1 Introduction

Parties to the United Nations Framework Convention on Climate Change (UNFCCC) are committed to report anthropogenic emissions and removals of greenhouse gases not covered by the Montreal Protocol[1], which includes Agriculture, Forestry and Other Land Use (AFOLU). Due to practical difficulties of separating anthropogenic from natural emissions for AFOLU the 2006 IPCC Guidelines provides that it is good practice to report emissions and removals from managed land as a proxy for anthropogenic emissions and removals (IPCC, 2014).

For the EU a binding target of reducing GHG emissions by 20% (from 1990 levels) is set in the 2020 Climate & Energy Package[2]. For the agricultural sectors, which is not covered by the *Emission Trading System* (ETS), the EU countries have taken on binding annual targets until 2020 for cutting emissions in these sectors (compared to 2005). The EU legislation thus covers the targets set by the Kyoto Protocol for the 2nd Commitment Period.

Estimating CO_2 emissions and removals from changes in soil organic carbon (SOC) stocks in the sector of Land Use, Land Use Change and Forestry (LULUCF) for accounting purposed is mandatory for Afforestation, Deforestation and Reforestation (ARD) and Forest Management (FM) and voluntarily of Cropland Management (CM), Grazing Land Management (GM), Revegetation (RV) and Wetland Drainage and Rewetting (WDR) under the Kyoto Protocol. *Decision 529/2013 of the European Parliament and of the Council of 21 May 2013*[3] extends for the Member States of the European Union (EU) mandatory accounting for GHG emissions and removals to the activities CM and GM for the years 2013-2020.

Decision 529/2013 specifies stipulates under item (9) that for the LULUCF sector the accounting rules be in line with the relevant guidelines for estimating GHG emissions and removals provided by the *International Panel on Climate Change* (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2006), subsequently referred to as the *2006 IPCC Guidelines*.

Under item (12) Decision 529/2013 stipulates that "*Emissions and removals relating to grazing land management, cropland management, revegetation and wetland drainage and rewetting are all accounted for by applying a base year to calculate changes in emissions and removals.*" According to Article 3(2) Member States should at least use a Tier 1 method, as specified in the 2006 IPCC Guidelines. Article 4(5) lists '*soil organic carbon*' as one of the carbon pools, for which Member States shall include any change in the carbon

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1 UNFCCC Article 4.1 (a) http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf

2 https://ec.europa.eu/clima/policies/strategies/2020_en

3 Decision No 529/2013/EU of the European Parliament and of the Council of 21 May 2013 on accounting rules on greenhouse gas emissions and removals resulting from activities relating to land use, land-use change and forestry and on information concerning actions relating to those activities
OJ L 165, 18.6.2013, p. 80–97.
http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32013D0529

stock in their accounts[4]. For the purpose of accounting the *2006 IPCC Guidelines* specify the use of a geographically explicit approach (Approach 3) for assessing land use conversions in the LULUCF sector. The use of a geographically explicit assessment for land use conversions has been more explicitly specified in Regulation (EU) 2018/841 on the inclusion of GHG emissions and removals from LULUCF in the 2030 climate and energy framework[5].

To estimate CO_2 emissions and removals for CM and GM from changes in SOC stocks for the base years of 1990 and 2005 the IPCC Tier 1 method with Approach 3 was implemented in a *Geographic Information System* (GIS) (Hiederer, 2016). In a feasibility study the implementation was used to evaluate CO2 emission and removal estimates from changes in SOC stocks from land use and land use changes (Hiederer, 2017).

The main findings of the study were:

a) Consistency of statistical data

The spatially explicit layers of the land use categories are based on annual statistical data for administrative regions. For a baseline of 1990 data on land use should be available starting from 1970 (20 year adjustment period of SOC stocks under Tier 1). To improve the availability of data information from several sources were used the pre-processing procedure is designed to integrate data coming from different sources. However, irregular differences between the data coming from sources were found as well as inexplicable variations in the time-series of a single source.

b) Allocation of land use change

In the previous study the spatial allocation procedure used a land use spatial layer as a reference. To account for differences between the spatial layer and the statistical data annual changes in areas were allocated rather than total areas. The reference spatial layer was used as a background to present areas not allocated. Depending on the type of conversion between categories and the demand in area this arrangement did not guarantee that changes in the area of a category were presented accordingly in the final spatial layer.

Following the study findings the pre-processing procedure was modified to generate a more consistent time-series of annual data of each IPCC land use category, sub-category and ancillary data. In the interest of a transparent process manually adjusting the data was not considered an option. Therefore,

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4 When a Member State has demonstrated that a carbon pool listed in Article 4(5) is not a source the Member State may choose not to include in their accounts any changes in carbon stocks for that carbon pool.

5 Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU (OJ L 156 19.6.2018 p.1) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.156.01.0001.01.ENG&toc=OJ:L:2018:156:TOC

the existing process was modified and extended, but retains a fully deterministic process.

The spatial allocation procedure was modified from allocating changes to one that allocates total areas of each and all land categories. The advantage of the modification is that the process no longer depends on a reference spatial layer, but on the driving factors. An inconvenience of the method is that there is no common land use layer to be used a basis for exchanging data with other land use data. As a consequence, the procedure of estimating SOC stock changes from land use scenarios had to be modified accordingly.

2 Data Processing

The data and processing arrangements for estimating the effect of land use and land use change on SOC stocks following the IPCC Tier 1 method are presented in (Hiederer, 2016) and (Hiederer, 2017). Presented in this chapter are the features of processing data and processing that were modified from the previous implementation. Not covered are the specifications of the IPCC Tier 1 method or Approach 3. These have been presented in detail in the cited references.

2.1 Processing Periods

Processing is divided into four periods, each spanning 20 years. An overview of the processing periods is presented in Figure 1.

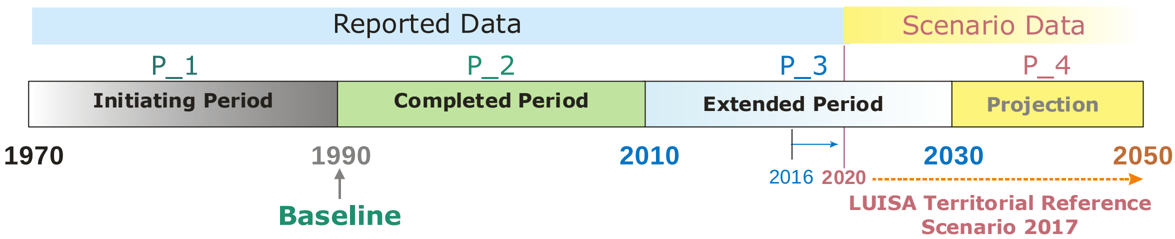

Figure 1: Data Processing Periods

The first period covers 1970 – 1990, which comprises the initial phase for generating a 1990 baseline year. The second period covers the years 1991 to 2010 and represents the completed years. The data processed for these periods are not expected to change unless significant changes are made to the input data or the processing algorithms. This period ended in 2015 in the previous implementation.

The extended period covers the years 2011 to 2030 and includes reported data as well as scenario data. The limit of reported data advances over time, depending on data availability. Eurostat and FAOSTAT publish data with a delay of approx. 2 years, e.g. data for 2016 become available in 2018. The third period also covers part of the projections made by the JRC project LUISA[6] under the *Territorial Reference Scenario* (Jacobs-Crisioni, et al., 2017). For the SOC estimates from land use changes the projected data start in 2015. Estimates are given starting in 2020, although scenario data are processed from 2015 onwards. Projections for the period 2031 to 2050 are processed in the fourth period.

[6] LUISA: Land-Use based Integrated Sustainability Assessment modelling platform https://ec.europa.eu/jrc/en/luisa

2.2 Data Structures

The main working structures for data are:

- tables containing attribute data
- spatial layers for local properties

The structure and relationships between tables is given by the structure of the NUTS levels. Statistical data are prepared in tabular format and initially processed in a RDBMS. Spatial layers cover the area of interest with a regular grid. Each grid cell contains the expression of a property of the location.

This arrangement should not be confused with a spatial location – attribute relationship. The information stored in tabular format are not attributes to the grid cells of the spatial layers. Rather, the value of each grid cell is a property of the location of the grid cell. The (statistical) tabular data can be represented as a spatial layer, but the values of the grid cells pertain to the administrative feature, to which the grid cell belongs, not the property of the location of the grid cell.

Once acquired data are processed and analysed as much as technically feasible in a single environment. As GIS software package Idrisi[7] is used. To make use of the Idrisi macro language all data, spatial and statistical, use a raster format. To simplify procedures the information stored in the tables of the RDMS and aggregated data from spatial layers use an exchange structure.

The standard data are exported from the database tables to structured ASCII files. The structure of the ASCII files allows the data to be directly converted to and from binary files in the GIS. It is therefore used as the exchange format between the GIS and other applications.

The structure of the data format is depicted in Figure 2.

[7] IDRISI. IDRISI is a Registered Trademark of Clark University
Clark Labs, Clark University, 950 Main Street, Worcester MA 01610-1477 USA
URL: http://www.clarklabs.org

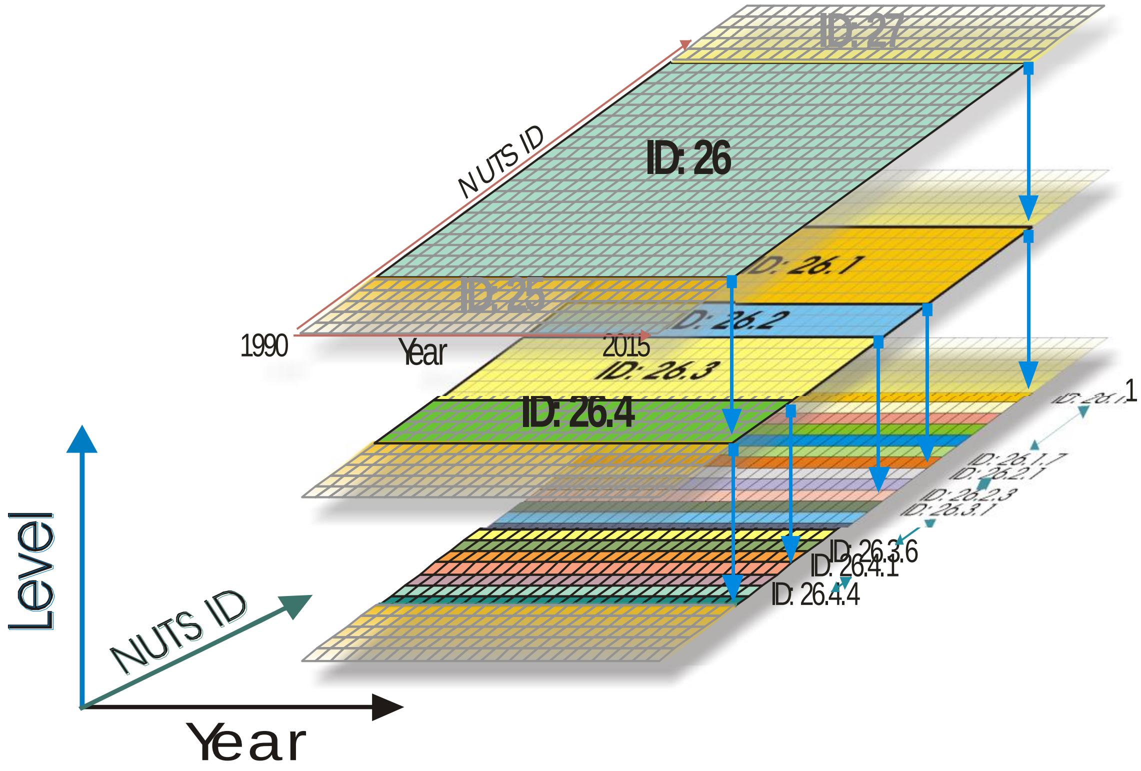

Figure 2: Structure of data storage format

For each data item a 3-dimensional stack is defined. A single file contains on the x-axis the years and the IDs of a NUTS level on the y-axis. The NUTS levels present the z-axis. Although the storage format of the binary files is a GIS format the data are not spatial. However, the format allows processing and analysing the statistical data directly using the GIS software package and simple exchange with other software packages.

2.3 Pre-Processing

The objective of the pre-processing stage is to adjust data coming from diverse sources to standard categories and an interchangeable data format. The main steps are presented in Figure 3.

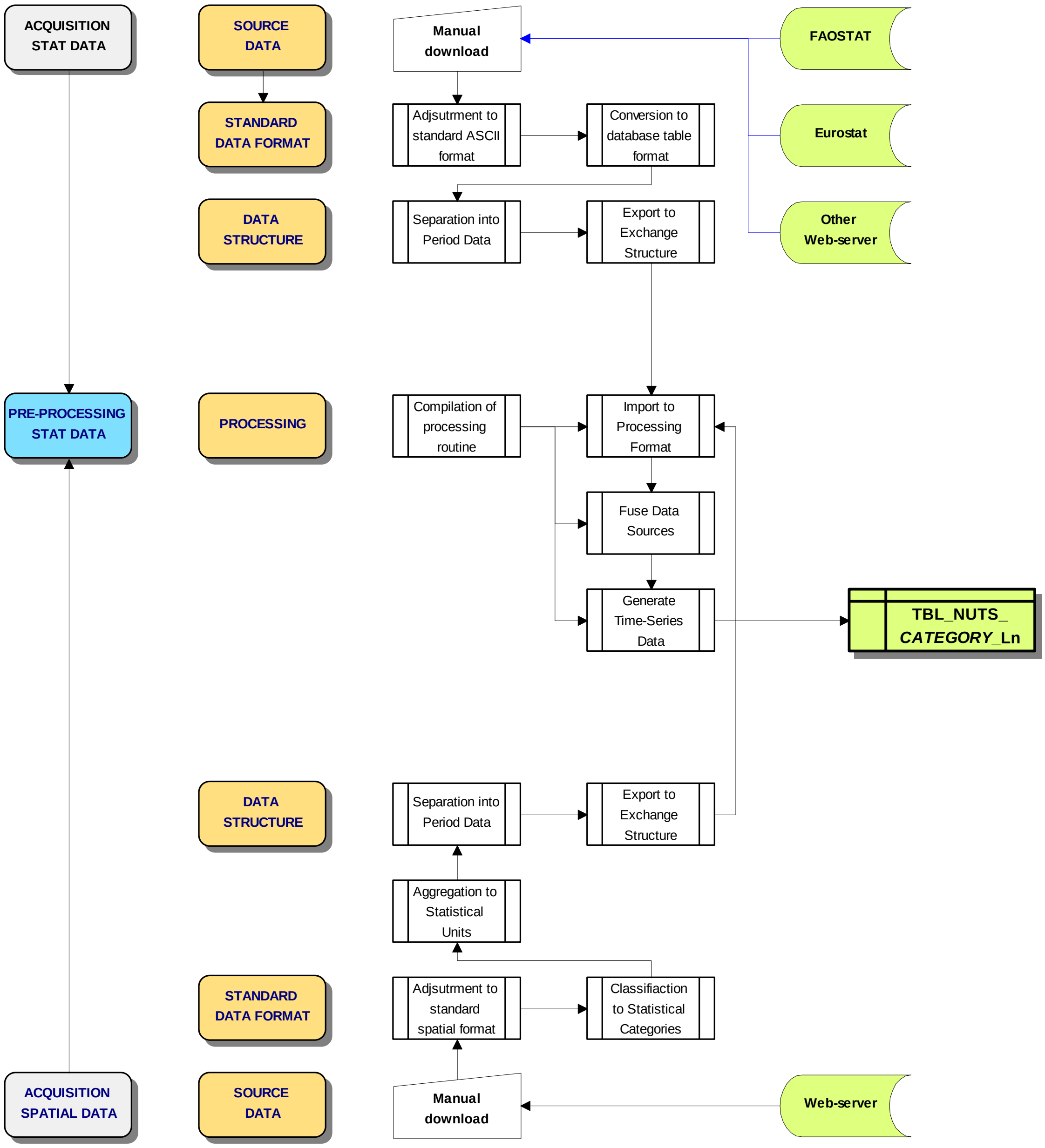

Figure 3: Schematic steps for pre-processing statistical and spatial data

Pre-processing covers data acquisition from the various sources, the adjustment to a standard data format and nomenclature and the transfer of data to the exchange format by processing period.

2.3.1 Data Preparation

The objective of the data preparation stage is to convert the data available from the various sources to the standard structures for tabular and spatial data.

a) Statistical Data

Statistical data are downloaded manually from web-sites and servers. Wherever possible the download format is a text file in ASCII format with a Unicode character set. The TAB character (Dec: 9) is the preferred choice for the field separator.

The downloaded ASCII data are parsed into a table format of a *Relational Database Management System* (RDBMS). The data are then adjusted to standard categories and units. The adjustment process includes:

- adjust codes to conform to a standard dictionary;
- assign standard identifiers for reporting entities;
- convert values to standard units;
- assign standard identifier for missing values.

The standard data are exported to the structured ASCII files for further processing in the GIS.

b) Spatial Data

Spatial data are adjusted to a common geographic projection and frame. The parameters of the spatial frame are given in Table 1.

Table 1: Standard parameter settings for spatial data

Parameter	Value
File format	Idrisi Raster A.1
Columns	6900
Rows	6000
Reference system	ETRS 89 LAEA
Reference unit	meter
Min. X	700000.0
Max. X	7600000.0
Min. Y	600000.0
Max. Y	6600000.0
Resolution	1000.0

The spatial frame for processing is slightly larger than the frame for output data (see Hiederer, 2016: Chapter 5.2.1). This avoids artefacts from processing areas close to the border when using spatial neighbourhood functions. The geographic projection *European Terrestrial Reference System 89, Lambert Azimuthal Equal Area projection* (ETRS 89 LAEA) is compatible with the specifications of the Inspire Directive for spatial data.

All spatial data are adjusted to a common land–sea mask. The mask is derived from the NUTS 2010 layer of administrative or statistical units at scale 1:1,000,000, as available from the *Geographic Information System of the Commission* (GISCO)[8].

Some spatial data may be aggregated to administrative units and stored as statistical data.

While the data acquisition is a manual task the process of data adjustments is largely automated using the form functionality of the RDMS. The procedure are adapted to manage the particular file formats and coding conventions of the various data sources.

2.3.2 Processing Consistent Time-series Data

The objective of the stage is to provide the spatial allocation process with a complete and consistent time series of data for all NUTS level 0, 1 and 2. The need for generating a continuous time-series is shared by many applications and numerous techniques are published (Han, et al., 2011). Common requirements with the *Complete and Consistent Data Base* (COCO) for the *Common Agricultural Policy Regionalised Impact analysis* (CAPRI) (Britz & Witzke, 2014), to use but one example, are:

- use of documented data from official and publicly available sources;
- complete time-series without gaps for areas or category;
- consistent representation of groups of categories.

A wide variety of method and technics may be used. The method developed for the spatial Tier 1 implementation is tailored to the processing environment. The procedures applied are not directly comparable with other efforts and may give dissimilar results.

Following the results from the previous study some aspects of this stage have been modified from those presented in (Hiederer, 2016). The processing steps for producing a time-series of statistical data are presented in Figure 4.

[8] URL: http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/nuts

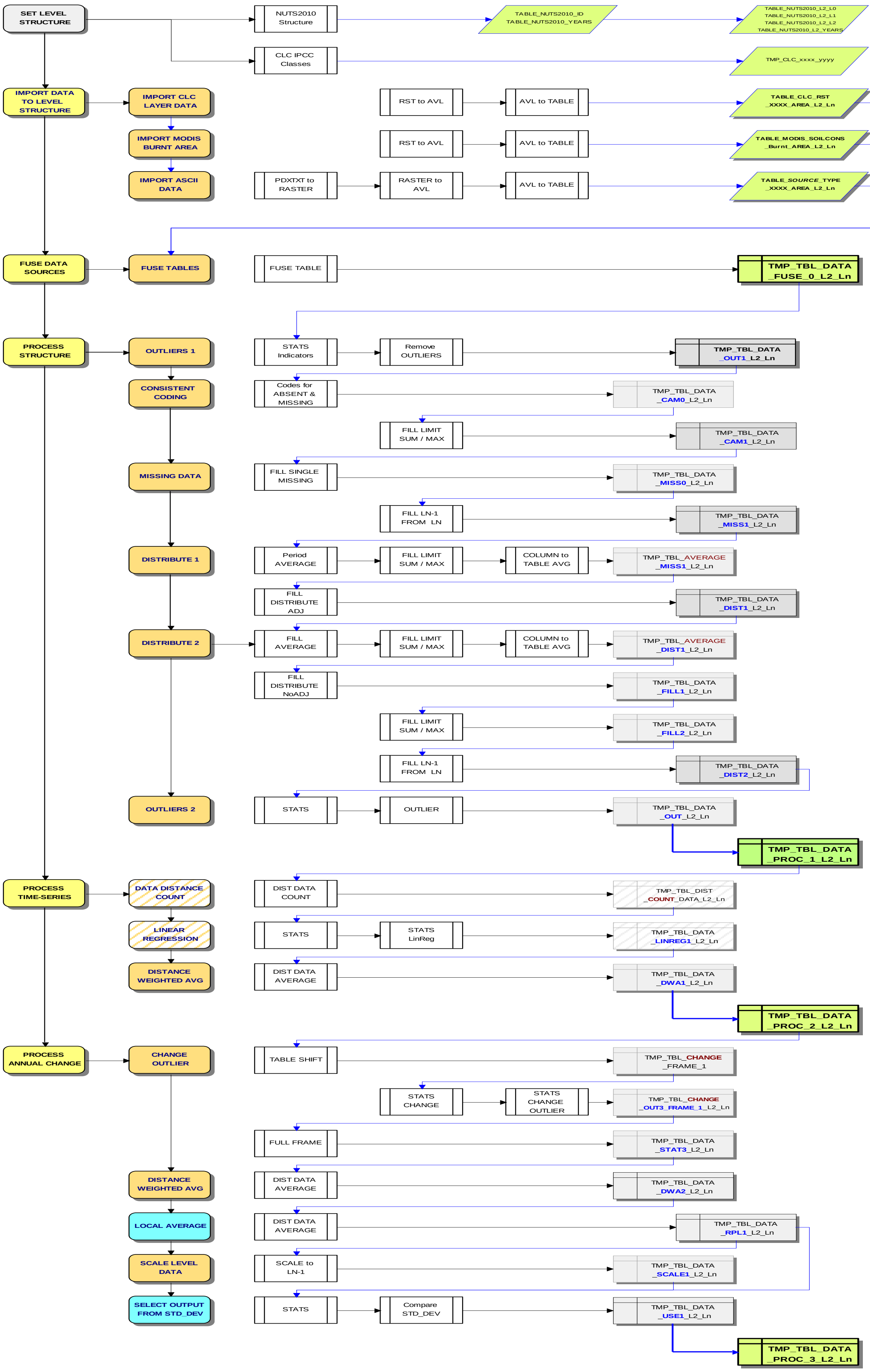

Figure 4: Schematic steps for processing statistical data

The individual processing steps are explained in detail in Chapter 5.1.5 of (Hiederer, 2016). The steps removed in the modified processing are indicated by a striped fill pattern in the graph and are:

- **Structure**

  No change.

- **Temporal Sequence of Data**

  The step of estimating values by a linear regression was removed. Data are no longer extrapolated beyond the limits of existing values. The interpolation of values is achieved by a linearly-weighted distance function. Extrapolating values was found to be unreliable. It has to be accepted that the set of drivers of change is incomplete and changing with time. Given the variability in the reported data the reliability of trends, even within the range of reported values, may be low. This was also found to be the case where the trend was highly significant (based on the coefficient of correlation). Adjusting the estimated according to the level of significance of the coefficient of correlation (Britz & Witzke, 2014) was tried, but found unreliable and removed.

  It is assumed that the annual data used does not contain periodic fluctuations and no attempt is made to remove cyclical components in the time series.

- **Change**

  No change.

Steps added to the procedure are indicated by a blue fill pattern and are:

- **Local Average**

  A local average is calculated for a three-year window. The step was introduced to reduce the effect of annual variations of data coming from diverse sources with periodic data, but gaps between reporting years. This happens for some Eurostat data that are available at two- or three-year intervals and where data differ notably from the data from the higher-rated surveys. These data are not treated as outliers, since the domain generally contains values for several years and not as fluctuations, since any cyclic component is introduced by the absence of values in one data source that differs from data of another source and not by the reported data.

- **Standard Deviation Criterion**

  The standard deviation of values over the whole temporal period is used as a criterion to select either data from the local average process or the data adjusted by NUTS level. The data selected are not annual values, but the whole time-series.

An overview of the data processed as statistical data is presented in Table 2.

Table 2: Data processed for consistent time-series

Land Use	Crop[1]		Tillage	Soil Conserv.	Livestock	Grazing	N Fertiliser	N Rate		Manure Mgmt.
Grassland	Cereals	Other Roots	Con-ventional	Bare Soil	Dairy Cows	Total Fodder	Manure N	Rice	Other Roots	Pasture Range
Cropland	Common wheat	Rape & Turnip	Con-servation	Burnt Area	Growing Cattle	Grazing Months	Min. N Consumpt.	Common wheat	Rape & Turnip	Daily Spread
Rice	Durum wheat	Sunflower	Zero	Cover Crop	Buffaloes	Permanent Meadow	Org. N Consumpt.	Durum Wheat	Sunflower	Solid Storage
Permanent Crop	Rye	Soya		Normal Crop	Non Dairy Cows	Permanent Pasture	Other N Input	Rye	Soya	Dry Lot
Set-aside	Barley	Cotton		Residues	Growing Pigs	Rough Grazing		Barley	Cotton	Liquid Slurry
Native	Oats	Tobacco			Breeding Pigs			Oats	Tobacco	Anaerob. Lagoon
Wetlands	Grain Maize	Green Maize			Equidae			Grain Maize	Green Maize	Pit Below
Artificial	Other Cereals	Fodder Legumes			Goats			Other Cereals	Fodder Legumes	Deep Bedding
Other	Pulses	Temp. Grass			Sheep			Pulses	Temp. Grass	
	Potatoes	Energy Crops			Poultry			Potatoes	Energy Crops	
	Sugar beet	Mushrooms						Sugar beet		

[1] Area, Production, Yield and Irrigated Area

Affected by the modification to processing demands are the 9 categories of Land Use, indicated in red text in Table 2. For other feature types the demands were already allocated by the annual total rather than the annual change.

2.4 Demand Processing

The results of the pre-processing stage provide the annual demands in area, production, yield or livestock numbers that are allocated in the spatial layers. The principles of the allocation are presented in Chapter 5.3 in (Hiederer, 2016). Particular observations of applying the procedure are presented in Chapter 3.2 in (Hiederer, 2017).

2.4.1 Demand Processing Overview

The general procedure for processing demands (area, yield, rate, etc.) is schematically presented in Figure 5.

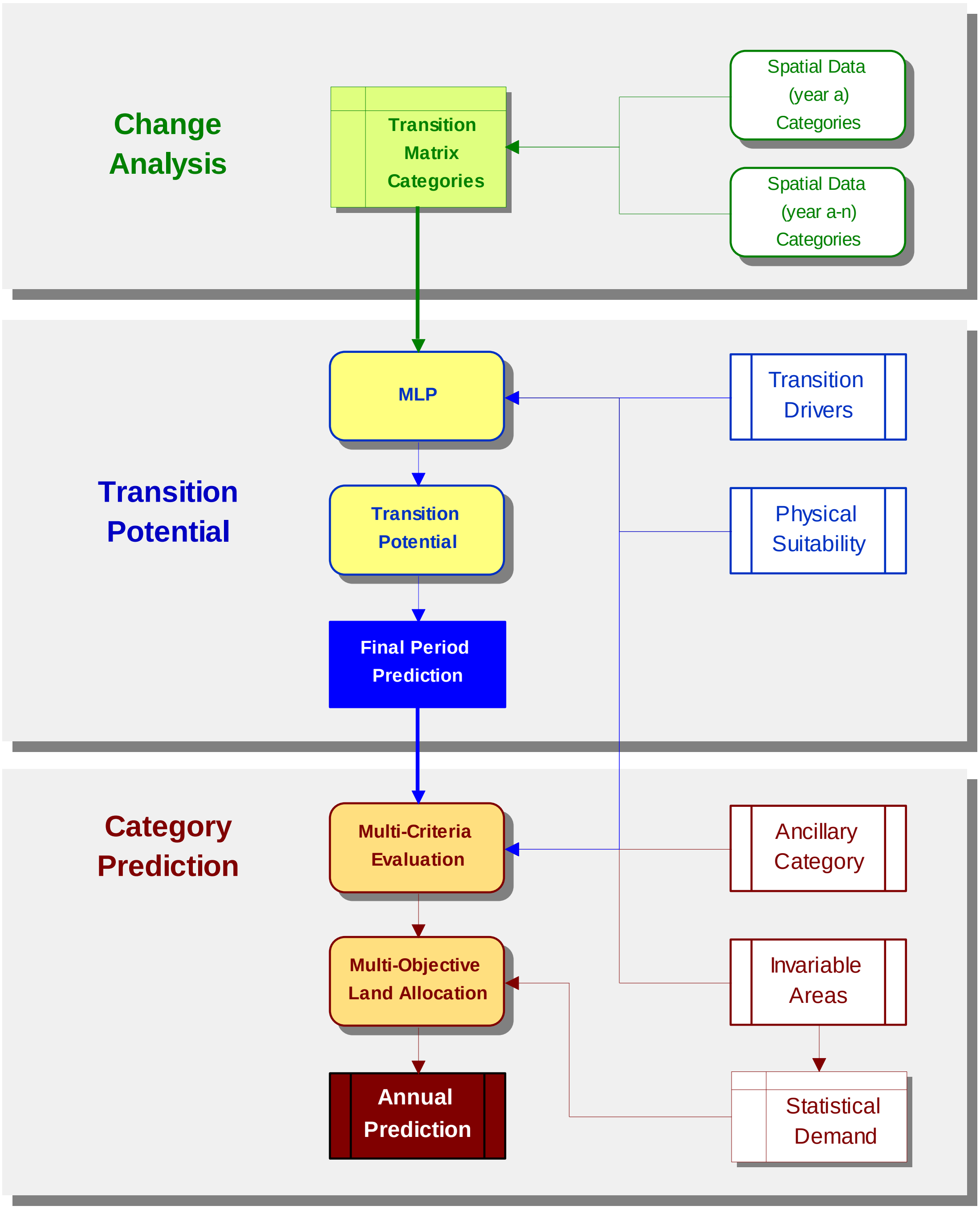

Figure 5: Processing demands for spatial allocation

The process of generating spatially layers from statistical demands can be separated into three stages:

- Change analysis
- **Transition potential**
- **Category Prediction**

The **change analysis** uses two spatial layers that are *n* years apart and are classified according to the categories to be allocated. The dates should as much as possible correspond to the starting and end years of the period processed. Where available CLC data are used, else EAS CCI data. From the locally specific changes between categories over time a transition matrix is generated.

The transition matrix of the change analysis is transformed to a transition likelihood and is one of the input factors that defines the **transition potential**. The other factors are the suitability of a location for a category, such as the crop suitability for a given crop type. The transition drivers are static and dynamic conditions that affect the persistence or change potential. A static parameter remains unchanged over time, such as terrain slope, while dynamic parameters are updated according to changes in the allocation layer, such as distances to a category. These elements form the input factors to compute the transition potential for all categories. The tool used to perform this task is a multi-layer perceptron neural network.

For periods without an actual spatial layer of categories for the final year the distribution of categories is predicted based on a Markovian transition estimator. The estimator use as input the transition probability and the transition potential data to produce layers of the conditional probabilities for the allocation of each category and, subsequently, a single layer with the predicted spatial distribution of the categories.

When using historic data the predicted layer is substituted by the actual land use layer. In case scenario data are processed the predicted layer is substituted by the final scenario data.

This modification to processing demands was introduced as part of using the full demand instead of changes in demand between years. For allocating changes in demand an existing CLC layer could be used, such as CLC 2000 or 2012. The use of a widely available base layer greatly facilitates exchanging data, since it may provide common initial condition. This is no longer the case when allocating the full demand. Therefore, to retain a close similarity with existing data the concept of a final category layer was introduced.

The annual data of **category predictions** are produced by a multi-criteria evaluation (MCE) followed by a multi-objective land allocation (MOLA). The MCE takes the factors from the transition potential stage and includes ancillary data into the allocation procedure. Ancillary data are other sources of the spatial distribution of the categories to be allocated. The result of the MCE are layers with ranked potentials of locations for attributing a category.

The adjusted demands are forwarded to the MOLA procedure for allocation of the locations to a category where change is possible. The result are spatial layers for each category and each year processed.

2.4.2 Demand Processing Implementation Steps

The implementation of the procedure for transferring a time-series of statistical data to spatial locations has been modified for all types of categories processed to apply an IPCC Tier 1 method to spatially explicit data.

An example of the specific processing steps implemented is presented for Land Use data in Figure 6.

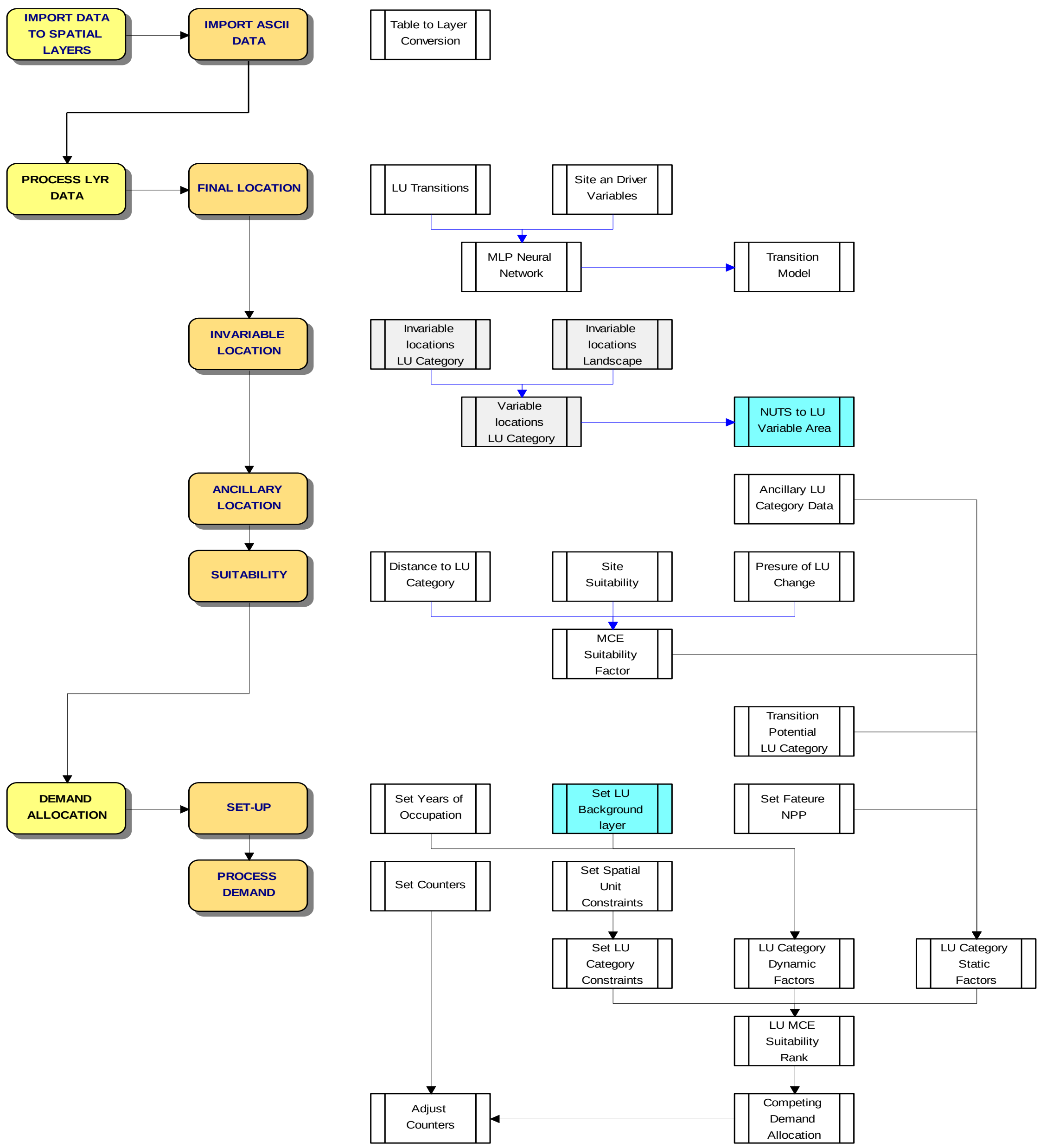

Figure 6: Steps and routines for processing spatial data

The changes to the previous implementation are highlighted in the graph by boxes with a blue fill pattern.

- ## NUTS to LU Category Area

  The number of locations allocated to a category in the MOLA is governed by the statistical data. That there are differences between the statistical data and the spatial areas is unavoidable. The statistical data does not cover all land areas according to the land use categories. There are no adequate statistical data on natural areas, wetlands, artificial areas or other areas that would correspond to the IPCC definitions. Estimates for these categories are compiled from data coming from a variety of sources. As a consequence, the sum of all land areas of the statistical data differs from the land area of the spatial layer. The statistical areas are aligned with the area available in the spatial layer by a weighted adjustment.

This statistical data is modified by regions considered invariable. Such regions are e.g. inland waters, permanent snow field or areas of bare rock. These regions are deducted from the total area available for allocation. As a consequence of the presence of invariable areas and differences between the area available for allocation between the spatial and the statistical data the demand from the statistical data as produced by the pre-processing step has to be adjusted to the available area of the spatial data.

$$A_{Total} = A_{Var} + A_{Fix}$$

where

$$A_{Var} = A_{Cat} + c_{Total}$$

with

A_{Total}	total area of region
A_{Var}	area available for category change
A_{Fix}	area with fixed and invariable category
A_{Cat}	statistical data for area of a category
c_{Total}	total difference between available and statistical data for region

c_{Total} must be distributed to the demand of the categories that exist in the region. A simple proportional distribution of the difference to categories would affect categories with relatively dependable statistical data as much as categories derived from other sources and with a lower levels of constancy, such as wetlands and natural areas. The difference is therefore distributed by using weights for each category:

$$c_{Total} = \sum a_{Cat} x f x WGT_{Cat}$$

where

$$f = \frac{1}{\sum WGT_{Cat}}$$

with

a_{Cat}	adjustment for area of category
WGT_{Cat}	weight for adjustment of area for category
f	correction factor for weights

The correction factor *f* is applied to re-adjust the sum of the weights of the categories present in the area to 1.

The weights are set reduce the effect of the adjustment for the land use categories of grassland and arable land. This increases the distribution of the difference between statistical and spatial area to the land use categories containing natural areas and other land, while the demand for artificial land and wetlands is not modified over the processing period.

The effect of adjusting the demand in land use to the available resource for grassland is presented in Figure 7.

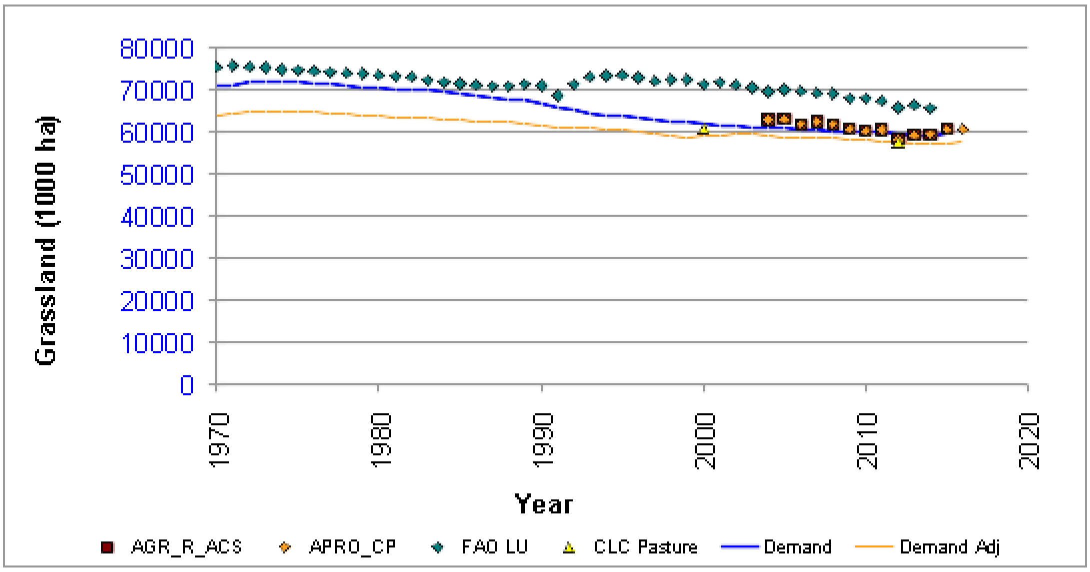

Figure 7: Comparison of demand for Grassland of statistical data, pre-processing statistical time-series and after adjustment to available spatial locations in (EU-28)

The graph shows the statistical data on grassland areas from a selection of sources as points and as lines. The blue line displays the demand for the land use category after gap-filling and adjustment to other land use categories during pre-processing statistical data. The orange line shows the adjusted demand, which is established based on the area available for allocation in the spatial layer. The time-series of the adjusted data shows less variability than the combination of statistical data and noticeably less than the source data. The adjusted is better suited to represent the trend in the spatial data then the merged statistical data, but is not apt to replace data for individual years.

- **Spatial Background**

The spatial background layer is used for locations that are not allocated to a land use category. The initial background is set to "Native", which is the default category for changes in SOC stocks. All factors for soil organic C-stock changes are neutral for this category. For all other years the land use layer of the previous year is used as background.

3 Results

During pre-processing statistical data are combined from various sources to a single set. This set covers all years of a time-series and all NUTS levels used. The statistical data set for land use categories is compiled from 16 domains and tables. The data, their temporal and geographic coverage and the time-series of areas for land cover categories are presented hereafter.

3.1 Changes to Pre-Processing Procedure for a Consistent Time-Series

The integration of data from diverse sources and estimating outliers and values for missing data is processed for each NUTS level to be consistent over time. Data are also adjusted between NUTS levels to be consistent with the NUTS structure. The changes introduced during the pre-processing stage affect values only for years and NUTS levels where a value was estimated.

The results of the changes for the time-series of permanent grassland at country level are exemplified in Figure 8.

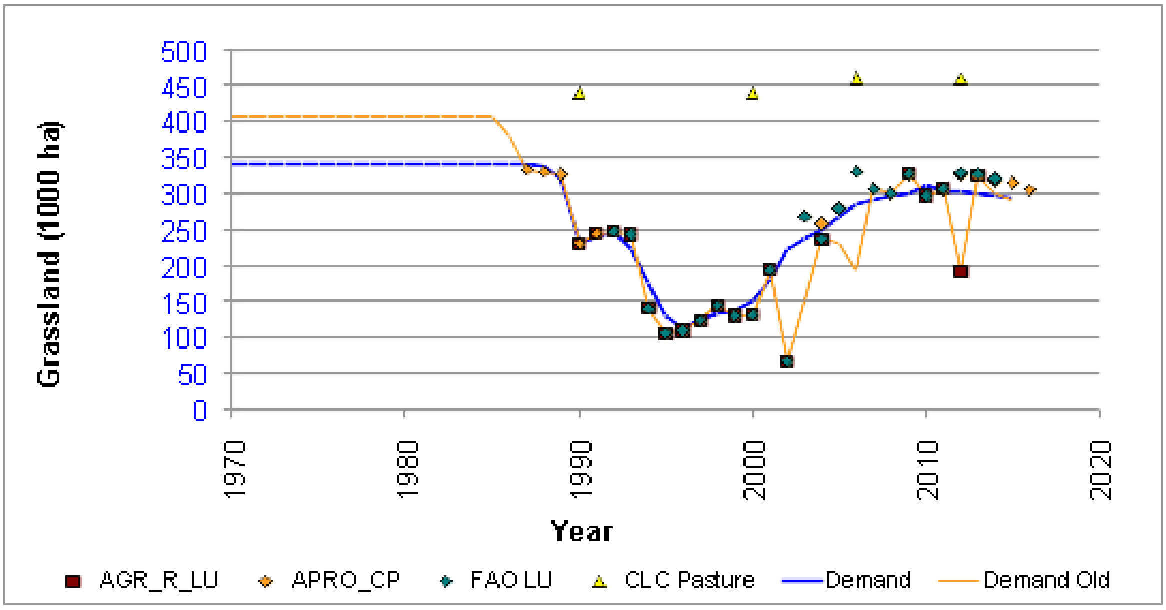

Figure 8: Effect of changes in pre-processing procedure on time-series (Permanent Grassland, Estonia)

The line "Demand" (-) presents the estimates of the area for a land use category after the data were adjusted during the modified pre-processing procedure, while the line "Demand Old" (-) depicts the values generated by the previous procedure. The graph shows:

- Reduction in annual variations from data coming from different sources and years. This is evident in the new area estimates after the year 2000.
- No extrapolation of data beyond range. The previous procedure used a local analysis of a linear trend (6 valid years, significant slope) and extrapolated data for 3 years. While a trend can be highly significant, this property only applies to the range (years) of the data. Extrapolating trends beyond the range of data was found to lead to at times ambiguous estimates and was removed from the procedure.
- The CLC area for pastures is no longer used to estimate data beyond the range of statistical data. The category was found to be only loosely related to statistical data for grassland. The separation of managed grazing land from other grassland is implemented as a module when processing spatial data.

Changes in the estimates of land use areas in the order shown in Figure 8 are few and the case illustrates the most pronounced case. With respect to the consequence of the pre-processing modifications on estimates of soil organic C-stocks only the removal of extrapolating a trend is expected to have a significant effect and then only when it affects arable land. As a consequence, the selection of the base year in a period of only estimated data becomes important.

With a rate of change that does not distinguish between the direction of change from or to a land use category the annual variations in area would largely annul any effect on long-term changes in soil organic C-stocks.

3.2 Availability of Data for time-Series of Areas for Land Use Categories

The initial year of the availability of statistical data at country and NUTS Level 2 from Eurostat and FAOSTAT data is summarised in Table 3.

Table 3: Initial Year of Availability of Statistical Data at Country and NUTS Level 2 Data (Arable Land Area)

Country	NUTS Level 0		NUTS Level 2
	FAOSTAT	**EUROSTAT**	**EUROSTAT**
Code	**Year**	**Year**	**Year**
AT	1961	1974	1974
BE	2000	1955	1974
ES	1961	1965	1974
FR	1961	1955	1974
IT	1961	1955	1974
LU	2000	1955	1974
NL	1961	1955	1974
UK	1961	1955	1974
CY	1975	1987	1990
CZ	1993	1987	1995
DE	1961	1988	1991
EE	1992	1987	1990
EL	1961	1972	1985
HU	1961	1987	1995
IE	1961	1955	1990
LT	1992	1987	1990
LV	1992	1987	2005
MT	1961	1991	1991
PL	1961	1987	1995
PT	1961	1979	1986
RO	1961	1987	1995
BG	1961	1987	2007
DK	1961	1955	2006
FI	1961	1983	1999
HR	1992	2000	2009
SE	1961	1983	1998
SI	1992	1991	2007
SK	1993	1987	1997

Initial year : 1970 : 1990 : 2000

The table provides an approximation for the starting year of country and NUTS Level 2 data to set a base year for the estimates of changes in soil organic C-stocks. A graphical representation of the data is given in Figure 17, which may provide a more accessible overview. The approximated initial year is a combination of the availability of data at country and NUTS Level 2.

- A possible starting year of 1970 could be set for 8 countries.
- A starting date of 1990 is considered for 13 countries.
- For the remaining 7 countries a starting date of 2000 can be deemed suitable.

A base year of 2005 for accounting for CO_2 emissions from land use and land use changes based on changes in soil organic C-stocks would require data starting from 1985 onwards. Based on the sources of statistical data for some countries this would require some assumptions for extending the available data. However, the national statistical offices may have access to more historic data than available from Eurostat.

3.3 Progression for Combining Data

Data are combined following a sequence, with the data from a higher rank given priority over data from lower ranks. The sequence for combining data sources for land use categories is presented in Table 4.

Table 4: Statistical data for time-series of Land Use Categories areas

Order	Data		Period	
	Code	**Label**	**Start**	**End**
1	AGR_R_LU	Agricultural land use (no longer available)	1974	2013
2	AGR_R_ACS	Crop statistics by NUTS 2 regions	2000	onwards
3	AGR_R_ACS_H	Crop statistics by NUTS 2 regions, historic data	1974	1999
4	AGR_R_CROP	Crop statistics (no longer available)	1975	2014
5	EF_R_NUTS	Structure of agric. Holdings by NUTS 3 regions	2000	2007
6	EF_LU_OVCROPAA	Farmland: number of farms and areas by size of farm (UAA) and NUTS 2 regions	1990	2007
7	EF_OLUAAREG	Land use: number of farms and areas of different crops by agricultural size of farm (UAA) and NUTS 2 regions	2005	2013
8	APRO_CPSHR	Crop production in EU standard humidity by NUTS 2 regions	2000	onwards
9	APRO_CPNHR_H	Crop production by NUTS 2 regions – historical data	1975	1999
10	APRO_ACS_A	Crop statistics (from 2000 onwards) (no longer available)	2000	2018
11	APRO_ACS_H	Crop statistics – historical data (no longer available)	1955	1999
12	APRO_CPP_CROP	Crops products: areas and productions (no longer available)	1955	2014
13	APRO_CPP_LUSE	Land use statistics (no longer available)	1955	2013
14	FAO_LU	Domain: Inputs – Land Use	1961	onwards
15	FAO_CROP	Domain: Production – Crops	1961	onwards
16	AGR_R_ACS_MAIN	Crop statistics by NUTS 2 regions, Main area (1000 ha)	2000	onwards
*	LAN_LCV_OVW	LUCAS Land cover overview by NUTS 2 regions	2009	2015
17	CLC_RST	Corine Land Cover	1990	2012

* not used until 2015

Following changes to the public Eurostat Web-server during 2016, 2017 and 2018 several source data are no longer available from the server site. The data were conserved and are still used for combining statistical data to improve coverage back to the year 1970, since new data only start in 1975 ([apro_cpnhr_h], [apro_cpshr]). Other data are not available as continuous years, such as the [ef_r_nuts] data or CLC.

In addition to the data sources specified in Table 5 (Hiederer, 2016) data from the Eurostat domain [agr_r_acs] with the STRUCPRO variable "Main area (1000 ha)" (Code: MA) is processed. The table provide areas for the main land use categories, which are not available for the variable "Area (cultivation/harvested/production) (1000 ha)" (Code: AR). Because the data provide fairly extensive information on areas for the main land use categories up to NUTS Level 2 and from 2000 onwards they were initially used in preference to other data.

The data largely corresponds to values from other sources, but not always. An example of significant differences between data sources for Greece is given in Figure 9.

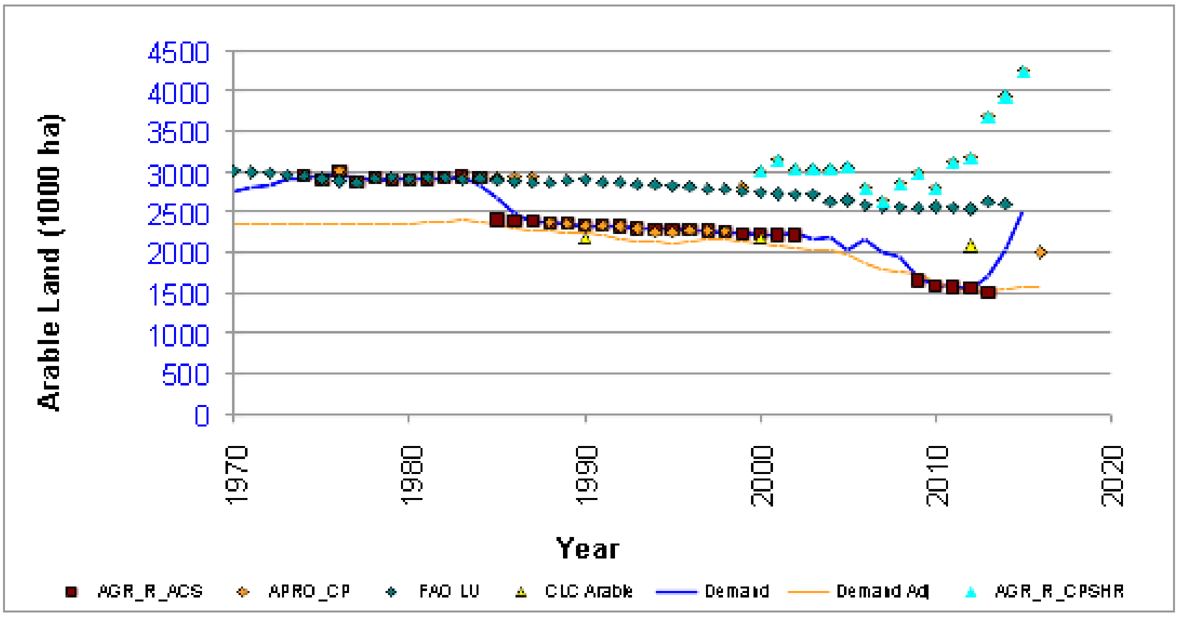

Figure 9: Example of Deviation of [agr_r_acs] data for "Main Area" data to other sources for Arable Land (Greece)

From 2000 to 2009 the values largely agree with the FAOSTAT data, but not the [agr_r_acs] area data. After 2009 the "Main Area" data exhibits a very different trend from any found in the other data sources and is therefore deemed unlikely. The data are also present in the [apro_cpshr] data, which were only published in February, 2018. However, the [apro_cpshr] table contains a value for 2016 that is a strong deviation from the data from 2010 to 2015 and closer to the [agr_r_acs] data, now discontinued. As a consequence, the data was given a lower rank in pre-processing procedure for fusing various data sources.[9]

Other data are not without anomalies. While for arable land data from the [apro_acs] domain seems to be more consistent than the [agr_r_acs] data

[9] Subsequent to the publication of the crop production data [apro_cpshr] and [apro_cpsnhr] EUROSTAT was contacted on March, 2018 with respect to the anomalies found. EUROSTAT looked into the matter and the data published on 16.04.2018 are in line with [agr_r_acs] data figures. Data on Permanent Grassland were not concerned.

this is not always the case for permanent grassland. An example of the development of the [apro_acs] data for Spain is presented in Figure 10.

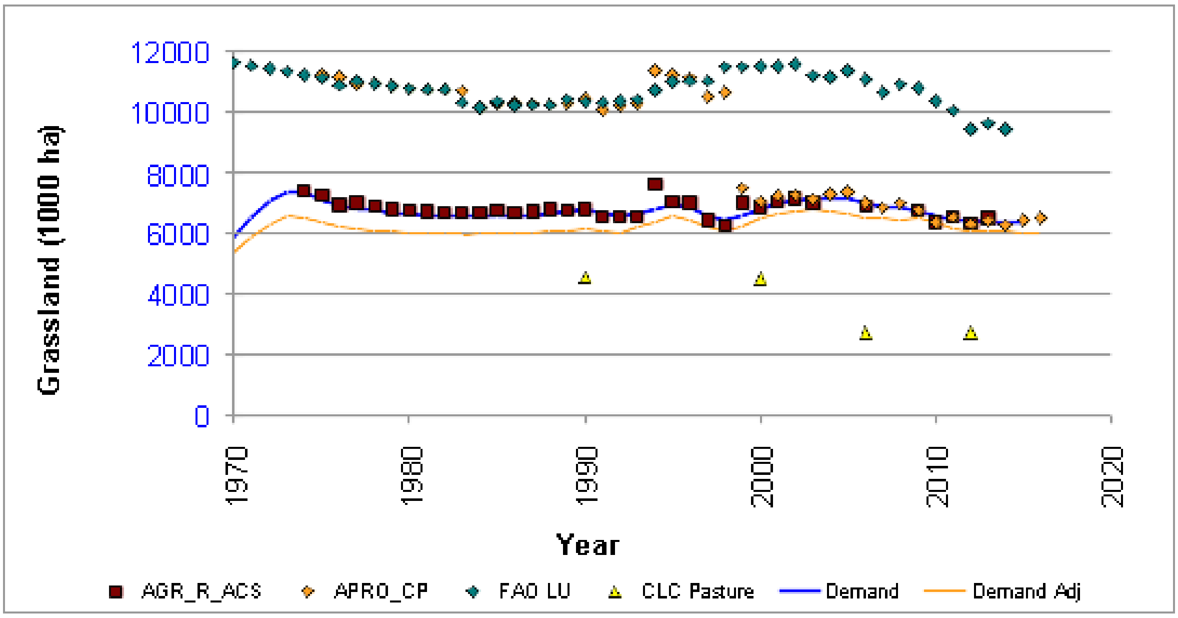

Figure 10: Example of Deviation of [apro_acs] data for "Main Area" data to other sources for Permanent Grassland (Spain)

From 1972 to 1998 the [apro_cpnhr_h] data agrees with the FAOSTAT land use data for the category. From 1999 onwards the data agrees with data from the [agr_r] domain. Using the [apro_acs] or [apro_cpnhr_h] data in preference to the [agr_r_acs] data, as suggested for arable land, would introduce a decrease in permanent grassland of 30% between the periods. This can be considered an artefact in the data rather than an actual change in land use.

Finding a method of combining data from different sources that suits all cases is not a straightforward task. A method that averages data from different sources is inappropriate and impractical where the time-series contains missing data. The ordered structure gives priority to data coming from sources ranked at higher levels, and therefore respects values where they exist, but depends on the consistency of the source data. The tool developed to generate the processing procedure allows setting the order of data sources by period and by individual category, but not by country. The order presented in Table 4 was found to be an acceptable compromise for historic data.

3.4 Time-series of Areas of Land Use Categories (EU28)

For EU28 the data for arable land and grassland are presented in Figure 11.

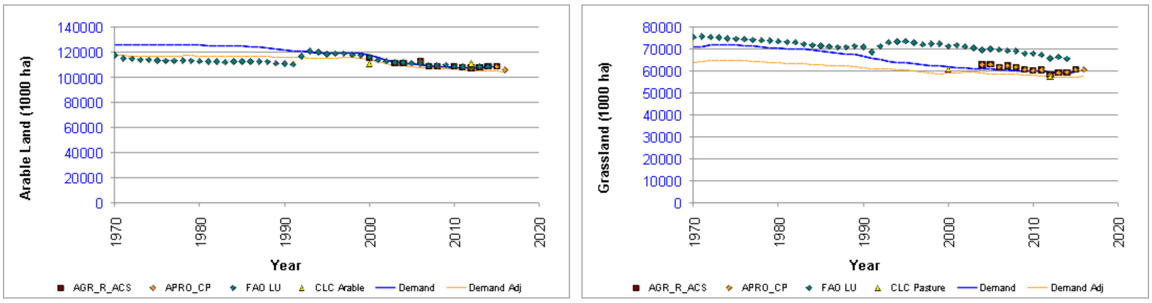

Figure 11: Time-Series of Statistical data for Arable Land and Grassland Categories for EU28

The graph show data for the geographic unit "EU28" (Eurostat) or "European Union + (Total)" (FAOSTAT). For the processed statistical data (Demand) and the statistical data adjusted to the spatial layer data (Demand Adj) the graph contains the sum of EU28 Member States.

For EU28 the data from Eurostat domains with information on land use correspond to each other. Data onEU28 as a geographic unit with data are included from 2003 onwards, at times for the year 2000 as an estimate. CLC data (only years 2000 and 2012 for EU28) are close to Eurostat data. FAOSTAT provide data on land use areas for the region "European Union + (Total)" starting in 1961. However, individual data of EU Member States in Eastern Europe start in 1992 or 1993. Noticeable on the graph is a change in values for these years. FAOSTAT data on areas of arable land agrees with Eurostat values from 1993 inwards, but differs with a constant offset to the EU28 estimates from the combined statistical data (Demand). The situation is reversed for grassland areas, where Eurostat data and FAOSTAT data differ for later years, while the combined data are close to FAOSTAT data for years before 1992.

The general trend in arable and grassland areas is a decrease over the period. However, there are quite diverse trends between and within countries. Graphs by country for the time-series of arable land and grassland are presented in the Annex.

3.5 Statistical Data and Selection of a Baseline Year

Under a Tier 1 method a preparatory period of 20 years should precede the year selected as the baseline conditions for soil organic C-stocks. The effect of setting the years (i) 1990 or (ii) 2005 as the baseline or (iii) using 2005 as a starting year without taking previous changes into account are evaluated based on the changes in arable land reported in the combined statistical data.

The evaluation of the effect selecting different years for a baseline is based on the temporal development of arable land. Graphs illustrating the trends from 1970 onwards for arable land and permanent grassland are given in the Annex. The evaluation concentrates on changes of arable land, because arable land is the most influential LU category for changes in soil organic C-stocks following land use change and, by extension, for estimates of GHG emission and removals from soil organic C-stock changes.

From the trends in the area of arable land the effect of using a land use history or not on soil organic C-stock changes is inferred, selecting 2015 as the reporting year. The results of the evaluation are given in Table 5.

Table 5: Evaluation of the trends in the area of arable land and potential effect on estimating changes in soil organic C-stocks for 2015

Country	Period Trend			Lack of historic data in 2005
	1970 - 1990	1985 - 2005	2005 – 2015	Effect
AT	↘	↘	↘	⇔
BE	↘	↗	⇨	⇕
BG	↘	↘	↗	⇕
CY	○	⇨	⇨	⇔
CZ	○	↘	↘	⇔
DE	⇨	⇨	⇨	⇔
DK	↘	↘	⇨	⇔
EE	○	↘	↗	⇕
EL	↘	↘	↗	⇕
ES	↘	↘	⇨	⇕
FI	↘	↘	⇨	⇕
FR	↗	↗	⇨	⇔
HR	○	↘	⇨	⇕
HU	↘	↘	↘	⇔
IE	↘	↗	↘	⇕
IT	↘	↘	↘	⇔
LT	○	↘	↗	⇕
LU	↘	↗	↗	⇔
LV	○	↘	↗	⇕
MT	↘	↘	↗	⇕
NL	↗	↗	↘	⇕
PL	↘	↘	↘	⇔
PT	↘	↘	↘	⇔
RO	⇨	↘	↘	⇔
SE	↘	↘	↘	⇔
SI	○	↘	⇨	⇕
SK	○	↘	⇨	⇕
UK	↘	↘	⇨	⇕

○ no data ↗ increase ↘ decrease ⇨ no change ⇔ no effect ⇕ differing effect

The trend indicator is based on a linear regression of the area values over the period. A direction of change is indicated when the difference between the area at onset of the period and at the end exceeds 3%. Otherwise no change is indicated. A potential effect of not using the land use history on changes in soil organic C-stocks is indicated when:

- the direction of change for the period with a history differs from the direction of change for the period 2005 to 2015 and
- the relative difference between the data with and without LU history exceeds 3%.

The evaluation of an effect of including or not the LU history in the estimates of changes in soil organic C-stocks is only an approximation. It does not provide an appraisal of the magnitude of the changes, which may still be notably different when there is a strong difference in the area changes between the periods.

4 Results of Spatial Tier 1

The statistical and spatial data are processed following a Tier 1 method for each NUTS Level 2 spatial unit of a country. NUTS Level 2 units are then combined to the country, which is the storage unit. The country data are combined to provide EU-wide information on an ad-hoc basis as needed.

4.1 Estimates of Changes in Soil Organic C-Stocks

The changes in soil organic C-stocks for all land use categories from 1990 to 2016 for EU28 are presented in Figure 12.

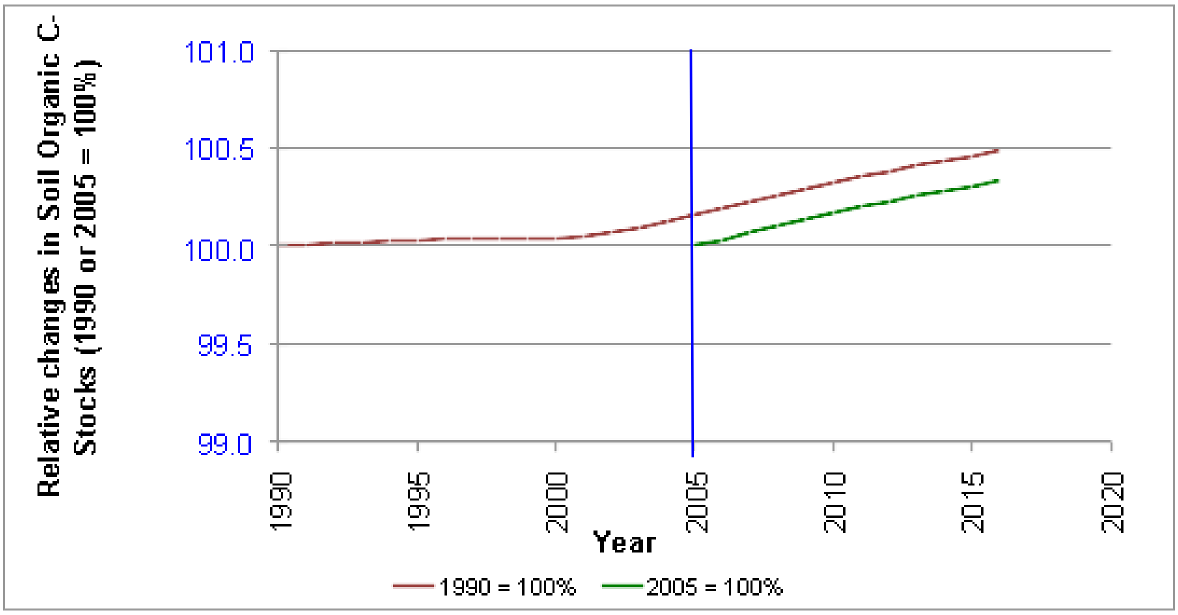

Figure 12: Relative changes in soil organic C-stocks for land use and land use changes on mineral soils for period 1990 to 2016 (1990 or 2005 = 100%)

The graph shows the changes in soil organic C-stocks in mineral soils from either 1990 or 2005 to 2016 for annual data for EU28. Until the year 2000 only minor changes in soil organic C-stocks are estimates for EU28. After the year 2000 the C-stocks are estimated to increase steadily to reach about 0.5% more in 2016 as compared to 1990 soil organic C-stocks. Using 2005 as a baseline for calculating relative changes the increase from 2000 to 2005 is not included and the C-stocks are estimated to increase by 0.35% over 2005 C-stocks.

The relative changes in soil organic C-stocks from 1990 to 2016 for individual EU 28 Member States are presented in Figure 13.

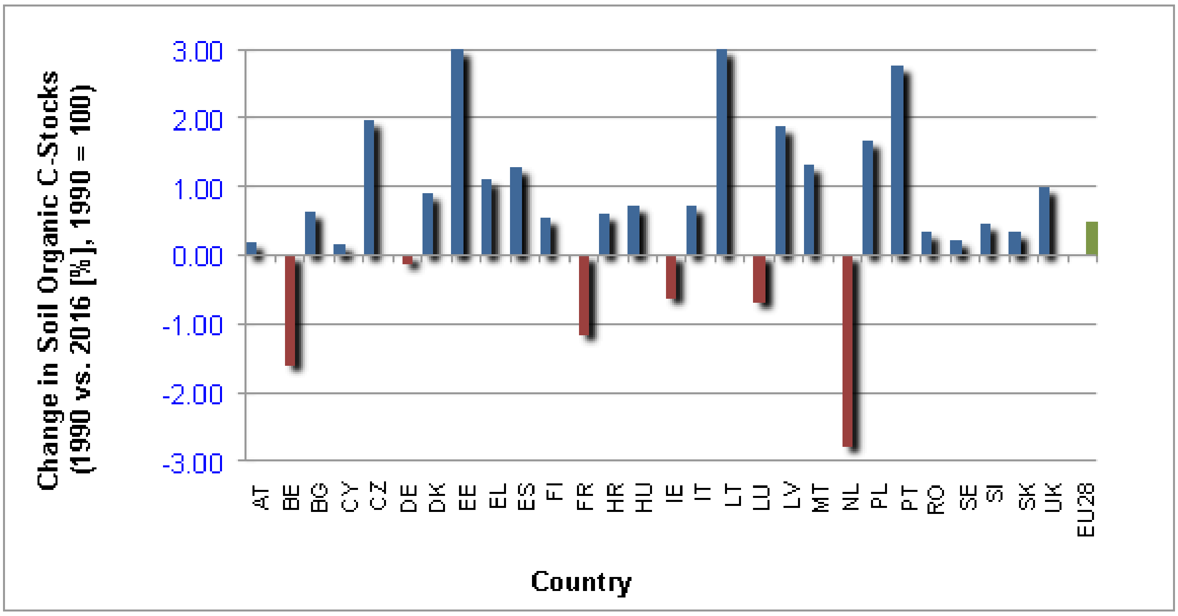

Figure 13: Estimate of relative changes in soil organic C-stocks from 1990 to 2016 for individual EU28 Member States (1990 = 100)

The graph indicates that there have been diverse trends in the development of soil organic C-stocks between countries. The countries with the most notable decreases in soil organic C-stocks relative to the national soil organic C-stocks over the period are Belgium, France, Ireland, Luxembourg and The Netherlands. This contrasts with increases in soil organic C-stocks in most other countries, most pronounced in Estonia, Lithuania and Portugal.

The changes in soil organic C-stocks in absolute values (Mt C) for the period 1990 to 2016 compared to the 1990 soil organic C-stock are presented in Figure 14.

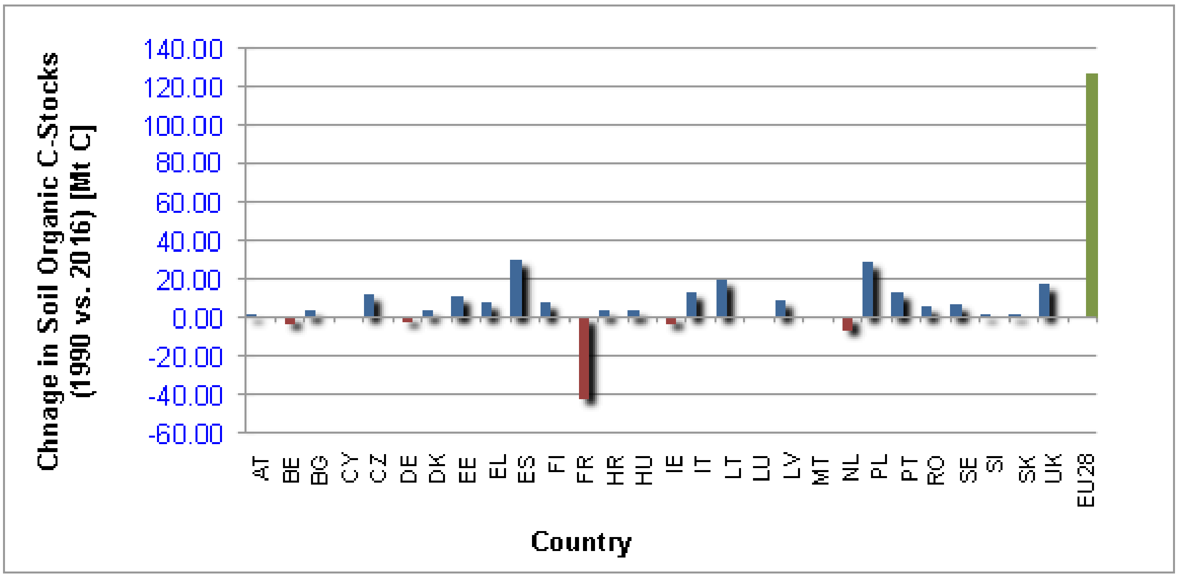

Figure 14: Estimate of absolute changes in soil organic C-stocks from 1990 to 2016 for individual EU28 Member States and EU28 (Mt C)

The graphs shows that in absolute terms the changes in soil organic C-stocks for EU28 increased by an estimated 148 Mt C (99 Mt C when using 2005 as base year). The only country with a notable decrease in soil organic C-stocks is France, where mineral soils 37 Mt C (9 Mt C when using 2005 as base year).

4.2 Estimates of Annual Emissions from Managed Organic Soils

With 276.7 1000km^2 the total area of organic soils in the spatial data is close to the total peatland area of 277.75 1000km^2 given in Table 3a.3.3 of Appendix 3a.3 Wetlands Remaining Wetlands: Basis for future methodological development for EU28 Member States with significant areas of organic soil. In Table 3a.3.3 the area given for drained peatland for agriculture (cropland + grassland) is 31.1 1000km^2. This contrasts with an area of 53.9 1000km^2 for organic soils under cropland and grassland in the spatial data.

This would be a notable difference in the area of managed organic soils. However, Table 3a.3.3 may be incomplete in the representation of organic soils. Based on the figures given in the table the proportion of peatland drained for agriculture is 11.2% and 31.2% for agriculture and managed forests of the total peatland area. Yet, the table text states that "56-65% of wetlands drained for agriculture and forestry". This suggest that the area of drained organic soils that is used for agriculture could be close to the 19.5% of the spatial data.

Estimates of emissions from managed organic soils (arable land and grassland) for 2016 are presented in Figure 15.

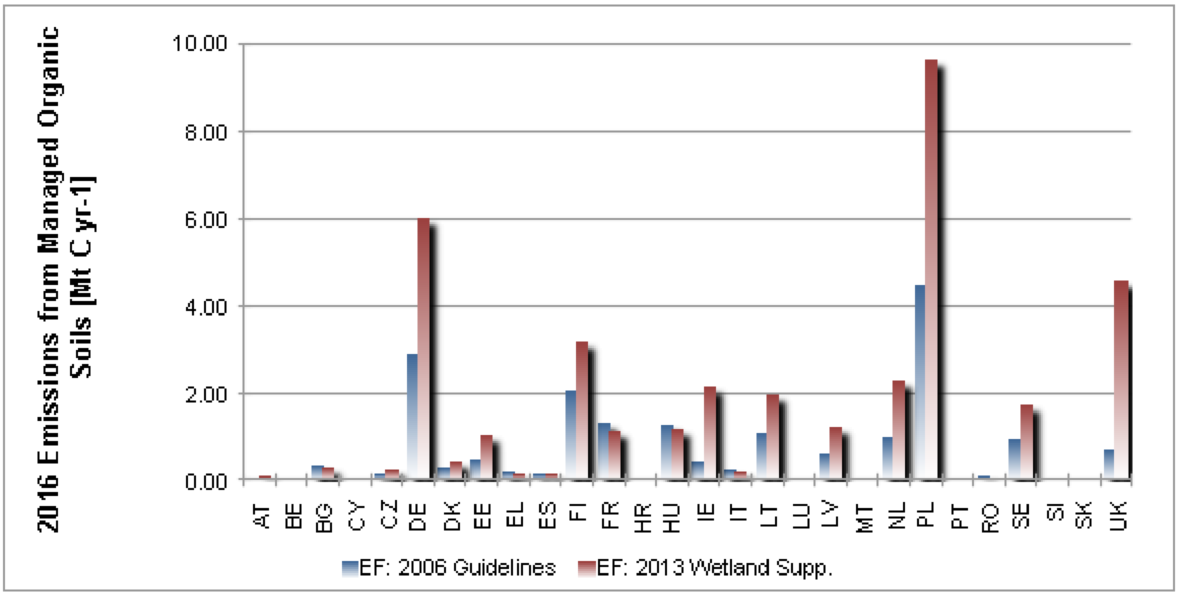

Figure 15: Estimate of emissions from managed organic soils for 2016 for EU28 Member States, using emission factors from 2006 IPCC Guidelines and 2013 Wetland Supplement (Mt C yr^{-1})

For 2016 the emissions from managed organic soils are estimated at 17.0 Mt C for EU28. With an estimated emissions of 4.3 Mt C for 2016 Poland accounts for 25% of EU28 emissions from managed organic soils. This is followed by Germany, with 2.3 Mt C for 2016, which corresponds to 14% of EU28 emissions from managed organic soils.

The estimates of annual emissions from managed organic soils should be treated with some care. An indicator of the uncertainty of the estimates are the changes in emission factors between IPCC guideline documents, such as the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 2006) and the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories:Wetlands (Wetlands Supplement)* (IPCC, 2014). When using emission factors from Table 2.1 of the 2013 Wetland supplement overall emissions more than double from 16.9 Mt C yr^{-1} to 37.2 Mt c yr^{-1} for 2016. Most affected by the change are managed organic soils in the United Kingdom, where emissions increase from 0.5 Mt C yr^{-1} to 4.5 Mt C yr^{-1}.

The change in emission factors for managed (drained inland) organic soils was not applied to forest areas and other stipulations of the Wetland Supplement were not considered, such as rewetted of organic soils. When taking these aspects into account the emission estimates are expected to change from the simple change of in values for emission factors. However, the exercise serves as a demonstration how uncertain emissions from organic soils are.

4.3 Estimates of Annual CO_2 Emissions (+) / Removals (-) from Land Use and Land Use Changes

The combined estimates of changes in soil organic C-stocks and emissions from managed organic soils for EU28 over the period 1990 to 2016 is presented in Figure 16.

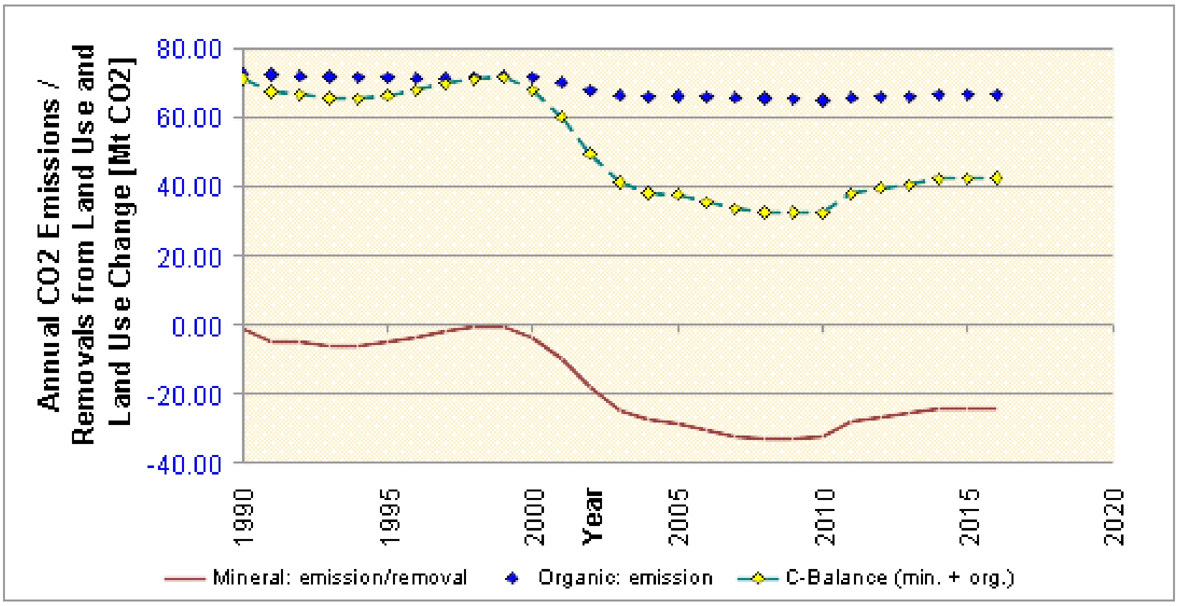

Figure 16: Estimate of annual CO_2 emissions (+) / removals (-) from mineral and managed organic soils for areas under Cropland and Grazing Land Management for EU28 (Mt CO_2)

According to the estimates emissions from the soil effected by land use decreased from approx. 63 Mt CO_2 in 1990 to 31 Mt CO_2 in 2016. This decrease was not gradual over the period, but mainly occurred from 1999 to 2008. Since 2008 emissions from the soil have remained relatively stable. The CO_2 emissions from managed organic soils are twice as much as the sequestration of CO_2 in mineral soils.

Using Tier 1 default values for emission factors for managed organic soils 95% of the emissions are from cropland and rice cultivated on organic soils and only 5% from managed grassland. For EU28 the area of cropland, rice and managed grassland on organic soils is less than 4% of the total area of these areas. From these estimates it would appear that minerals soils sequester annually 0.07 t CO_2 ha^{-1}, while managed organic soils emit 2.2 t CO_2 ha^{-1}. Hence, under 2016 conditions the sequestration rate of 31 ha of mineral soil are needed to compensate for the emissions from 1 ha of managed organic soil.

5 Summary and Conclusions

Building on the experience from previous runs the procedures for retrieving information from their sources and for combining and cleaning statistical data were modified at the data pre-processing stage. All statistical data were up-dated as available from the various sources by February, 2018 and processed. Also implemented were changes to processing spatial data for land use, management practice and input level according to the IPCC Tier 1 method. Estimates for changes in soil organic C-stock in minerals soils and annual emissions from managed organic soils were processed from 1970 to 2016, the last year of generally available statistical data.

5.1 Statistical Data

The statistical data for LU categories and management practices originate mostly from Eurostat and FAOSTAT. The assessment of the data availability and temporal changes concentrated on LU areas, although data on crop production, yield or animal numbers were processed using the same procedures for combining data and generating a complete time-series. The discussion of particular aspects is restricted to country data. To keep the number of the issues presented within manageable limits any aspects of processing the NUTS structure to Level 2 and consistency are only covered in general terms or to highlight any regularly occurring issues.

The evaluation of the statistical data leaves a mixed message. For many countries data coming from different sources agree and show no obvious anomalies in the time-series. However, there is no single data source that covers the categories at the level of detail required, be it for the temporal completeness or structural consistency. Also, none of the data offer a time-series without artefacts. There is no apparent common characteristic that could explain the artefacts and no general system of rules could be defined to exclude artefacts from entering the combined data. The procedure implemented to combine data coming from different sources work adequately to remove any outliers, but it is not adapted to cover systematic differences, such as multi-annual steps in the data. In the end it was necessary to give priority to data continuity over using unaltered statistical data to provide a reasonable time-series.

Despite the effort made during the pre-processing stage to generate a consistent data set some uncertainties remain about the direction of change. For several countries, mainly new Member States, the years 1992 and 2005 indicate a change in reporting data[10]. 1992 is the year when data become gradually available at NUTS level. For several countries 2005 is a turning point in the trend of changes in categories, such a as arable land. The year and the changes in the statistical data have some significance when considering 2005 as the baseline for estimating CO_2 emissions and removals from changes in soil organic C-stocks, i.e. from mineral soils. For a 2015

[10] In [apro_cpnhr_h] data this has been extended to 1987, but without data for higher NUTS levels.

reporting year it is estimated that in half of EU28 Member States using 2005 as a baseline for reporting without taking the LU history into account could lead to results that differ from an approach that covers land use and changes starting in 1995.

5.2 Spatial Data

The processing method for spatial data underwent a major modification by allocating areas rather instead of areas of change. This approach deviates from the generally used method of land change modelling. The adjustment to the procedure facilitates keeping the changes in land use area of the spatial data in line with the statistical data.

Drawbacks of the approach are more intensive data processing and increased storage demands. It also requires to process in parallel complete and spatially explicit time-series for all factors affecting land use categories, management practice and input level. Some of the time-series layers were already set in the previous version to avoid unrealistic fluctuations in land use or to support the application of a crop rotation system.

There is further no spatial land use or land cover layer that could be used as a common reference when exchanging data on land use between applications. In the previous implementation of processing land use changes a Corine Land Cover layer, such as CLC 2012, served as a basis to which changes were applied in temporal succession. Instead, to process spatially explicit changes coming from other sources the data have to be adjusted to the differences, usually by using a common year for comparison. While this step is an overhead for processing, it increases the consistency of the results when comparing processed data before and after the reference year.

5.3 Emissions and Removals Estimates

Emissions and removals from land use and land use changes on mineral soils are estimated from changes in soil organic C-stocks. Emissions from managed organic soils are estimated for cropland and managed grassland. The time-series of the data starts with the year 1970. For some EU28 Member States statistical data on land are available for this period, but for many countries statistical data in Eurostat become available starting with 1992 or 1993. Where data are missing a steady state situation is assumed. The approach to processing data, but not necessarily the availability of data, allow using 1990 as the base year for estimating C emissions and removals from the soil following land use change. In this study all land use conversions are considered, with the exception of changes from a category to wetlands.

Minerals soils are estimated to sequester CO_2 in the years following 1998. Emissions from managed organic soils (cropland and grassland) are estimated to have been reduced by 10% from 1990 to 2016. The combined effect for EU28 emissions from the soil is a decrease after 1998 to reach about half the pre-1998 amount in 2008. This was mainly due to a reduction in cropland areas and conversion to other land use categories.

5.4 Conclusions

The aim of the study was to investigate the possibility of using generally available statistical data on land use as a source for processing changes in soil organic C-stocks and emissions from managed organic soils to estimate CO_2 emissions and removals from the soil according to an IPCC Tier 1 method and Approach 3 (spatially explicit modifying factors for land use, management practice and input level).

The main conclusions reached from the study are:

- Statistical data on land use differ between sources, at times representing opposing trends in area changes. This has led to a notable extension of pre-processing data. The original objective of using one source as a reference and only estimate any missing data had to be modified. Instead, all values from the statistical data can be modified to better represent the trend in area changes.
- A less conventional approach to processing spatial data had to be implemented to maintain the statistical data on areas and any temporal changes in the spatial layers. This increases temporal consistency is made at the expense of data exchangeability.
- The results suggest that there has been a notable decrease in emissions of CO_2 from soils following land use changes. For 2016 conditions the results suggest that for EU28 to compensate for the CO_2 emissions from 1 ha of organic soils under CM and GM the sequestration of 31 ha of mineral soil is needed.
- The emission factors used for managed (drained inland) organic soils and treatment of organic soils under the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* may have a considerable effect on the overall soil emission and removal estimates. The magnitude of the effect remains to be investigated.
- There is a notable lack of data for an independent validation of the results. One method can be to use the national reports on GHG emissions and removals as a basis. However, this cannot compensate for any uncertainty in the input data.

In the assessment of estimates on GHG emissions and removals one should be aware that a model, however complex, cannot recover uncertainties or artefacts in the input data. This condition is quite independent from the tier used, but more apparent when using a Tier 1 method than modelling.

Annex I: Data by Country

Statistical Data Availability

Graphical presentation of Table 3.

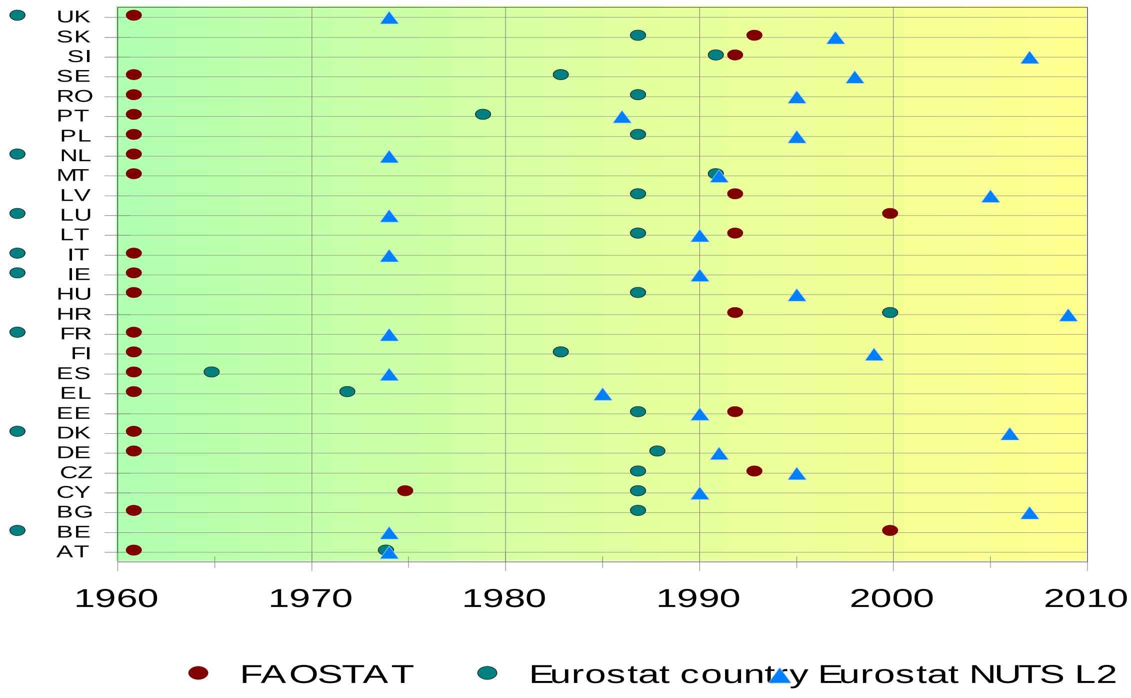

Figure 17: Initial year of availability of statistical data at country and NUTS Level 2 data (Arable Land Area as proxy for Cultivated land)

Annex II: Data by Country

The development of changes in soil organic C-stocks on minerals oils and emissions from managed organic soils for all land use categories are presented by country.

a) Temporal series of statistical data of areas of arable land and grassland

For the main sources of statistical data the areas for arable land and grassland are shown, starting in 1970. The final year of data is given by the data available in February, 2018. A line is added that depicts the values of the time-series generated by the pre-processing procedures.

b) Changes in soil organic C-Stocks, relative to 1990

The graph shows the changes in soil organic C-Stocks relative to the C-stocks estimated for 1990. Values > 100% indicate a soil organic C-stock that is above the C-stock of 1990. In this case CO_2 is removed from the atmosphere.

The inter-annual changes are relatively small, because the soil organic C-stock is large compared to the annual change, which is 1/20th of the difference between the stats of equilibrium. For reasons of comparison the data are always scaled from a minimum of 95% to a maximum of 105%.

c) Emissions from managed organic soils [Mt C yr-1]

The annual emissions from managed organic soils are given as mass C. The values are always ≥ 0. Emissions from organic soils are always additions to atmospheric CO^2.

The IPCC Guidelines specify mass C yr^{-1} for the emissions factors of managed organic soils instead of CO_2. The data are generally plotted with a minimum value of 0 Mt C yr^{-1}.

To express the data as CO_2 emissions and removals the values for the soil C-balance should be multiplied by a factor of -3.67.

When data contain inconsistencies or the results of the changes in soil organic C-stocks or emissions from organic soils are not consistent a red line covers the graph concerned. The graph for the soil C-balance is replaced by a graph showing the development of arable and grassland areas that highlight an uncertain condition.

Austria

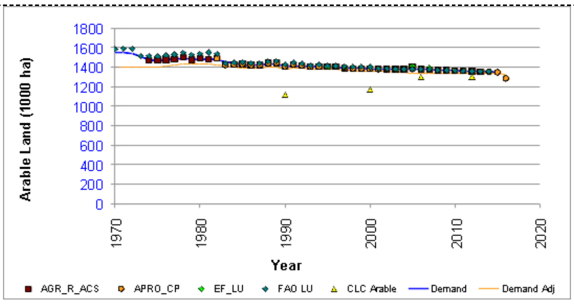

Figure 18: Time-series processed for Arable Land area [1000 ha] (Austria)

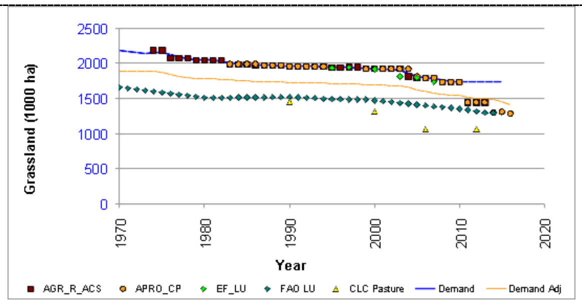

Figure 19: Time-series processed for Permanent Grassland area [1000 ha] (Austria)

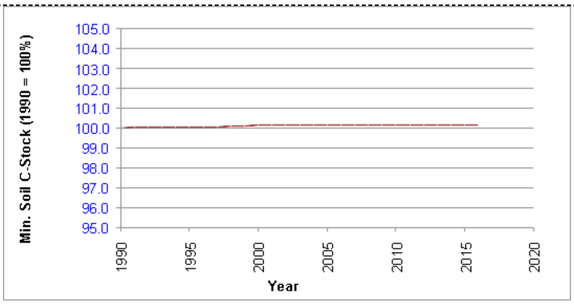

Figure 20: Changes in soil organic C-Stocks, relative to 1990 (Austria)

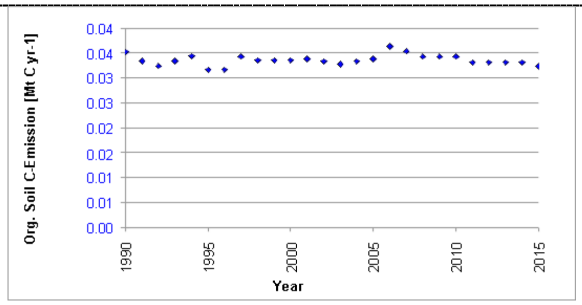

Figure 21: Emissions from managed organic soils [Mt C yr^{-1}] (Austria)

Land Use Area

For arable land the area steadily decreases from 1970 to 2016 by about 9%, with all statistical data sources in agreement. CLC indicates an increase in arable land from 1990 to 2012.
The areas of permanent grassland decreased gradually until 2003 and at an accelerated pace after 2003 to approach FAOSTAT data in 2015. It cannot be excluded that the trend in Eurostat may be an adaptation of the statistical data to comply with the data provided to FAO.

Mineral Soil

Soil organic S-stocks increased by 0.15%from 1990 to 2016. The rate is 0.01 Mt C yr^{-1} and relatively stable.

Organic Soils

Emissions from managed organic soils remain stable over the period at 0.04 Mt C yr^{-1}.

Annual Change in Soil Organic Carbon

Land use and land use change has hardly affected SOC stocks over the years. When combining emissions and removals from mineral and emissions from managed organic soils the situation indicates that soils to act as neither a source nor a sink.

Belgium

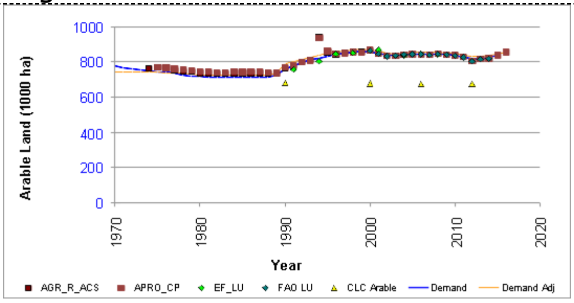

Figure 22: Time-series processed for Arable Land area [1000 ha] (Belgium)

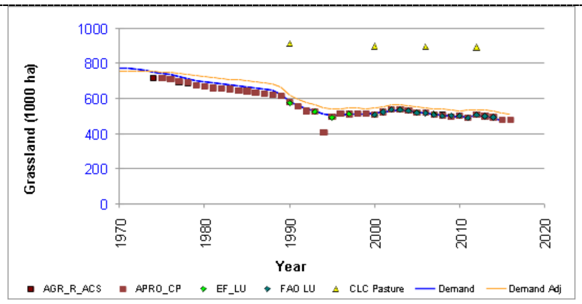

Figure 23: Time-series processed for Permanent Grassland area [1000 ha] (Belgium)

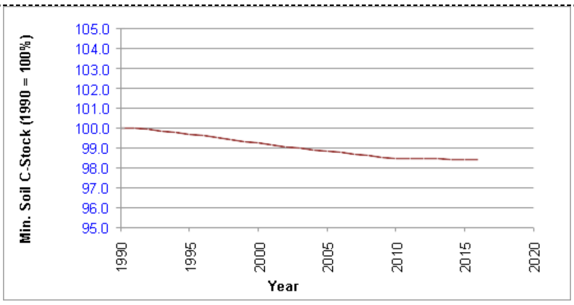

Figure 24: Changes in soil organic C-Stocks, relative to 1990 (Belgium)

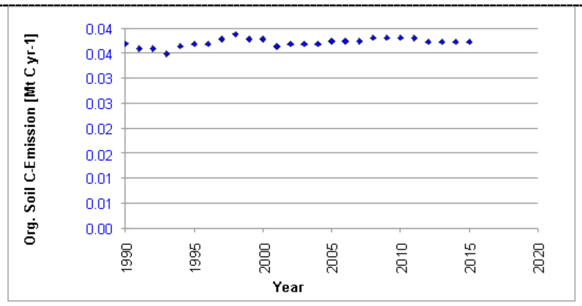

Figure 25: Emissions from managed organic soils [Mt C yr^{-1}] (Belgium)

Land Use Area

For arable land the area decreases slightly from 1970 to 1990, then increases until about 2000. Statistical data largely agree, but CLC data remains at the level of 1990 for all years.
Permanent grassland decreases continuously from 1970 to about 1995. It remains largely stable after 1995. Statistical data sources generally agree, while CLC data indicate a different trend and level for permanent grassland.

Mineral Soil

SOC-stocks decreased by 1.5% from 1990 to 2016. This is attributed to the increase in arable land, which is largely cultivate land.

Organic Soils

Emissions from managed organic soils show over the period. The annual rate of emissions is stable at 0.04 Mt C yr^{-1}.

Annual Change in Soil Organic Carbon

The SOC balance is negative for managed soils, but with a tendency to decrease emissions following the year 2001.

Bulgaria

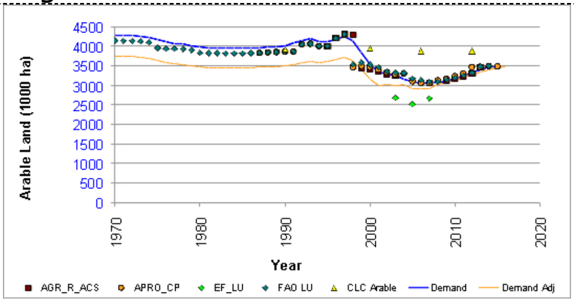

Figure 26: Time-series processed for Arable Land area [1000 ha] (Bulgaria)

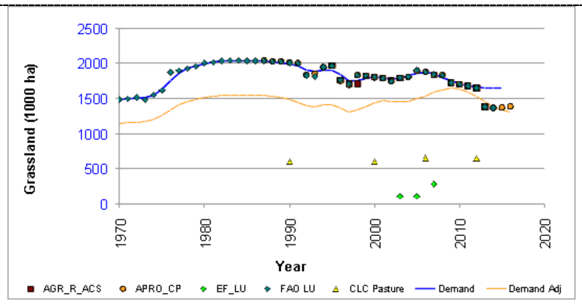

Figure 27: Time-series processed for Permanent Grassland area [1000 ha] (Bulgaria)

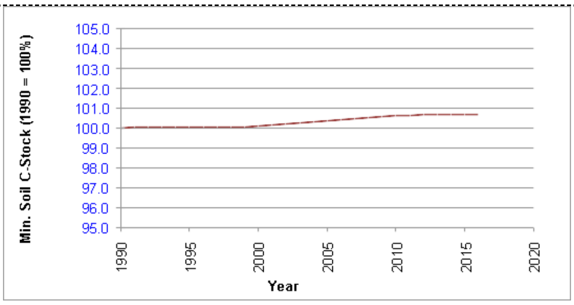

Figure 28: Changes in soil organic C-Stocks, relative to 1990 (Bulgaria)

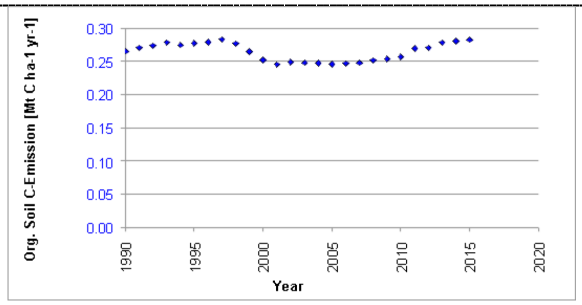

Figure 29: Emissions from managed organic soils [Mt C yr^{-1}] (Bulgaria)

Land Use Area

The statistical data on the area of arable land remains essentially stable until 1998, but then decreased notably until about 2007 to increase until 2016.
Permanent grassland shows a notable increase from 1973 to 1976 with stable areas until 1991. The area slowly decreases until 2013, when a sudden drop in areas is reported. The processed data differ, indicating some inconsistency in the area of other land use categories.
CLC data for arable land essentially agrees with the statistical data for arable land. For permanent grassland the CLC data is only about 30% of the statistical data.

Mineral Soil

SOC-stocks increase from 1999 to 2011 and then remain stable. SOC-stocks for 2016 are estimated to have increased by 0.16% over 1990.

Organic Soils

Emissions from organic soils vary around 0.25 Mt C yr^{-1}.

Annual Change in Soil Organic Carbon

After a period of relative CO_2 neutrality from 2000 to 2008 soils have become a source of CO_2 in subsequent year, with a loss of 0.3 Mt C yr^{-1}.

Cyprus

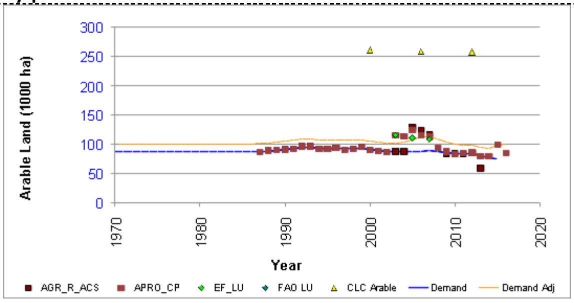

Figure 30: Time-series processed for Arable Land area [1000 ha] (Cyprus)

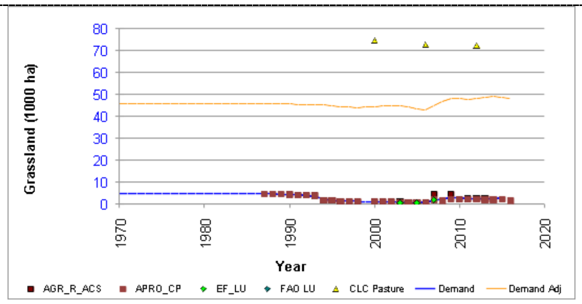

Figure 31: Time-series processed for Permanent Grassland area [1000 ha] (Cyprus)

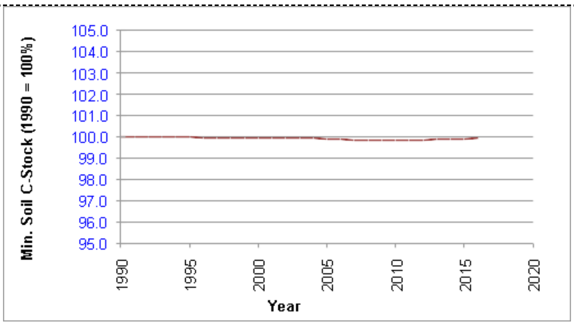

Figure 32: Changes in soil organic C-Stocks, relative to 1990 (Cyprus)

No managed organic soils.

Figure 33: Emissions from managed organic soils [Mt C yr^{-1}] (Cyprus)

Land Use Area

FAOSTAT data were excluded from the data combination, since the data refer to different areas over temporal period, but use the same geographic code.
For arable land areas some deviations from a long-term trend are found for the years 2005-2007, to a lesser degree also for permanent grassland. This could have implications when using 2005 as the base year, since it would induce a strong decrease in arable land. CLC data are notably different from the statistical data for both land use categories.

Mineral Soil

Following the stable situation for land use data SOC-stocks remain basically unchanged.

Organic Soils

No managed organic soils.

Annual Change in Soil Organic Carbon

In the absence of managed organic soils the removals / emissions from soils are defined by changes in SOC-stocks, which are stable.

Czech Republic

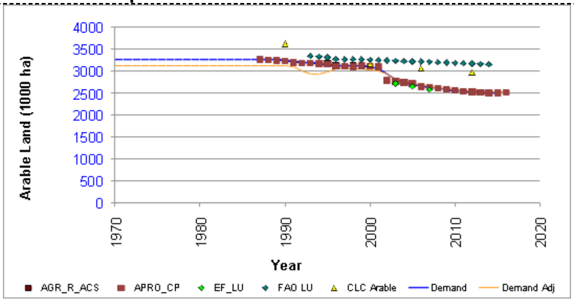

Figure 34: Time-series processed for Arable Land area [1000 ha] (Czech Republic)

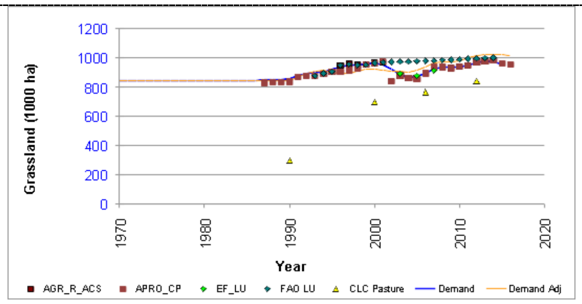

Figure 35: Time-series processed for Permanent Grassland area [1000 ha] (Czech Republic)

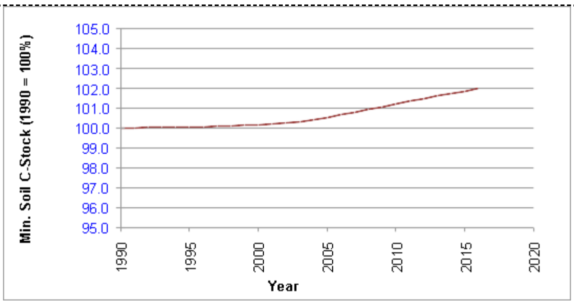

Figure 36: Changes in soil organic C-Stocks, relative to 1990 (Czech Republic)

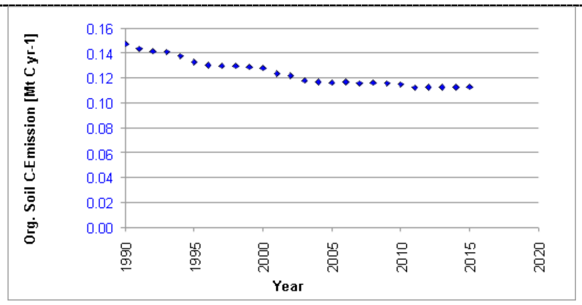

Figure 37: Emissions from managed organic soils [Mt C yr^{-1}] (Czech Republic)

Land Use Area

Some statistical data are available from 1987 onwards. The area of arable land decreases slowly until 2001 and then at a stronger pace. The area of permanent grassland increases over the period, but with a decrease from 2001 to 2004. FAOSTAT data are more linear with only a marginal increase in the area of arable land and a steady increase in permanent grassland. CLC data for arable land agrees well with FAOSTAT data, but more than triples from 1990 to 2012, thus indicating a much more pronounced trend in area changes.

Mineral Soil

SOC-stocks increase steadily and more strongly after 2002. The increase from 1990 to 2016 is estimated to be 2.2%.

Organic Soils

Emissions from managed organic soils gradually decreased to 0.1 Mt C yr^{-1} in 2016.

Annual Change in Soil Organic Carbon

With the increase in SOC-stocks the soil C-balance indicates soils to act as a sink for CO_2 with a sequestration of 0.6 Mt C yr^{-1} in 2016.

Germany

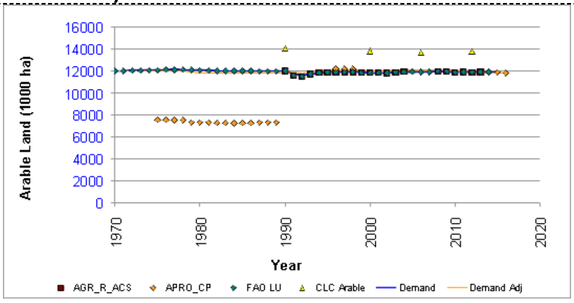

Figure 38: Time-series processed for Arable Land area [1000 ha] (Germany)

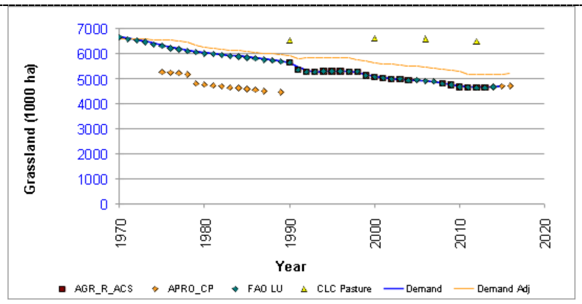

Figure 39: Time-series processed for Permanent Grassland area [1000 ha] (Germany)

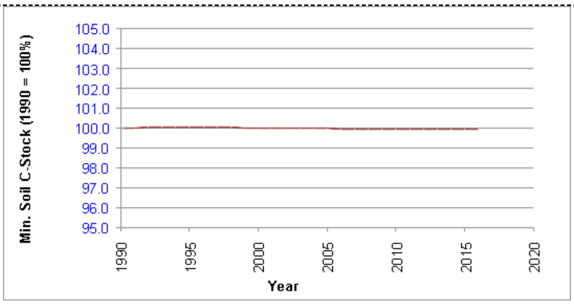

Figure 40: Changes in soil organic C-Stocks, relative to 1990 (Germany)

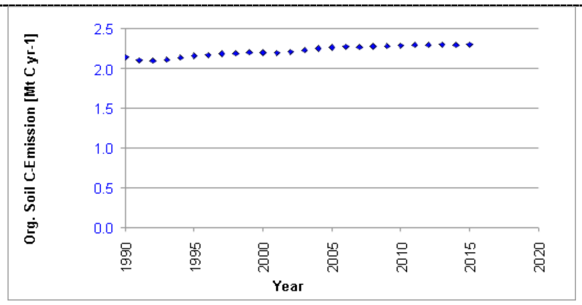

Figure 41: Emissions from managed organic soils [Mt C yr^{-1}] (Germany)

Land Use Area

The area of arable land remained almost unchanged from 1970 to 2018. In contrast, the area of permanent grassland gradually decreased until about 2010 and then remains stable. An anomaly in the data are the pre-1990 data in the [apro_cp] tables. The data refer to the area of the Federal Republic of Germany before unification, but the table uses the same country code for the whole period. Using such data for a baseline would result in an artificial increase in arable land with consequences on GHG emission estimates.

Mineral Soil

SOC-stocks remain stable from 1990 to 2016.

Organic Soils

Emissions from managed organic soils indicate an increase to 2.2 Mt C yr^{-1} in 2016. It is not obvious why the area of managed organic soils would have increased over the period and the data should be interpreted with some caution.

Annual Change in Soil Organic Carbon

With emissions from managed organic soils and no change in SOC-stocks for mineral soils the soil C-balance is negative over the whole period.

Denmark

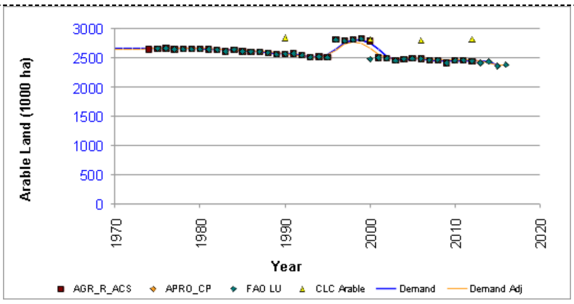

Figure 42: Time-series processed for Arable Land area [1000 ha] (Denmark)

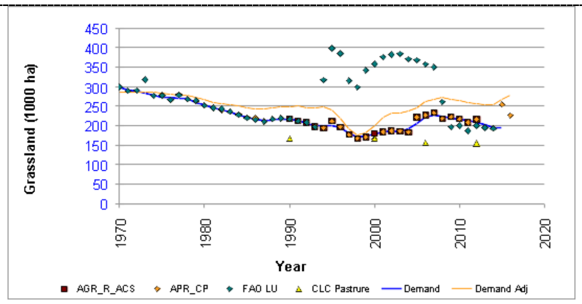

Figure 43: Time-series processed for Permanent Grassland area [1000 ha] (Denmark)

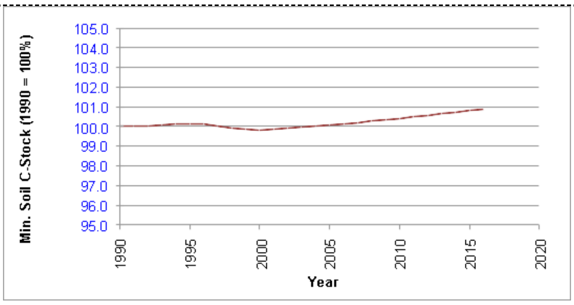

Figure 44: Changes in soil organic C-Stocks, relative to 1990 (Denmark)

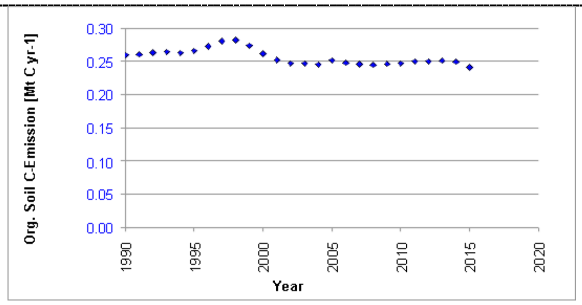

Figure 45: Emissions from managed organic soils [Mt C yr^{-1}] (Denmark)

Land Use Area

The area of arable land slowly decreases from 1970 to 2018, with an anomaly from 1996 to 2000. The area of permanent grassland is more variable over time and between data sources. FAOSTAT data from 1994 to 2007 is outside the general range of values. Using such data for a 2005 baseline would introduce anomalies in the GHG estimates. CLC data remains close to Eurostat statistical data.

Mineral Soil

SOC-stocks increased gradually from 2000 to 2016. SOC-stocks for 2016 are estimated at 1.4% above the SOC-stocks of 1990.

Organic Soils

Emissions from organic soils indicate some variability until 2003 to remain at 0.24 Mt C yr^{-1} until 2016.

Annual Change in Soil Organic Carbon

The increase in SOC-stocks started to off-set emissions from managed organic soils in 2003. Since then, managed soils maintained a neutral C-balance.

Estonia

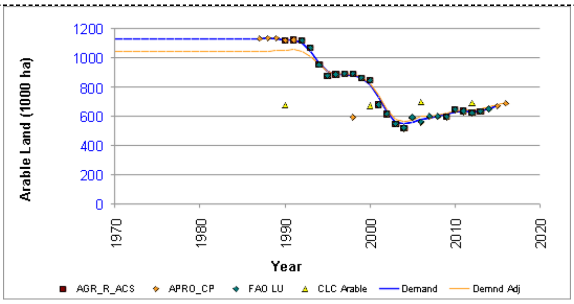

Figure 46: Time-series processed for Arable Land area [1000 ha] (Estonia)

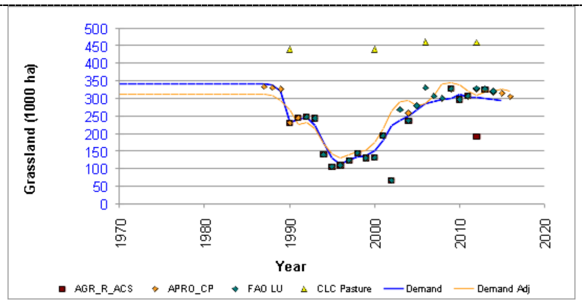

Figure 47: Time-series processed for Permanent Grassland area [1000 ha] (Estonia)

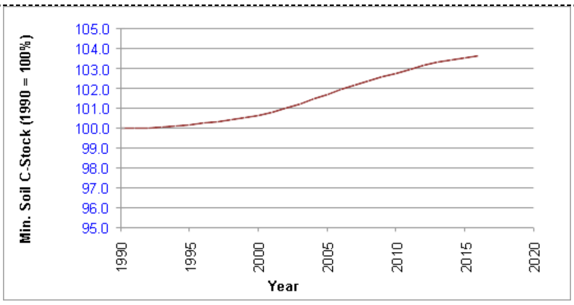

Figure 48: Changes in soil organic C-Stocks, relative to 1990 (Estonia)

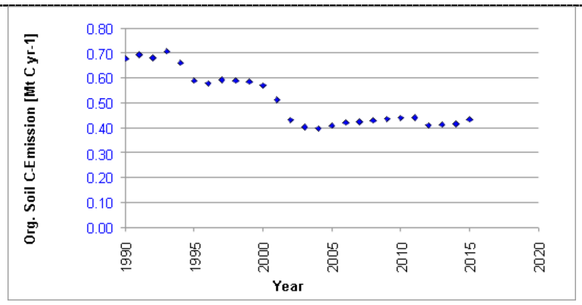

Figure 49: Emissions from managed organic soils [Mt C yr^{-1}] (Estonia)

Land Use Area

Data are only available for years after 1992. The arable land area drops by 50% from 1992 to 2004. Following 2004 it the increased gradually until 2016. A similar tendency, but more strongly pronounced, is found for areas of permanent grassland.
The choice of a baseline year may result in significantly different estimations of GHG emissions. Using 1990 would indicate a decrease in GHG, while a 2005 baseline could result in an increase.

Mineral Soil

SOC-stocks increased by 3.6% from 1990 to 2016, with a slowing-down of the annual rate. .

Organic Soils

Emissions from managed organic soils decreased from 1990 to 2003 to remain at 4.5 Mt C yr^{-1}.

Annual Change in Soil Organic Carbon

Following the changes in SOC-stocks the soil C-balance became positive in 2003. However, since 2003 the soil C-balance slowly approaches a neutral or negative state as a consequence of increases in arable land.

Greece

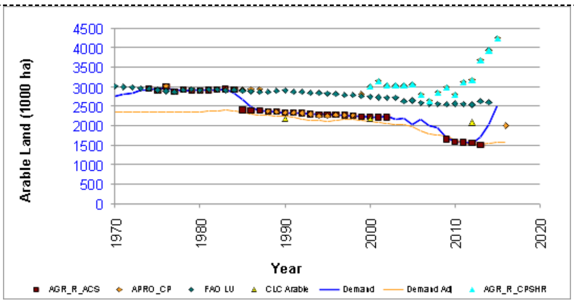

Figure 50: Time-series processed for Arable Land area [1000 ha] (Greece)

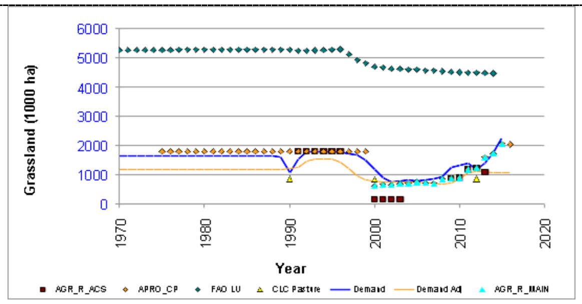

Figure 51: Time-series processed for Permanent Grassland area [1000 ha] (Greece)

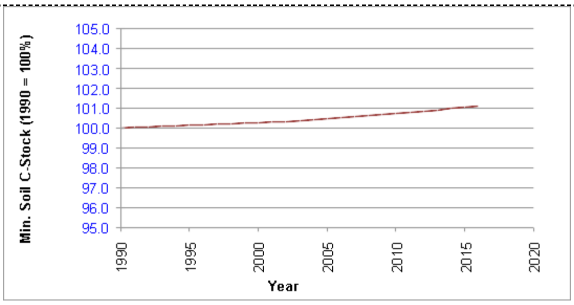

Figure 52: Changes in soil organic C-Stocks, relative to 1990 (Greece)

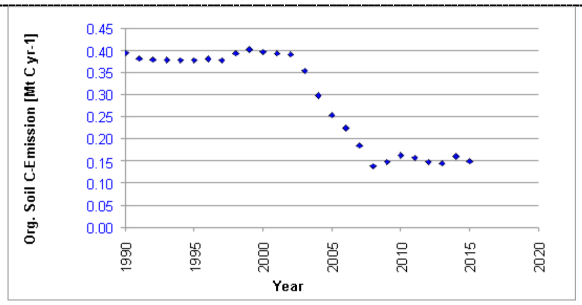

Figure 53: Emissions from managed organic soils [Mt C yr^{-1}] (Greece)

Land Use Area

In most source data the area of arable land decreases until 2015. The new [apro_cpshr] data shows an unusual increase in the area after 2010 to drop to more general value for 2016 (was later adjusted). The area of permanent grassland[11] increases in Eurostat data after 2000, but not in FAOSTAT data, where it decreased.

Mineral Soil

SOC-stocks increased by 0.9% from 1990to 2016 with a steady annual rate.

Organic Soils

Emissions from managed organic soils decreased after 2001 to reach 0.15 Mt C yr^{-1} in 2011 and to remain at this level until 2016.

Annual Change in Soil Organic Carbon

The soil C-balance has become positive after 2006 due to the C-sequestration of mineral soils.

[11] The drop in the area of permanent grassland in 1990 is caused by the variability of the data over the –pre-processing period 1990 – 2015 (to align periods pre-processing extends 5 years over processing period). It could be removed by re-arranging the order of combining data or using the overlap years of the preceding pre-processing period (1970 – 1995). However, this would give precedence to the estimates from the 1970 - 1995 period over the relatively data-rich period 1990 – 2015.

Spain

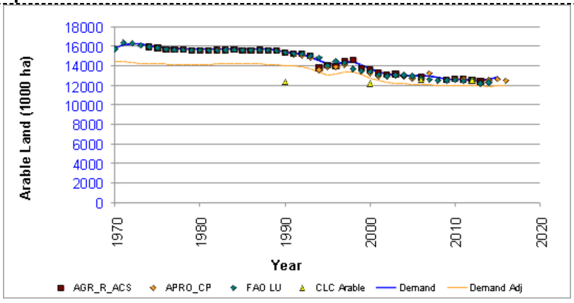

Figure 54: Time-series processed for Arable Land area [1000 ha] (Spain)

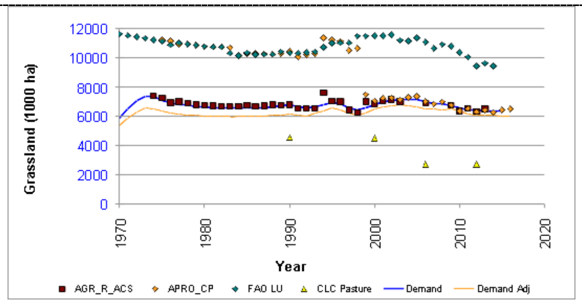

Figure 55: Time-series processed for Permanent Grassland area [1000 ha] (Spain)

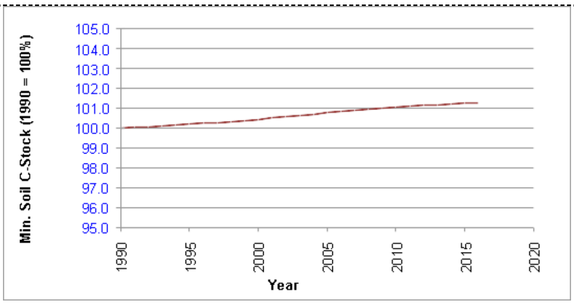

Figure 56: Changes in soil organic C-Stocks, relative to 1990 (Spain)

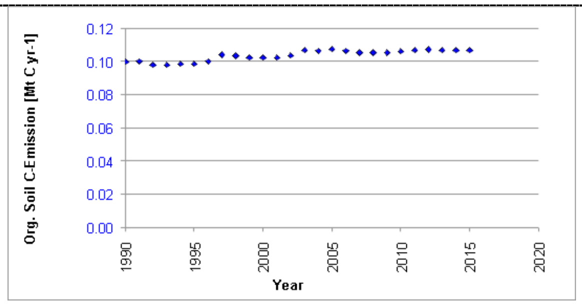

Figure 57: Emissions from managed organic soils [Mt C yr^{-1}] (Spain)

Figure 58: Development of Arable and Grassland areas [1000 ha] (Spain)

Land Use Area

The area of arable land generally decreases with time in all data sources. The area for permanent grassland remains largely stable in Eurostat data, except for [apro_cpnhr_h] data. The data agrees with other Eurostat data after 1998, but with FAOSTAT data for earlier years. CLC data agree with statistical data for arable land, but show different values and trend for permanent grassland.

Mineral Soil

SOC-stocks increase by 1.3% from 1990 to 2016 with a decreasing annual rate after 2003. It reached 0.6 Mt C yr^{-1} in 2016.

Organic Soils

Variations of emissions from managed organic soils are small and remain at slightly over 0.1 Mt C yr^{-1}.

Annual Change in Soil Organic Carbon

The soil C-balance remains positive from 1990 to 2016, but the annual rate of decreased from a peak of 1.5 Mt C in 2003 to 0.5 Mt C in 2016.

Finland

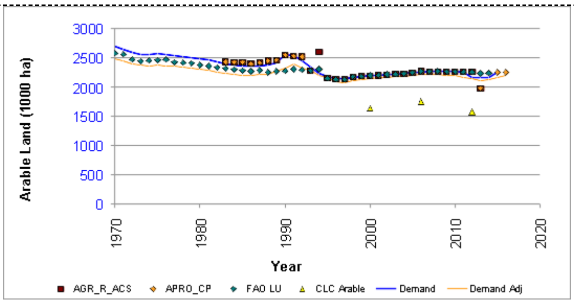

Figure 59: Time-series processed for Arable Land area [1000 ha] (Finland)

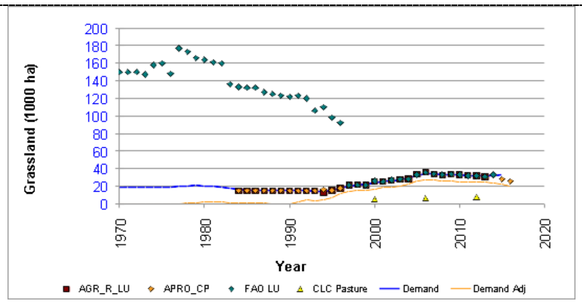

Figure 60: Time-series processed for Permanent Grassland area [1000 ha] (Finland)

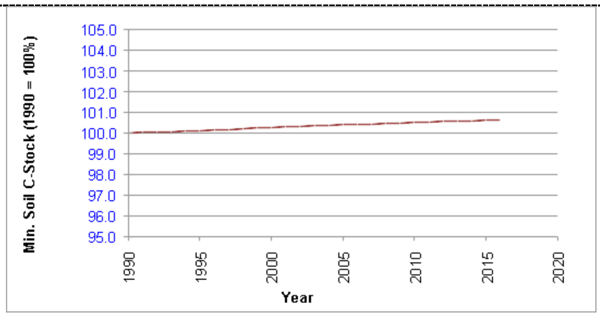

Figure 61: Changes in soil organic C-Stocks, relative to 1990 (Finland)

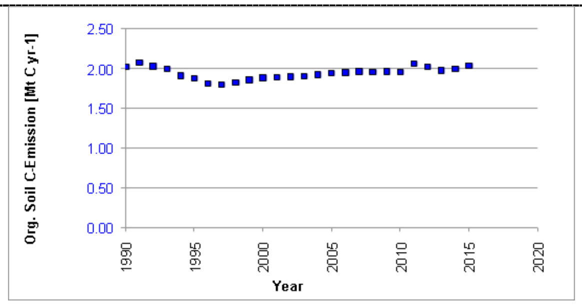

Figure 62: Emissions from managed organic soils [Mt C yr^{-1}] (Finland)

Land Use Area

Arable land decreases in area from 1970 to 1996 and then increases slightly until 2016. The area of permanent grassland remains stable until 1996 and then increased until 2006. Data sources agree for arable land, but FAOSTAT data are differ from Eurostat data until 1996 by a factor up to 9. After 1996 the data sources agree.

Mineral Soil

SOC-stocks increased by 0.6% from 1990 to 2016, with a drop in the annual change of 0.0 Mt C yr^{-1} in 2016.

Organic Soils

Emissions from managed organic soils varied until about 2005 to remain stable at 2.0 Mt C yr^{-1}.

Annual Change in Soil Organic Carbon

With the widespread presence of organic soils the C-balance is negative for all years from 1990 to 2016 and the increased in SOC-stocks could not off-set the emissions from managed organic soils.

France

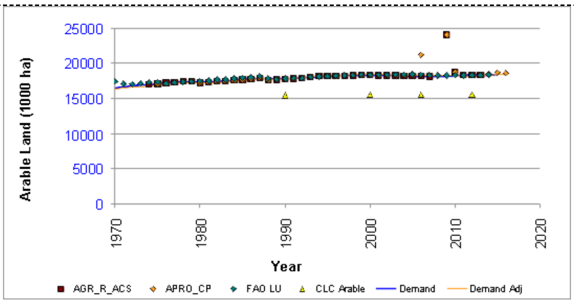

Figure 63: Time-series processed for Arable Land area [1000 ha] (France)

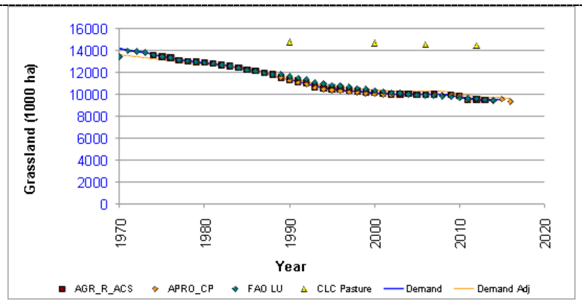

Figure 64: Time-series processed for Permanent Grassland area [1000 ha] (France)

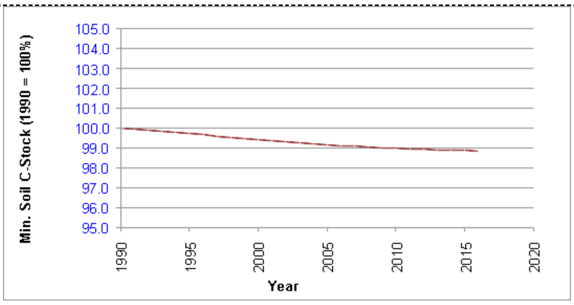

Figure 65: Changes in soil organic C-Stocks, relative to 1990 (France)

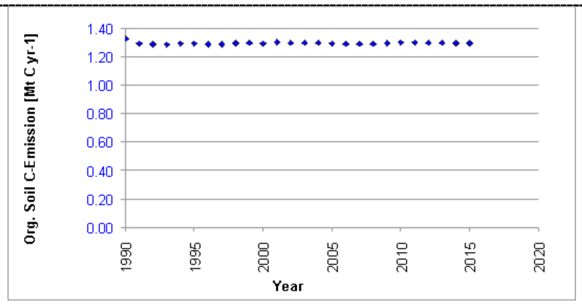

Figure 66: Emissions from managed organic soils [Mt C yr^{-1}] (France)

Land Use Area

The area of arable land steadily increased from 1970 to 2016 by 11.4%, while the area of permanent grassland declined markedly by 32.4% over the same period. The data from the various sources agree for both land use categories, but CLC da show an almost constant trend for arable land and permanent grassland.

Mineral Soil

SOC-stocks decrease by 1.0% from 1990 to 2016. The annual change in SOC-stocks decreased from 2.2 Mt C in 1994 to 0.4 Mt C yr^{-1} in 2016.

Organic Soils

With an estimated of 1.2 Mt C yr^{-1} emissions from managed organic soils remained largely stable over the period.

Annual Change in Soil Organic Carbon

The annual soil C-balance for the land use categories remains negative for the whole period. However, the imbalance is reduced to more than halves from 1994 to 2016.

Croatia

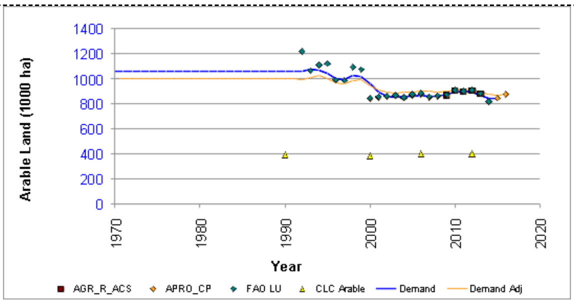

Figure 67: Time-series processed for Arable Land area [1000 ha] (Croatia)

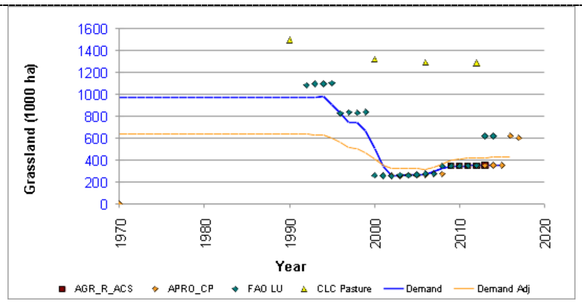

Figure 68: Time-series processed for Permanent Grassland area [1000 ha] (Croatia)

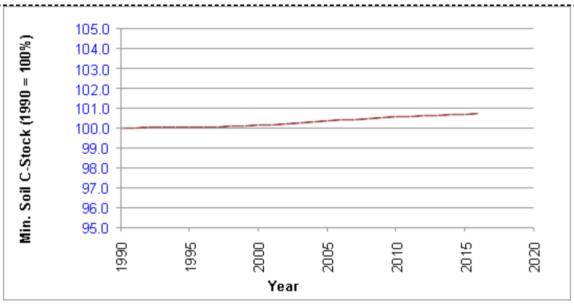

Figure 69: Changes in soil organic C-Stocks, relative to 1990 (Croatia)

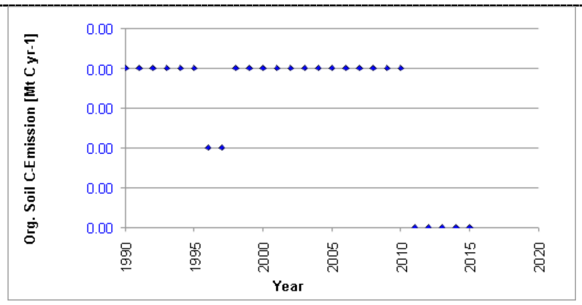

Figure 70: Emissions from managed organic soils [Mt C yr^{-1}] (Croatia)

Land Use Area

Statistical data on arable and permanent grassland are only available form 1992 onwards in FAOSTAT and 2000 in Eurostat data. The areas of both LU categories show a decrease from 1999 to 2000 (FAOSTAT) to remain stable after 2000. Permanent grassland decrease by 64% in FAOSTAT data from 1992 to 2000. Both data sources show an increase after 2000. The adjusted demand for permanent grassland indicates inconsistencies in the total area of LU categories in the data.

Mineral Soil

SOC-stocks increased by 0.7 % from 1990 to 2016 with an average annual change of 0.15 Mt C yr^{-1}.

Organic Soils

Emissions from managed organic soils are restricted to 1 or 2 locations, which cause the large variations shown in the graph.

Annual Change in Soil Organic Carbon

The soils C-balance is positive over the whole period from 1990 to 2016, and dominated by the LU changes on mineral soils.

Hungary

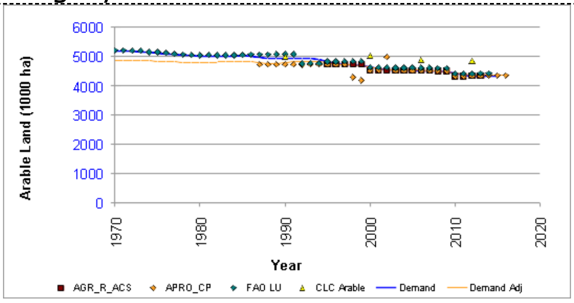

Figure 71: Time-series processed for Arable Land area [1000 ha] (Hungary)

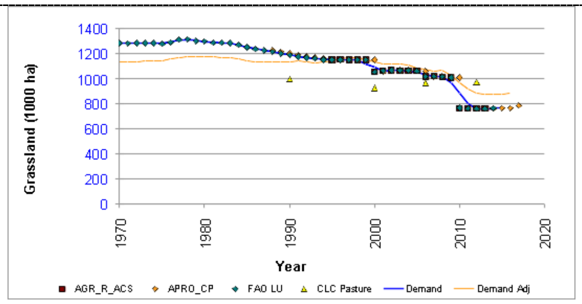

Figure 72: Time-series processed for Permanent Grassland area [1000 ha] (Hungary)

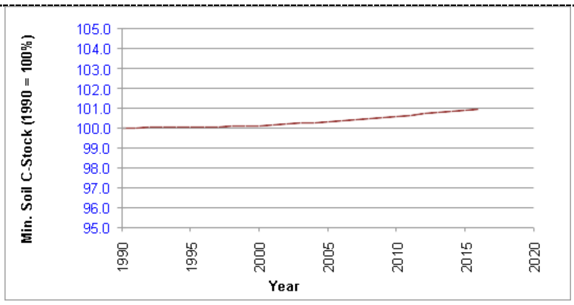

Figure 73: Changes in soil organic C-Stocks, relative to 1990 (Hungary)

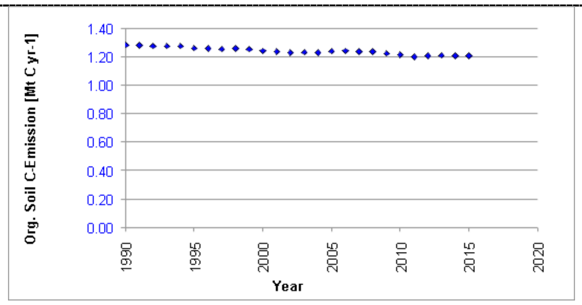

Figure 74: Emissions from managed organic soils [Mt C yr^{-1}] (Hungary)

Land Use Area

Areas of arable land decreased steadily over the years and amount to a decline of 10% from 1970 to 2018. The area of permanent grassland decreased by 40% over the period, with a drop of 25% from 2009 to 2010. CLC data by and large agree with the magnitude of the statistical data, but do not present a particular trend in areas.

Mineral Soil

SOC-stocks increased by 0.9% from 1990 to 2016. The annual change increased from almost zero in 1992 to 0.24 Mt C yr^{-1} in 2013.

Organic Soils

Emissions from managed organic soils decreased by 6% from 1990 to 2016.

Annual Change in Soil Organic Carbon

The soil C-balance is negative for the period 1990 to 2016. The imbalance is reduced by 25% from 1994 to 2016.

Ireland

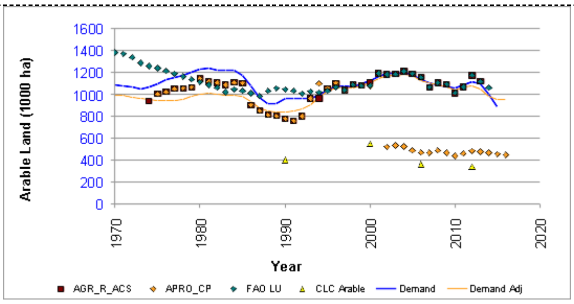

Figure 75: Time-series processed for Arable Land area [1000 ha] (Ireland)

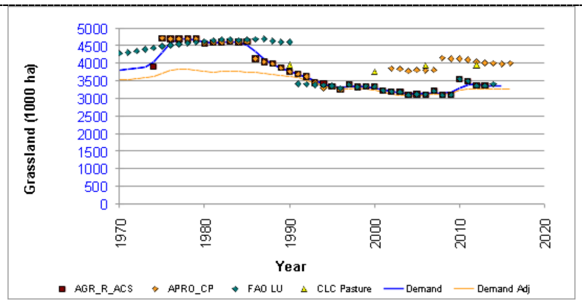

Figure 76: Time-series processed for Permanent Grassland area [1000 ha] (Ireland)

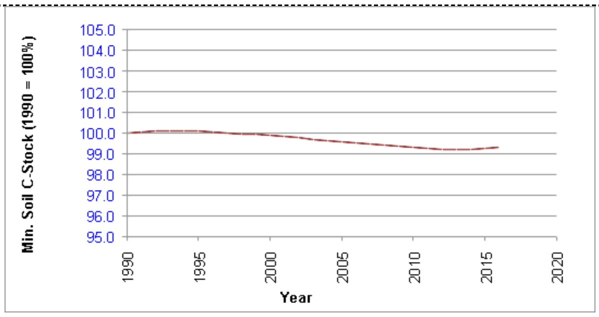

Figure 77: Changes in soil organic C-Stocks, relative to 1990 (Ireland)

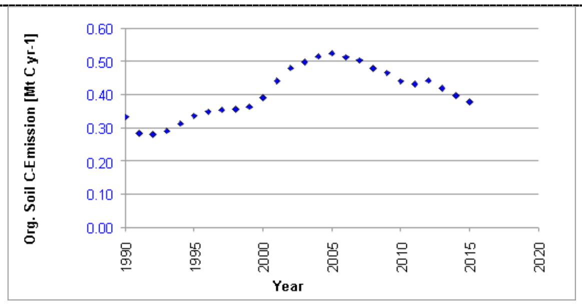

Figure 78: Emissions from managed organic soils [Mt C yr^{-1}] (Ireland)

Figure 79: Development of Arable and Grassland areas [1000 ha] (Ireland)

Land Use Area

Statistical data strongly differ between sources for arable and permanent grassland. In particular, for arable land the newly published [apro_cpshr] data do not agree with data from other sources. From 2002 to 2018 the values are about half of the values reported by other sources and over 15% higher for permanent grassland. Depending on the data used this makes for very different trends in areas when using a baseline before 2000, with corresponding effect on estimates of GHG emissions. CLC data agree quite closely with [apro_cpshr] data.

Mineral Soil

SOC-stocks show a trend to decrease between 1995 and 2014 with a maximum annual change of 0.34 Mt C yr^{-1}.

Organic Soils

Emissions from managed organic soils strongly increased from 1990 to 2004. This trend may be driven by allocating the expansion of cropland by site suitability.

Annual Change in Soil Organic Carbon

The soil C-balance is negative for all year, although with a trend to lessen after 2005.

Italy

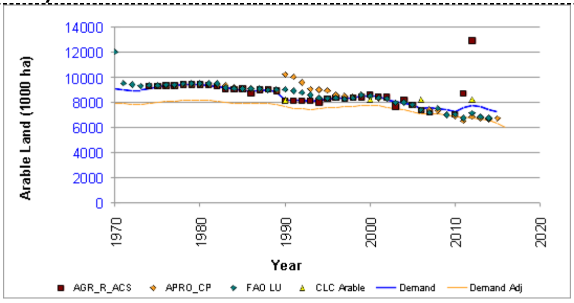

Figure 80: Time-series processed for Arable Land area [1000 ha] (Italy)

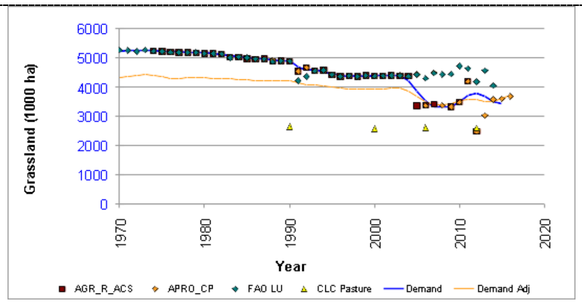

Figure 81: Time-series processed for Permanent Grassland area [1000 ha] (Italy)

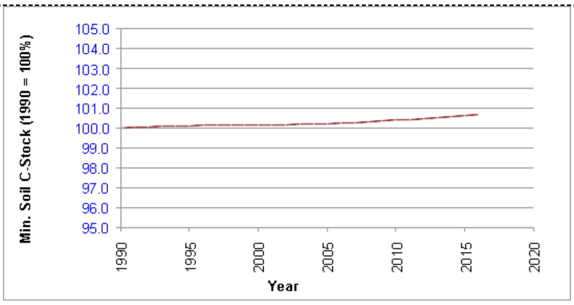

Figure 82: Changes in soil organic C-Stocks, relative to 1990 (Italy)

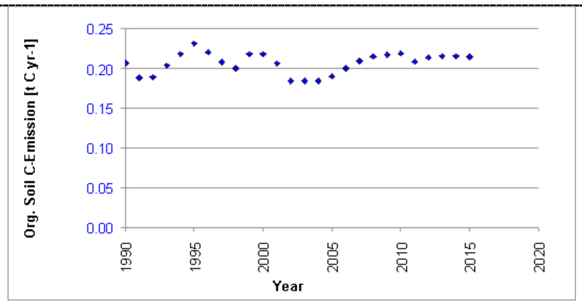

Figure 83: Emissions from managed organic soils [Mt C yr^{-1}] (Italy)

Figure 84: Annual Change in Soil C-Balance (mineral +organic soils) [Mt C yr^{-1}] (Italy)

Land Use Area

Areas of arable land and permanent grassland generally decreased after 1970, slightly more after 1992 than before. Arable land shows an outlier for 2012, which does not affect the adjusted data. Areas of permanent grassland show a distinct drop of 25%from 2005 to 2006 in Eurostat, but not FAOSTAT data. CLC data agrees well with statistical data for arable land, but remains significantly lower for permanent grassland and without indicating a trend.

Mineral Soil

SOC-stocks increased by 0.7% from 1990 to 2016 with a tendency to increase the annual change after 1997 to reach 0.9 Mt C in 2016.

Organic Soils

Emissions from managed organic soils varied somewhat around a value of 0.21 Mt C yr^{-1}.

Annual Change in Soil Organic Carbon

With the exception of the period 1997 to 2002 the soil C-balance was positive and reached an annual rate of 0.7 Mt C yr^{-1} in 2016.

Lithuania

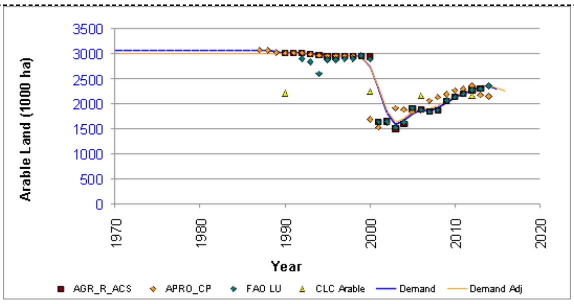

Figure 85: Time-series processed for Arable Land area [1000 ha] (Lithuania)

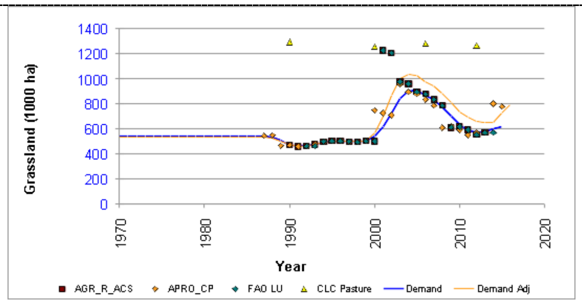

Figure 86: Time-series processed for Permanent Grassland area [1000 ha] (Lithuania)

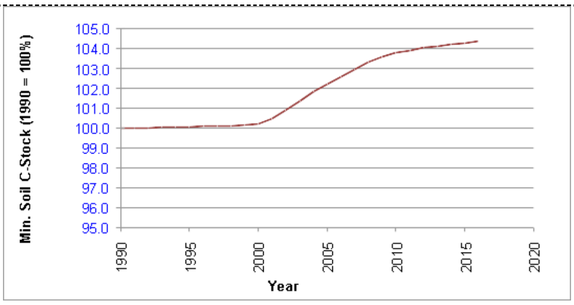

Figure 87: Changes in soil organic C-Stocks, relative to 1990 (Lithuania)

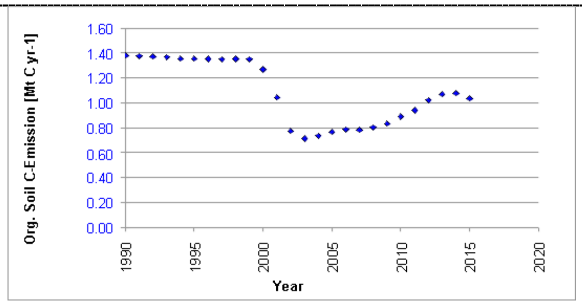

Figure 88: Emissions from managed organic soils [Mt C yr^{-1}] (Lithuania)

Land Use Area

Areas of arable land show a drop of almost 50% from 1999 to 2000 to then increase by almost 20% until 2018. In this the various sources agree. In contrast, the area of permanent grassland more than doubled from 1999 to 2000 in [agr_r_acs] and FAOSTAT data. Depending on the year used for a baseline divergent trends for either LU category follow. CLC data shows no trend in areas for the LU categories, but are almost twice as high for 1990, 2000 and 2012.

Mineral Soil

Following the sharp decrease in arable land SOC-C stocks notably increased by 5% from 1990 to 2016.

Organic Soils

Emissions from managed mineral soils decreased sharply from 1999 to 2004 to gradually rise to 1.0 Mt C yr^{-1} in 2016.

Annual Change in Soil Organic Carbon

The data indicates a positive soil C-balance from 2001 to 2012, with a small negative balance until 2016. However, the variability in the data suggests to interpret the results with caution.

Luxembourg

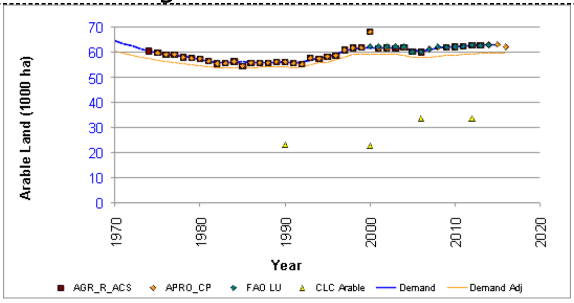

Figure 89: Time-series processed for Arable Land area [1000 ha] (Luxembourg)

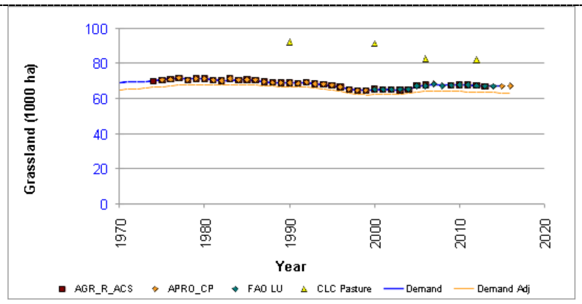

Figure 90: Time-series processed for Permanent Grassland area [1000 ha] (Luxembourg)

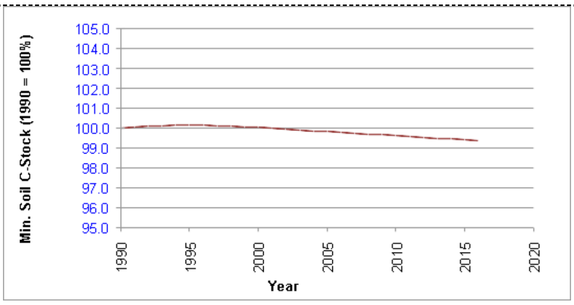

Figure 91: Changes in soil organic C-Stocks, relative to 1990 (Luxembourg)

No managed organic soils.

Figure 92: Emissions from managed organic soils [Mt C yr^{-1}] (Luxembourg)

Land Use Area

Arable land areas show some variations in development over time. The area in 1990 is 10% lower than the area reported for 2005. Using 1990 as a baseline would include the increase in arable land, but a year of 2000 or later would use a flat trend. Areas for permanent grassland show an opposite development, but with a reduced magnitude. In general, statistical data from different sources show very close agreement, but CLC data differ.

Mineral Soil

After 1996 SOC-stocks decreased a SOC-stocks of 2016 are 0.6% below those of 1990.

Organic Soils

No managed organic soils.

Annual Change in Soil Organic Carbon

After 1996 the soil C-balance has become negative. The annual changes remain stable after 2004.

Latvia

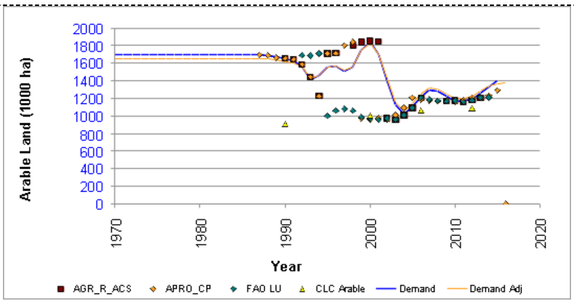

Figure 93: Time-series processed for Arable Land area [1000 ha] (Latvia)

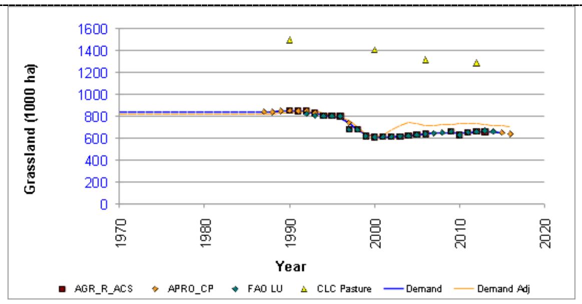

Figure 94: Time-series processed for Permanent Grassland area [1000 ha] (Latvia)

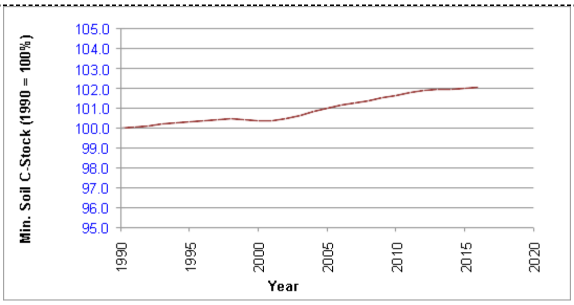

Figure 95: Changes in soil organic C-Stocks, relative to 1990 (Latvia)

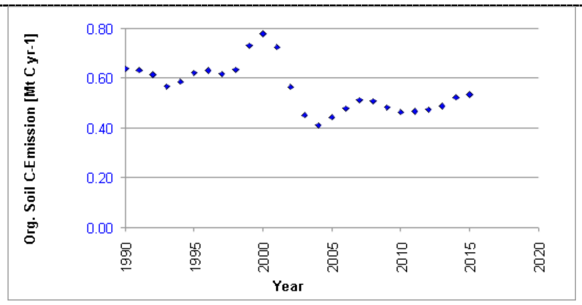

Figure 96: Emissions from managed organic soils [Mt C yr^{-1}] (Latvia)

Land Use Area

The area of arable land in [agr_r_acs] and [apro_cpshr] report a drop by 50% around the year 2000. FAOSTAT data show a similar drop, but from 1994 to 1995. From 2000 to 2006 the areas of arable land increased in both data sets. Permanent grassland areas decreased from 1996 to 1999 by almost 25%. While the data sources report similar values for grassland areas, they diverge for arable land for the years from 1990 to 2000. The variability of the areas for arable land would affect GHG emission estimates when selecting 1990, 2000 or 2005 as the baseline.

Mineral Soil

SOC-stocks increased by 2% from 1990 to 2016, with a decrease in the annual change from 0.9 Mt C in 1994 to 0.2 Mt C in 2016.

Organic Soils

Following the considerable changes in LU areas emissions from organic soils show uncommon variations to 0.5 Mt C yr^{-1} in 2016

Annual Change in Soil Organic Carbon

The soil C-balance is positive from 2003 to 2013 to become slightly negative until 2016.

Malta

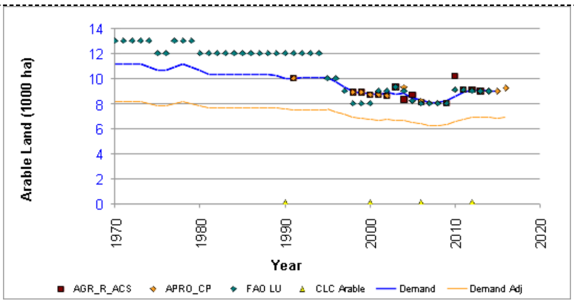

Figure 97: Time-series processed for Arable Land area [1000 ha] (Malta)

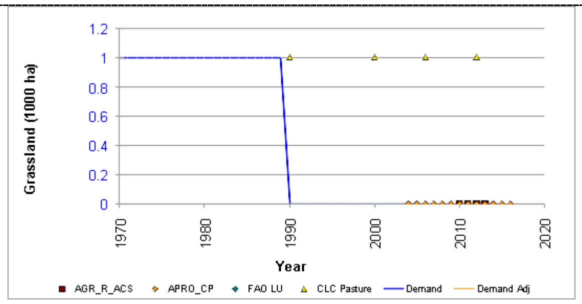

Figure 98: Time-series processed for Permanent Grassland area [1000 ha] (Malta)

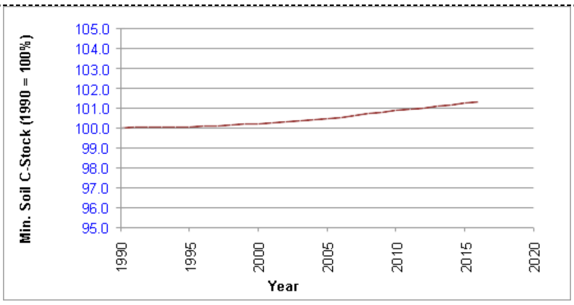

Figure 99: Changes in soil organic C-Stocks, relative to 1990 (Malta)

No managed organic soils.

Figure 100: Emissions from managed organic soils [Mt C yr^{-1}] (Malta)

Land Use Area

Eurostat data on Malta covers the year 1991, but not 1992 to 1997. The area statistics for arable land indicate a significant drop after 1994 and become more variable in subsequent years. Statistical data do not report an area for permanent grassland, only the CLC data classifies some locations as permanent grassland. The difference between the statistical data and the adjusted data indicates that some inconsistency between LU data exists in the statistical data.

Mineral Soil

SOC-stocks increased by 1.7% from 1990 to 2016.

Organic Soils

No managed organic soils.

Annual Change in Soil Organic Carbon

The soil C-balance is positive from 1990 to 2016, although with a decrease in annual changes after 2008.

Netherlands

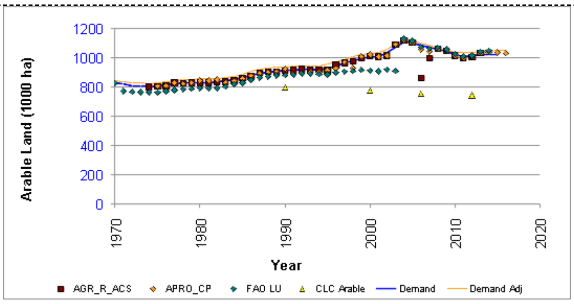

Figure 101: Time-series processed for Arable Land area [1000 ha] (Netherlands)

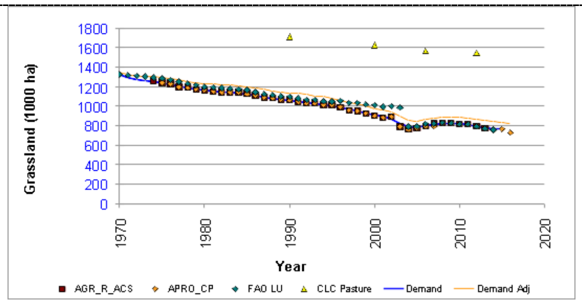

Figure 102: Time-series processed for Permanent Grassland area [1000 ha] (Netherlands)

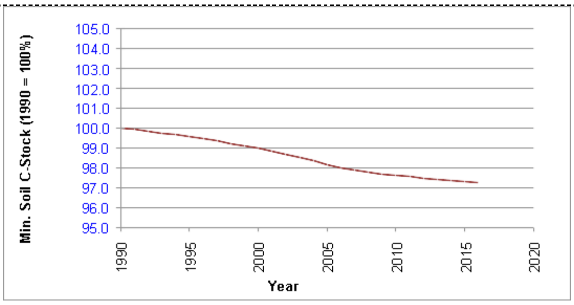

Figure 103: Changes in soil organic C-Stocks, relative to 1990 (Netherlands)

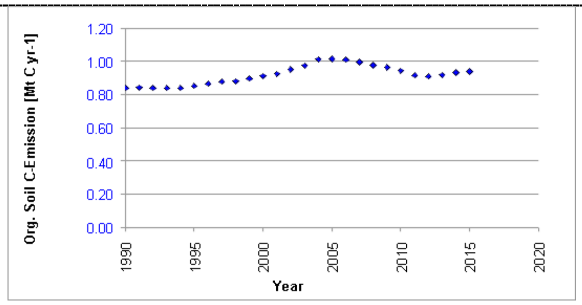

Figure 104: Emissions from managed organic soils [Mt C yr^{-1}] (Netherlands)

Land Use Area

The area reported for arable land increased from 1970 to peak in 2004, to decline in subsequent years. The area for permanent grassland continuously decreased, except for 2006. The area increase for arable land is not present in CLC data, but CLC data indicates the decrease in permanent grassland of the statistical data, albeit with notably different absolute figures for the areas.

Mineral Soil

SOC-stocks decreased by 2.8% from 1990 to 2016. The annual change was 0.13 Mt C in2016.

Organic Soils

Emissions from managed organic soils increased by 18%from 1990 to 2005 to reach at a level of 0.95 Mt C yr^{-1} thereafter.

Annual Change in Soil Organic Carbon

The soil C-balance is negative for the whole period. There is some indication of a stabilisation of emissions at 1.0 Mt C yr^{-1} after 2012.

Poland

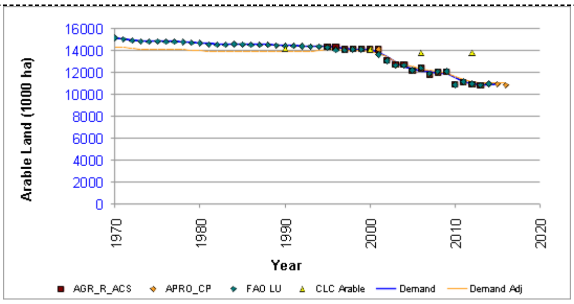

Figure 105: Time-series processed for Arable Land area [1000 ha] (Poland)

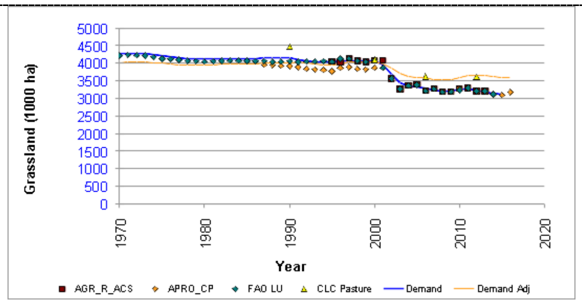

Figure 106: Time-series processed for Permanent Grassland area [1000 ha] (Poland)

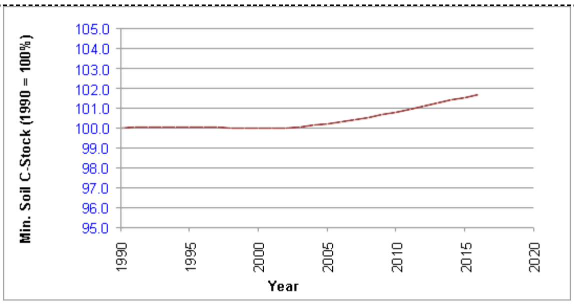

Figure 107: Changes in soil organic C-Stocks, relative to 1990 (Poland)

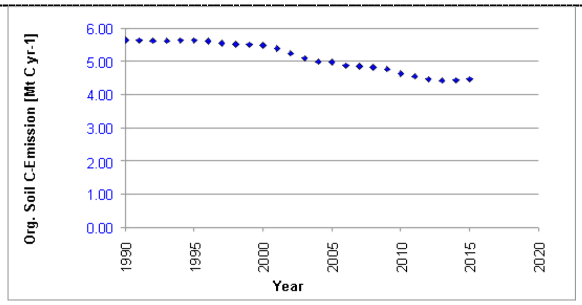

Figure 108: Emissions from managed organic soils [Mt C yr^{-1}] (Poland)

Land Use Area

The statistical data go back to 1987 and report a slight decrease in areas for arable and permanent grassland until 2001. After 2001 the decrease accelerates rather abruptly. Statistical data from the various sources generally agree, as do CLC for permanent grassland. The decrease in arable land of the statistical data is not evident in CLC data

Mineral Soil

SOC-stocks started to increase notably after 2003 and are 1.9% more in 2016. The annual change is 2.8 Mt C in 2016.

Organic Soils

Emissions from managed organic soils decrease by 21% from 1990 to 2016, mainly in the year following 2000 to 4.5 Mt C yr^{-1} .

Annual Change in Soil Organic Carbon

The soil c-balance is negative for the whole period, but the annual losses decreased after 2000 and in 2016 are less than 1/3 of those estimated for 1990.

Portugal

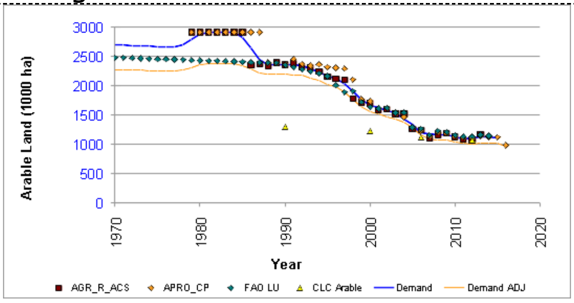

Figure 109: Time-series processed for Arable Land area [1000 ha] (Portugal)

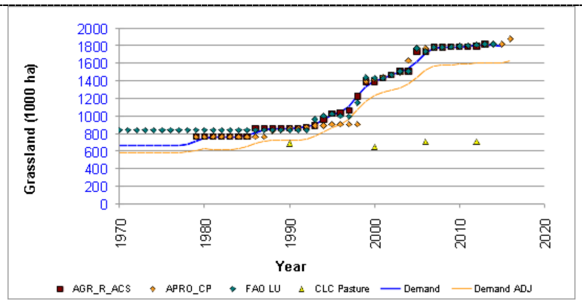

Figure 110: Time-series processed for Permanent Grassland area [1000 ha] (Portugal)

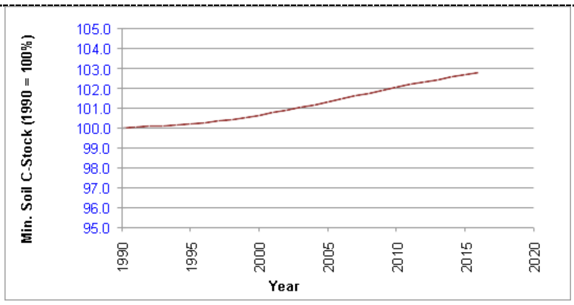

Figure 111: Changes in soil organic C-Stocks, relative to 1990 (Portugal)

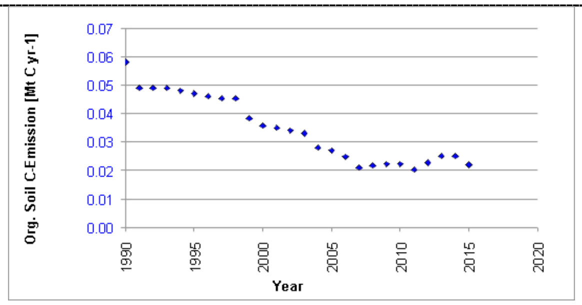

Figure 112: Emissions from managed organic soils [Mt C yr^{-1}] (Portugal)

Land Use Area

Areas for arable land and permanent grassland remain change little from 1970 to 1992 to change markedly until about 2006. After 2006 the area changes are limited. Over the period arable land decreased to almost 1/3rd of the 1990 area and permanent grassland more than doubled. CLC data vary comparatively little for both LU categories.

Mineral Soil

SOC-stocks increase by 2.9% from 1990 to 2016 with an annual change of approx. 0.6 Mt C.

Organic Soils

Emissions from managed organic soils decreased between 1994 and 2008 to stabilise at 0.02 Mt C yr^{-1} until 2016.

Annual Change in Soil Organic Carbon

The soil C-balance is positive from 1990 to 2016, although the annual rate of sequestration starts to decrease after 2006.

Romania

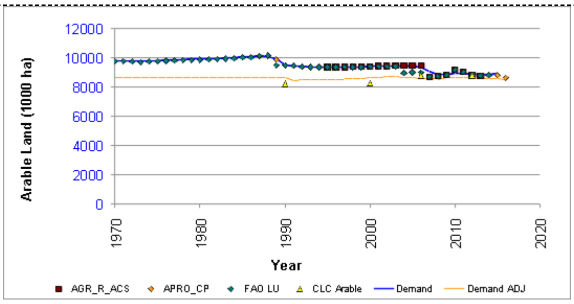

Figure 113: Time-series processed for Arable Land area [1000 ha] (Romania)

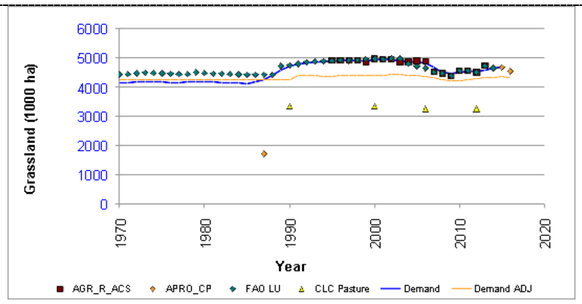

Figure 114: Time-series processed for Permanent Grassland area [1000 ha] (Romania)

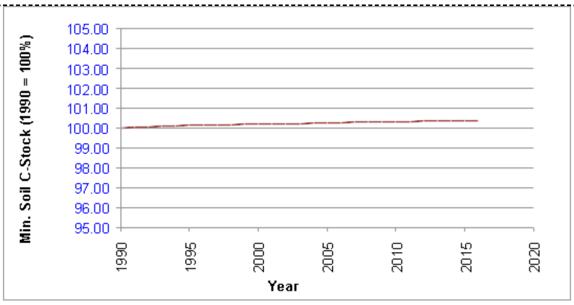

Figure 115: Changes in soil organic C-Stocks, relative to 1990 (Romania)

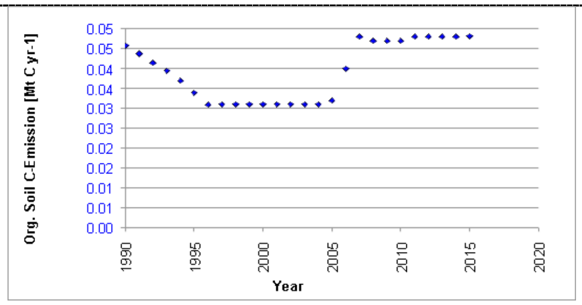

Figure 116: Emissions from managed organic soils [Mt C yr^{-1}] (Romania)

Land Use Area

The statistical data shows three distinct periods of limited change: 1970 to 1987, 1987 to 2006 and 2006 onwards. The area of arable land marginally decreased over time, while the area of permanent grassland is reported to be more extensive over the second period than either, before or thereafter. Except for an outlier in [apre_cpnhr_h] grassland data for 1987 the sources generally agree. CLC data agrees with statistical data for arable land, but less for permanent grassland and not for the trend of arable land.

Mineral Soil

SOC-stocks increased by 0.4% from 1990 to 2016 with an annual change of approx. 0.12 Mt C.

Organic Soils

Emissions from managed organic soils exhibit three stages of development, a gradual decrease from 1990 to 1995. A stable period from 1995 to 2005 and another stable period from 2007 onwards. The steps are to some degree due to the small number of the area involved and emissions remain at < 0.1 Mt C yr^{-1}.

Annual Change in Soil Organic Carbon

The soil C-balance is positive for the period 1990 to 2016, with a tendency to decrease the annual changes in SOC-stocks.

Sweden

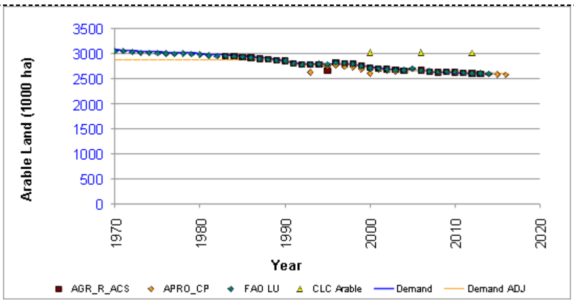

Figure 117: Time-series processed for Arable Land area [1000 ha] (Sweden)

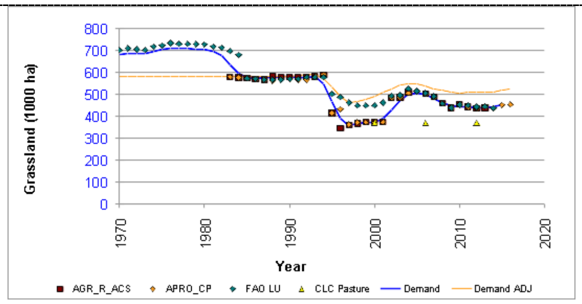

Figure 118: Time-series processed for Permanent Grassland area [1000 ha] (Sweden)

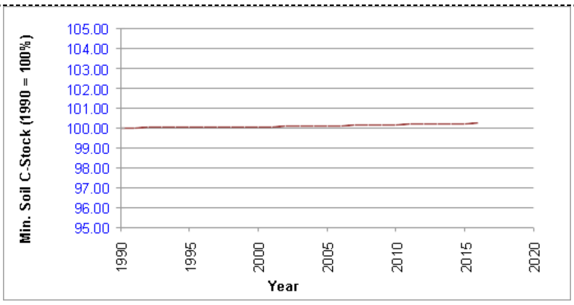

Figure 119: Changes in soil organic C-Stocks, relative to 1990 (Sweden)

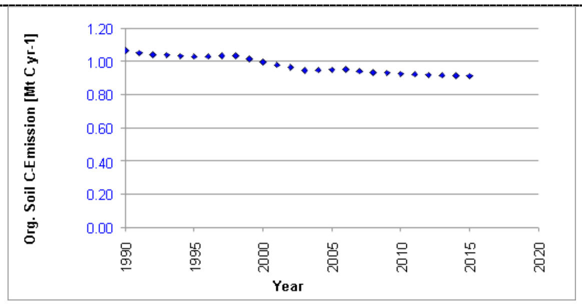

Figure 120: Emissions from managed organic soils [Mt C yr^{-1}] (Sweden)

Land Use Area

The area of arable land decreased steadily from 1970 to 2018, with a decrease of 16% over the period. The areas reported for permanent grassland show considerably more variation over the years. A significant loss in area is reported for the years from 1995 to 2001 with abrupt changes to adjacent years. Starting reporting during this period would show a trend of increasing permanent grassland, while it would be a decrease for any other year.

Mineral Soil

SOC-stocks of 2016 are 0.2% above those of 1990 with an annual change of 0.3 Mt C.

Organic Soils

Emissions from managed organic soils show only small changes. The level of emissions in 2016 is 14% less than in 1990.

Annual Change in Soil Organic Carbon

The soil C-balance was negative from 1990 to 2016. It remained at -0.6 Mt C yr^{-1} in 2004 and subsequent years.

Slovenia

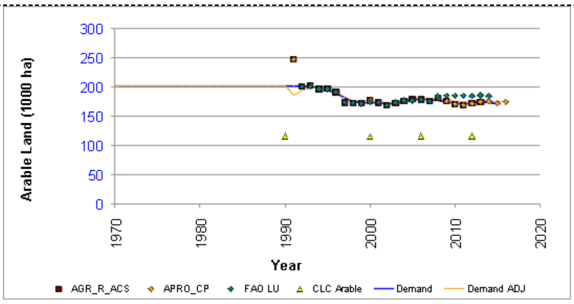

Figure 121: Time-series processed for Arable Land area [1000 ha] (Slovenia)

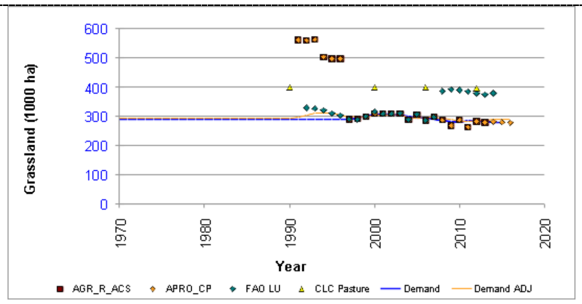

Figure 122: Time-series processed for Permanent Grassland area [1000 ha] (Slovenia)

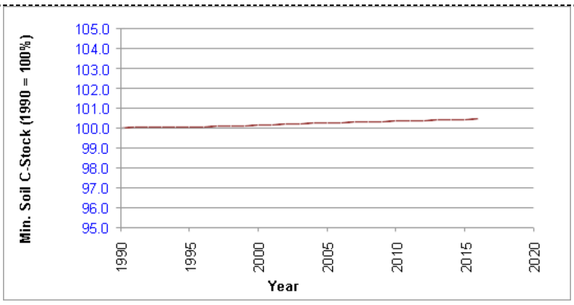

Figure 123: Changes in soil organic C-Stocks, relative to 1990 (Slovenia)

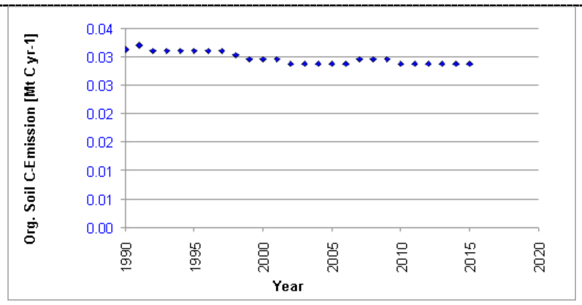

Figure 124: Emissions from managed organic soils [Mt C yr^{-1}] (Slovenia)

Land Use Area

With the exception of data for 1991 in [agr_r_acs] and [apro_cpnhr_h] data for arable land areas agree between statistical data sources. After a decrease in 1996 the area remained relatively stable. For the period 1991 to 1996 the area for permanent grassland reported in [agr_r_acs] and [apro_cpnhr_h] is almost twice the size of the areas reported for later years. Also FAOSTAT shows some data peculiarities for the years from 2008 to 2014. Depending on the data used and the year selected as the base very different trends in the area of permanent grassland can be defined.

Mineral Soil

SOC-stocks of 2016 are 0.4% above those of 1990 with an annual change of 0.03 Mt C.

Organic Soils

Emissions from managed organic soils show a very modest decrease to 0.03 Mt C yr^{-1} in 2016.

Annual Change in Soil Organic Carbon

The soil C-balance was positive from 1990 to 2016, at a level of change of 0.02 Mt C yr^{-1}.

Slovakia

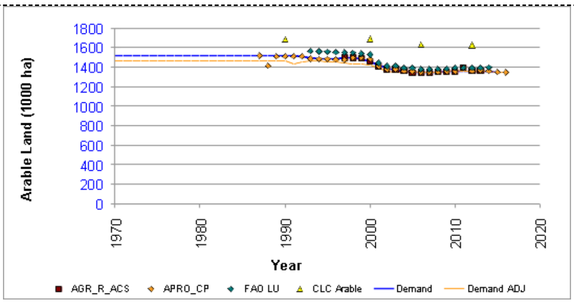

Figure 125: Time-series processed for Arable Land area [1000 ha] (Slovakia)

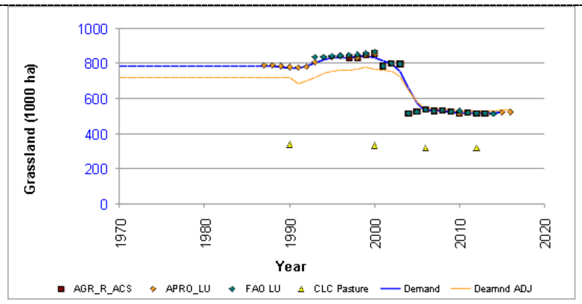

Figure 126: Time-series processed for Permanent Grassland area [1000 ha] (Slovakia)

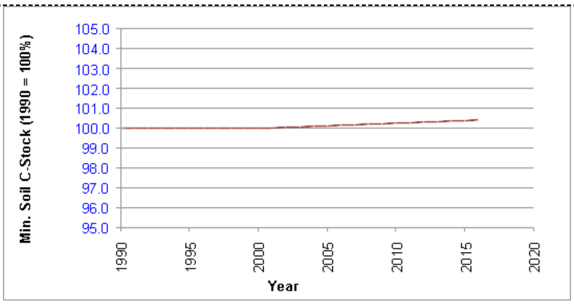

Figure 127: Changes in soil organic C-Stocks, relative to 1990 (Slovakia)

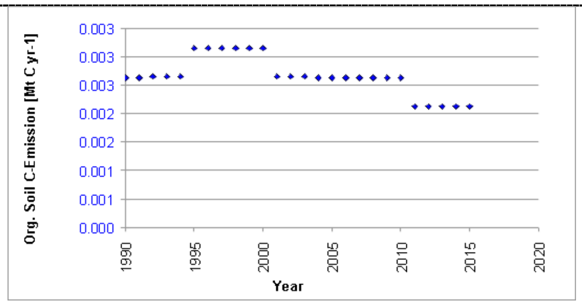

Figure 128: Emissions from managed organic soils [Mt C yr^{-1}] (Slovakia)

Land Use Area

The area of arable land remained stable from 1987 to 2000, then decreased by 8% to remain stable until 2018. Data sources generally agree, somewhat less for the years 1993 to 2000. The area reported for permanent grassland show a sudden decrease of 35% from 2003 to 2004, with a comparatively stable development before and after that year. Using only data after 2005 would show no change in permanent grassland, while using data before 2004 would indicate a strong decrease.

Mineral Soil

SOC-stocks increased by 0.4% from 1990 to 2016, although there was hardly a change between 1990 and 2000.

Organic Soils

Emissions from managed organic soils decreased numerically by 24.4 % from 1990 to 2016, but the level of emissions is very low throughout the period.

Annual Change in Soil Organic Carbon

The soil C-balance changed from a small negative rate until 1998 to become positive thereafter. The annual rate of change is 0.9 Mt C yr^{-1} in 2003 and subsequent years.

United Kingdom

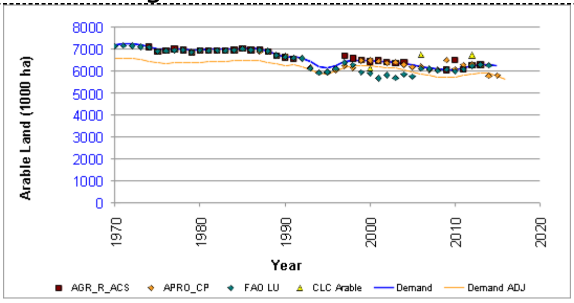

Figure 129: Time-series processed for Arable Land area [1000 ha] (United Kingdom)

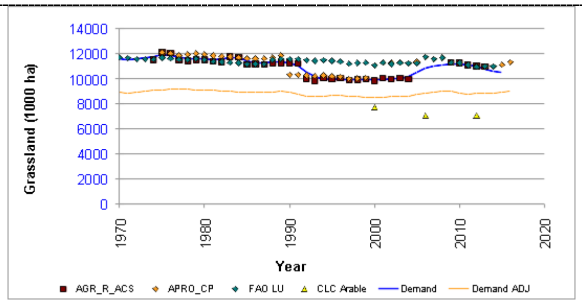

Figure 130: Time-series processed for Permanent Grassland area [1000 ha] (United Kingdom)

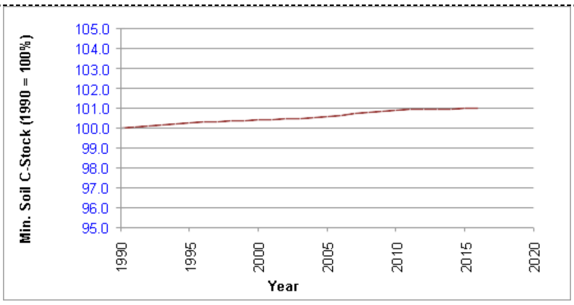

Figure 131: Changes in soil organic C-Stocks, relative to 1990 (United Kingdom)

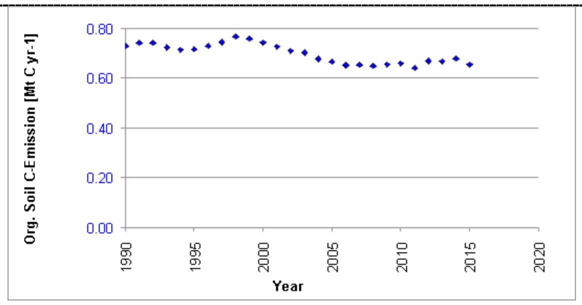

Figure 132: Emissions from managed organic soils [Mt C yr^{-1}] (United Kingdom)

Land Use Area

The areas reported for arable land show a decrease from 1970 to 2016. Statistical data sources largely agree until 1997 when they begin to show deviations. For permanent grassland the area remains mostly stable from 1970 to 2018. From 1990 to 2004 Eurostat data report values that are about 10% below those published by FAOSTAT. The data sources generally agree outside this period. CLC data agree with statistical data for arable land, but show a pronounced decrease for permanent grassland.

Mineral Soil

From 1990 to 2016 SOC-stocks increased by 1.1%. The annual change decreased form 1.0 Mt C yr^{-1} in 1998 to 0.58 Mt C yr^{-1} in 2016.

Organic Soils

Emissions from managed organic soils decreased by 20% from 1990 to 2016. Annual emissions are estimated at 0.65 Mt C in 2016.

Annual Change in Soil Organic Carbon

The soil C-balance fluctuates around a neutral state without a clear temporal trend.

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List of Acronyms

Acronym	Label
AFOLU	Agriculture, Forestry and Other Land Use
ARD	Afforestation/reforestation and Deforestation
AVHRR	Advanced Very High Resolution Radiometer
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact analysis
CCI	Climate Change Initiative (ESA)
CCI_LC	Climate Change Initiative Land Cover
CLC	CORINE Land Cover
COCO	Complete and Consistent Data Base
CORINE	Coordinate Information on the Environment
CM	Cropland Management
D	Deforestation
EEA	European Environment Agency
EF	Emission factor (organic soils)
ESA	European Space Agency
ETS	Emission Trading System
EU	European Union
EU28	European Union of 28 Member States
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization of the United Nations Statistics Division
FM	Forest Management
FSS	Eurostat Farm Structure Survey
GAEC	Good Agricultural and Environmental Conditions
GHG	Greenhouse gas
GIS	Geographic Information System
GISCO	Geographic Information System of the Commission
GM	Grazing Land Management
IPCC	Intergovernmental Panel on Climate Change

Acronym	Label
LULUCF	Land use, land use change and forestry
LUISA	Land-Use based Integrated Sustainability Assessment modelling platform
LUS	Land use system
MCE	Multi-criteria evaluation
MLP	Multi-Layer Perceptron
MODIS	Moderate Resolution Imaging Spectroradiometer
MOLA	Multi-object land allocation
NPP	Net Primary Productivity
NUTS	Nomenclature des Unités territoriales statistiques
RED	Renewable Energy Directive
RV	Re-vegetation
sDSS	Spatial Decision Support System
SOC	Soil organic carbon
SOC_{REF}	Default reference value for the soil organic carbon stock
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
WDR	Wetland Drainage and Rewetting
WRB	World Reference Base for Soil Resources

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