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Changes in Soil Organic C-Stocks from Land Use Change to estimate CO_2 Emissions and Removals from the LUISA Territorial Reference Scenario 2017

CAP and No-CAP scenario options

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Abstract

The land use changes of the *LUISA Territorial Reference Scenario* (TRS) 2017 with the *Common Agricultural Policy* (CAP) option were evaluated for changes in soil organic C-stocks and subsequent emissions and removals of CO_2. The procedure applied follows the *2006 IPCC Guidelines* for a Tier 1 method and is implemented as a spatial application in a GIS to conform to Approach 3.

The TRS scenario data from LUISA was processed under two suppositions, one treating the scenario data as a continuation of the previously processed statistical data (historic period) and a second that directly processed the scenario data. Another processing option evaluated was the treatment of a mixed class in the scenario data.

Under all processing options the TRS scenario data continues the trend in soil organic C-stocks from the historic period. Soil organic C-stocks in mineral soils continue to increase, albeit with a decrease in the annual rate of accumulation after 2020. Under the TRS-CAP scenario soil organic carbon stocks are approx. 0.6% higher than in 2005, which corresponds to a removal of 628 Mt CO_2 until 2030. Emissions from managed organic soils remain notably higher than removals on mineral soils, but with higher uncertainty of estimates.

An evaluation of an option without CAP pointed to a 0.1% higher accumulation of soil organic carbon in most regions than under the CAP in 2030. However, it should be noted that this evaluation did not take any supporting measures of the CAP for of management practices and input levels into account that are designed to increase soil organic carbon stocks.

1 Introduction

For the purpose of reporting *greenhouse gas* (GHG) emissions and removals from anthropogenic activities in *Agriculture, Forestry and Other Land Use* (AFOLU) under the *United Nations Framework Convention on Climate Change* (UNFCCC), the *Intergovernmental Panel on Climate Change* (IPCC) the *2006 IPCC Guidelines* (IPCC, 2006) state that it is good practice to use managed land as a proxy for anthropogenic emissions and removals. For the AFOLU sector *Decision 529/2013 of the European Parliament and of the Council of 21 May 2013*[1] extends for the Member States of the European Union (EU) mandatory accounting for GHG emissions and removals to the activities *Cropland Management* (CM) and *Grazing land Management* (GM) for the years 2013-2020.

As methods for estimating GHG emissions and removals the *2006 IPCC Guidelines* provide advice for three levels (Tier 1, Tier2 and Tier 3) of increasing detail. When an activity isd not a key category in terms of total national emissions and trend Tier 1 or Tier 2 can be used as methods. Independent of the method, for the purpose of accounting land use conversions leading to GHG emissions a spatially explicit procedure (Approach 3) should be used. 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 *Land use, land use change and forestry* (LULUCF) in the 2030 climate and energy framework[2].

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 *2006 IPCC Guidelines* for a Tier 1 method and Approach 3 were implemented as a *spatial Decision Support System* (sDSS) in a *Geographic Information System* (GIS) at the JRC. For comprehensive estimates of CO_2 emissions and removals from managed soils the implementation covers all land use categories and changes between categories, not only CM and GM. This extension is needed to allow accounting for land take from expanding urban and industrial areas or changes in the use of wetlands.

The spatially explicit layers of the land use categories are based on annual statistical data for administrative regions, starting in 1970. Statistical data from several sources were integrated in an extensive pre-processing process. The process includes estimating missing data in the time-series and the hierarchy of NUTS up to level 2 and reducing inexplicable variations procedure to provide

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1 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

2 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

complete and consistent time-series data. After having processed data for the period 1970 to 2016 only data for subsequent years need to be processed. The changes in SOC stocks from land use change of the spatial data are aggregated to NUTS Level 2 units, national level and EU28 and also expressed as CO_2 emissions and removals (Hiederer & Abad Viñas, 2018); (Hiederer, 2016).

The procedure relies on the availability of statistical data by NUTS Level 2. It is conceptually not designed to project area demands for the various land use categories for years beyond existing statistical data. For projections of CO_2 emissions and removals from changes in SOC stocks following changes in land use the output from the LUISA modelling platform is used.

2 Estimation Framework: IPCC SOC-Stock Estimation and LUISA Territorial Reference Scenario 2017

A detailed description of the *LUISA Territorial Reference Scenario 2017* (TRS) with the CAP option (TRS-CAP) and processing under LUISA is provided in (Jacobs-Crisioni, et al., 2017). The scenario was defined by DG JRC and DG REGIO specifically to support ex-ante an impact assessment of the post-2020 cohesion policy. The spatial layer output from LUISA can be imported into the SOC-stock tool after a straightforward format conversion and adjustment to the SOC-stock tool geometry for spatial data. For the import of the TRS output two particular characteristics of the data need to be addressed:

a) Conversion of TRS Classes to IPCC Land Use Categories

The assignment of the TRS classes to land use categories of the SOC tool are presented in Table 1.

Table 1: Assignment of TRS classes to SOC-toll Land Use categories

TRS Legend		**SOC-Stock Tool**	
ID_TRS	*TRS Label*	*ID_LU*	*LU Label*
0	No data	0	No data
1	Urban	8	Artificial
2	Industrial	8	Artificial
3	Arable	2	Long-term cultivated
4	Mixed crop / livestock	1	Grassland/grazing land
5	Livestock production	1	Livestock production
6	Forest, mature	6	Forest, mature
7	Transitional woodland-shrub	6	Native Ecosystems
8	Vineyards	4	Perennial / tree crops
9	Fruit Production	4	Perennial / tree crops
10	Olive Production	4	Perennial / tree crops
11	_abandoned arable	6	Native Ecosystems
12	_abandoned permanent crops	6	Native Ecosystems
13	_abandoned pastures	6	Native Ecosystems
14	_abandoned urban	8	Artificial
15	_abandoned industry	8	Artificial
16	Bio-energy crops	2	Long-term cultivated
17	Shrubland and semi-natural	6	Perennial / tree crops
18	Forest, young	6	Native Ecosystems
19	Natural grassland	6	Native Ecosystems
20	Rice production	3	Rice, paddy
21	Infrastructure	8	Artificial
22	Other nature	9	Other areas
23	Wetlands	7	Wetlands
24	Water bodies	9	Other areas
25	Urban green leisure	1	Grassland/grazing land

The thematic classes of the spatial layers that are produced by LUISA for the TRS scenario can in most cases be directly translated into the IPCC land use categories used in the SOC-stock tool. The TRS class "_abandoned arable" is assumed to be covered by vegetation and assigned to the land use category "Native Ecosystem", but with a transition period of 20 years. Other classes of abandoned areas were assigned to the corresponding land use category. TRS class "Bio-energy crops" is assigned to the land use category "Long-term cultivated", as the majority of these crops would be grown on arable land.

Only the class "Mixed Crop / Livestock" cannot be mapped to a single land use category. The class contains a mixture of cropland, grassland and other land cover types in unknown proportions[3]. Changes in the proportion of cropland and grassland within the class are not necessarily related to changes in cropland and grassland in the explicit classes. As a result, the proportion of the areas of the explicit classes cannot be used as a proxy to estimate the proportions of the land use areas within the mixed class.

To account for the character of the class, the data were processed twice, once assigning all areas of the class to cropland and then assigning all areas to grassland. The range of estimates of SOC-stock changes from the two runs are treated as uncertainty of the data, with the value to be estimated on between the boundaries.

b) Residual changes in SOC-stocks from historic land use changes

The land use of the TRS-CAP scenario is the projected change in land use areas from Corine Land Cover (CLC) for a specific year (CLC 2012). By contrast, the SOC-stock tool uses statistical data from Eurostat as the basis for the spatial allocation demand and a multi-criteria evaluation (MCE) procedure to assign spatial locations to a land use category. LUISA land use data are thus compatible with a spatial reference (CLC), while the SOC-stock tool data are more closely related to Eurostat statistical data and CAPRI. As a consequence, the TRS data cannot be treated as an immediate temporal extension of the SOC-stock data. This would introduce artificial changes in land use around the change year and thus unfounded and inflated estimates of CO_2 emissions and removals. The approach used to address the difference in the spatial data was to apply the changes in land use demands of the TRS scenario data to the SOC-stock data and continue processing the changes as for any historic year.

When excluding any residual changes in SOC stocks from historic years the TRS data can also be processed directly. The situation is graphically presented in Figure 1.

[3] The class aggregates Corine 2.4.1. Annual crops associated with permanent crops, 2.4.2 Complex cultivation patterns and 2.4.3 Land principally occupied by agriculture + sig. nat. vegetation

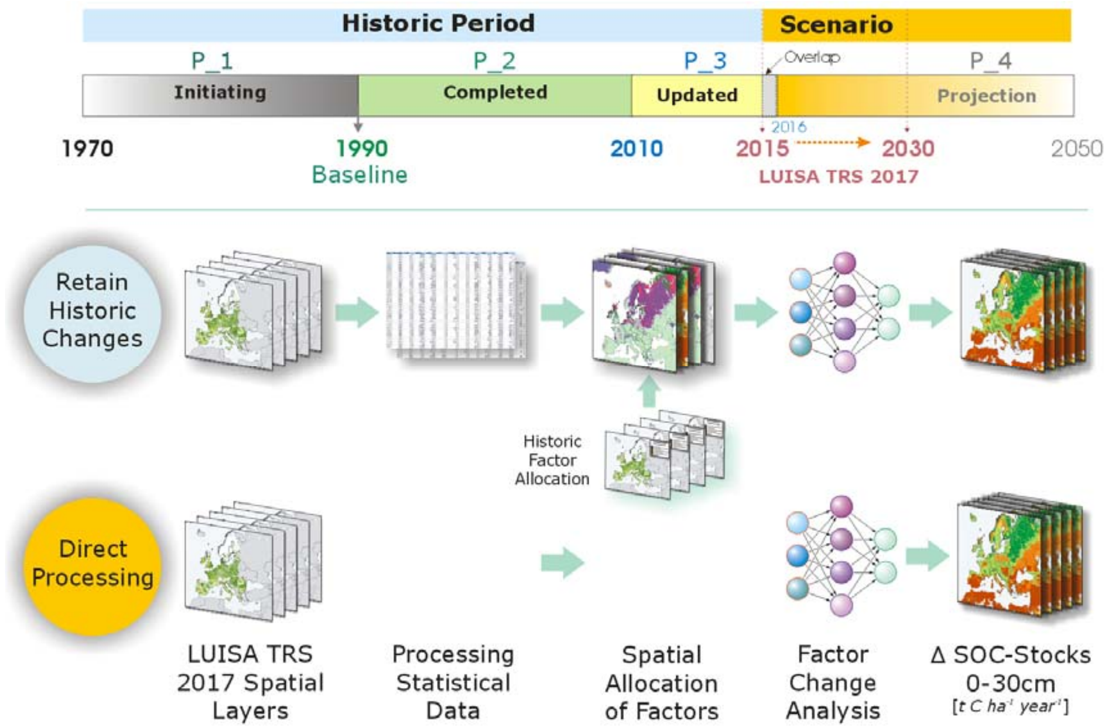

Figure 1: Processing options for retaining the effect of historic land use changes or processing TRS data directly

The historic period refers to the temporal availability of statistical data. The data are updated annually to account for new statistical data, which becomes available with a delay of about two years from current year. At the time of this study data until 2016 were processed (Hiederer & Abad Viñas, 2018). The scenario period of the TRS data begins in 2015, with estimates of land use for 2020, 2025 and 2030. There was a small overlap of processed data between the updated year and the start of the scenario period. The last year of statistical data was not used for this evaluation.

When retaining the effect of historic changes on SOC-stocks the TRS data are treated as any statistical data. The SOC-modifying factors are determined based on the time-series of 20 years of spatially allocated factors. From this the changes in SOC-stocks are computed.

Processing the TRS data directly omits processing the steps of allocating factors from statistical data and proceeds immediately to the factor change analysis. The base year is then the starting year of the scenario period, here 2015. This is by far the fastest approach to processing the data, but only covers changes that occur during the scenario period.

Various combinations of treating the mixed TRS class and options of processing the data with or without retention of historic conditions were evaluated for the period 2015 to 2030.

3 Results

The processing options were evaluated based on the results obtained for changes in soil organic C-stocks for any difference between treatments of the TRS class of mixed crop / livestock and the temporal consistency over the historic period.

3.1 Processing Options for TRS-CAP Scenario

Initially, the TRS-CAP scenario data were configured to take into account any residual changes in SOC-stocks from the historic period. For this configuration the effect of different treatments of the mixed crop / livestock class were evaluated. Subsequent to these runs, processing was restricted to the scenario data and the effect of including or not of the historic period was evaluated.

3.1.1 TRS-CAP Scenario with Residual SOC Stock Changes

To include the residual effects of land use changes on SOC-stocks for a period of 20 years, as put forward for the Tier 1 method in the *2006 IPCC Guidelines*, any non-accomplished changes from1995 onwards have to be carried forward when processing the scenario data with 2015 as the base year.

Since LUISA and the SOC-stock tool use different spatial land use layers the temporal changes in the areas of a land use category are transferred to the areas of the land use categories in the SOC stock spatial layers. The process can be expressed as:

$$A\_SOC_{LU}^{a} = A\_SOC_{LU}^{a-1} + (A\_TRS_{LU}^{a} - A\_TRS_{LU}^{a-1})$$

where

A_SOC	Area in SOC-stock tool data [km^2]
A_TRS	Area in TRS data [km^2]
LU	Land use category in SOC-stock tool
a	target year
a-1	previous year

Change in areas in the TRS data are transferred in absolute values, not as proportions of the total area. This approach retains the magnitude of area change of the TRS scenario. The SOC-stock tool allocates for each year the total area of a land use category instead of only changes in areas. Consequently, changes in area in the TRS scenario cannot exhaust the available area in the SOC-stock data. Furthermore, while the parameters for the transition potentials for the land use categories are those of the SOC-stock tool, the transitions are determined by the TRS scenario data.[4]

[4] The SOC-stock tool uses a Multi-Layer Perceptron (MLP) neural network to guide the transitions between land use categories for a period. This approach is applied since the demands for area of the land use categories are for statistical units, not explicit spatial locations. By contrast, the TRS scenario data is

The difference in SOC stocks relative to 1990 between assigning the area associated with the class “Mixed crop / Livestock” to the cropland or the grassland land use category for mineral soils are presented in Figure 2.

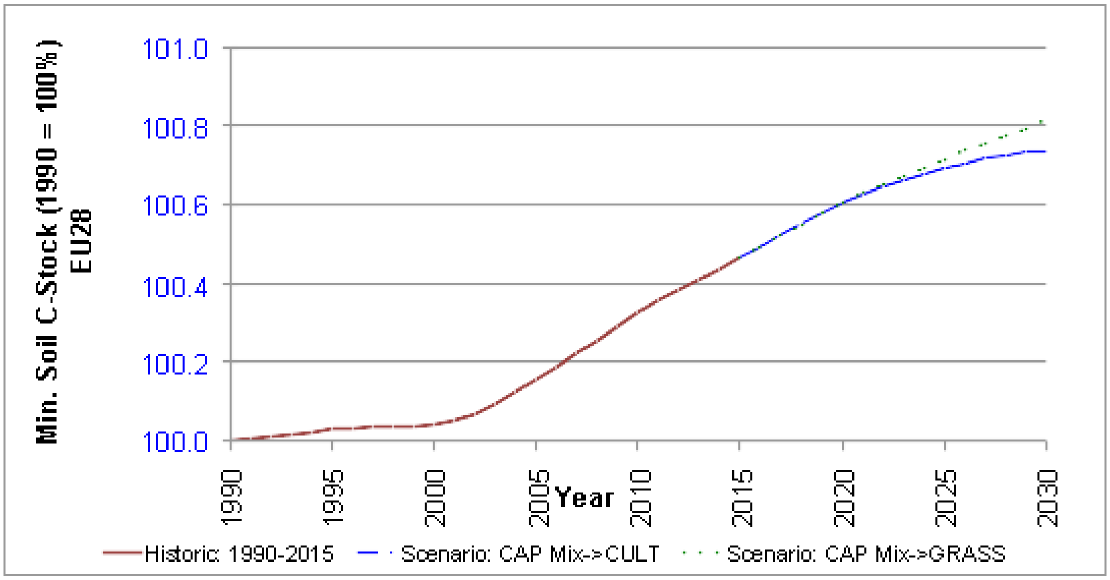

Figure 2: Annual data of relative changes in soil organic C-stocks in mineral soils (1990 = 100 %), residual changes carried forward to scenario periods, TRS-CAP mixed cropland / livestock, EU28

The relative changes in SOC stocks for the TRS-CAP scenario continue without notable disruption from the historic data. This is not necessarily an indicator that the data of the scenario period is fully in line with the changes in land use areas of the historic period. Instead, the continuity is enforced by the processing method and by carrying forward any residual changes in SOC-stocks. These conditions reduce annual variations in the change of SOC-stocks.

The scenario land use suggests a continuation of the increase in C-stock that started after the year 2000. In 2030 the soil organic C-stocks increase about 0.7 % over those of the year 2005. From 2015 to 2020 the rate of increase in SOC-stocks is 7.3 Mt C yr^{-1} and shows no particular difference between the two treatments of the mixed class areas. The annual rate of SOC-stock accumulation drops to an average annual increase of 5.4 Mt C yr^{-1} for the years 2025 to 2030 when assigning all mixed areas to the grassland use category and 2.5 Mt C yr^{-1} for the culture option.

explicitly spatial and transitions between land use categories are taken directly from the TRS data. This does not imply that the spatial locations of change in the SOC-stock data are identical to those of the TRS scenario, only that the transitions of the area change are comparable.

3.1.2 TRS-CAP Scenario without Residual SOC Stock Changes

Under the processing option of excluding any residual changes in SOC-stocks from the historic period the changes reported are entirely the result of the changes in land use in the scenario data. The year 2015 is taken as the starting year and changes in SOC-stocks are expressed relative to that year (2015 = 100%).

In its simplest form the TRS land use data are processed for each year for which they are available. For this evaluation TRS data with a 5-year time-step were used (2015, 2020, 2025 and 2030). SOC-stocks were estimated for each year with data. Annual changes in SOC-stocks form changes in land use were then estimated from interpolated the results from the 5-year interval. Changes in SOC-stocks were calculated as:

$$\Delta SOCmineral = \left[\sum_i SOCref_i^a \times fLU_i \times A_i^a - SOCref_i^p \times fLU_i \times A_i^p\right] \times \frac{a-p}{20}$$

where

ΔSOCmineral	annual change in SOC-stocks in mineral soils from changes in area of all land use types [*t C yr⁻¹*]
SOCref	reference SOC-stock under native, unmanaged conditions for mineral soil type and climatic zone [*t C km⁻²*]
fLU	adjustment factor for land use type [*dimensionless*]
A	area of land use type i [*km²*]
i	land use type
a	target year
p	previous year

The equation is an adaptation of the *IPCC 2006 Guidelines* for estimating changes in SOC-stocks from land use changes on mineral soils, but is a simplification of the procedure, since it does not include residual effects from previous land use changes. All parameters for processing SOC-stocks were those used in the runs of historic data.

The relative changes in SOC-stocks for assigning the class of mixed cropland / livestock to either the CULT or the GRASS land use category are presented in Figure 3.

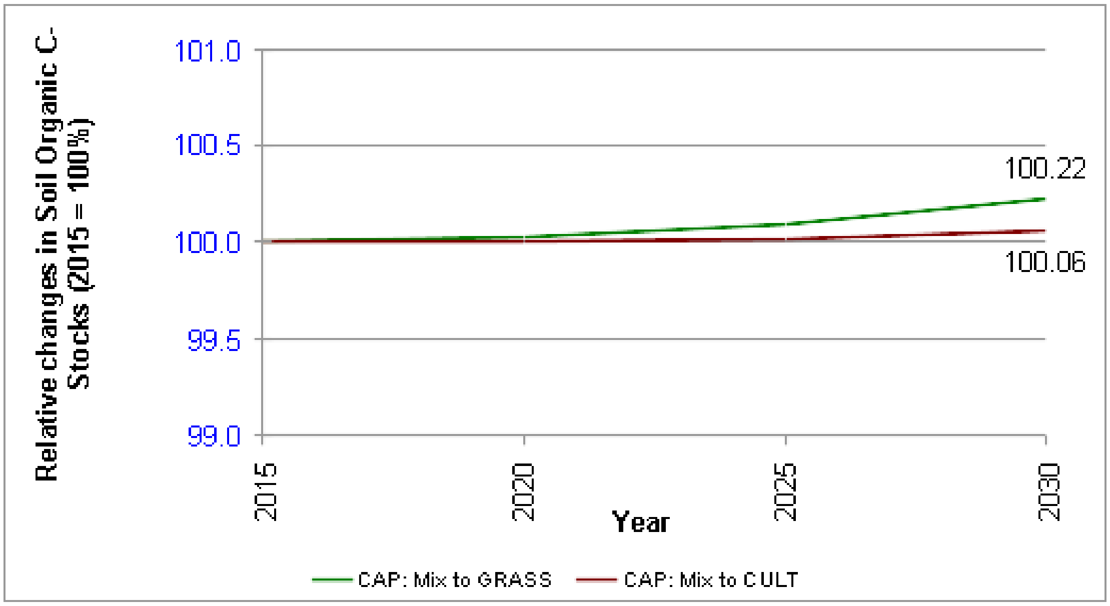

Figure 3: Relative changes in soil organic C-stocks in mineral soils from 2015 to 2030 (2015 = 100%) for TRS-CAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to GRASS or CULT land use category, EU28

Under both treatments SOC-stock increase between 2015 and 2030 (GRASS: +0.22%; CULT: +0.06%). For both options of treating the mixed TRS class increases with time. The increase in SOC-stocks when including residual effects from the historic period under the treatment are, therefore, attributed to some degree to historic changes in land use, rather than exclusively to the conditions of the scenario.

The area of the class of mixed crop / livestock increased from 5.7% in 2015 to 6.4% of the total land area in 2030, compared to 23.6% of arable land (2015). The areas assigned to the mixed class are quite dynamic, where 24.7% of the area in 2030 (61,1995 km^2) belonged to another class in the 2015 data.

In 2030 the difference in SOC-stock relative to 2015 is 0.16 %. This may seem small, but corresponds almost to the relative change in SOC-stocks estimated from 1990 to 2005. How much of this can be attributed to a changes in the area of either the grassland or cultivated land use categories is uncertain, because there is no linear relationship between changes in the area of land use categories and subsequent changes in SOC-stocks. In addition, the standard classes of arable land (3) and livestock production (pastures: 5) both decreased from 2015 to 2030, thus giving no indication of the changes of arable land and grassland within the mixed class.

3.2 TRS-CAP Scenario Emission and Removals

According to the *IPCC 2006 Guidelines* any CO_2 emissions and removals from managed soils are represented by changes in SOC-stocks for mineral soils and emissions from managed organic soils. Managed mineral soils can act as sources or sinks for atmospheric CO_2, managed organic soils always represent a source for as long as the areas fulfill the criteria for managed organic soils. The method and factors suggested to be used for accounting emissions from managed organic soils of the *2006 IPCC Guidelines* were amended by the *2013 Wetlands Supplement* (IPCC, 2014).

The results presented in this chapter were obtained from processing the TRS data without residual effects from the historic changes. This may appear to be the less "realistic" treatment of the data, but by excluding the historic changes in SOC-stocks the changes introduced by the scenario are not affected by any residual effects, which could affect the results until 2035.

3.2.1 TRS-CAP Scenario Soil Organic C-Stock Changes in Mineral Soils

As presented in Figure 3 SOC-stocks increase for EU28 from 2015 to 2030, regardless of the treatment of the mixed class of land use categories. The changes in SOC-stocks by EU Member State from 2015 to 2030 are presented in Figure 4.

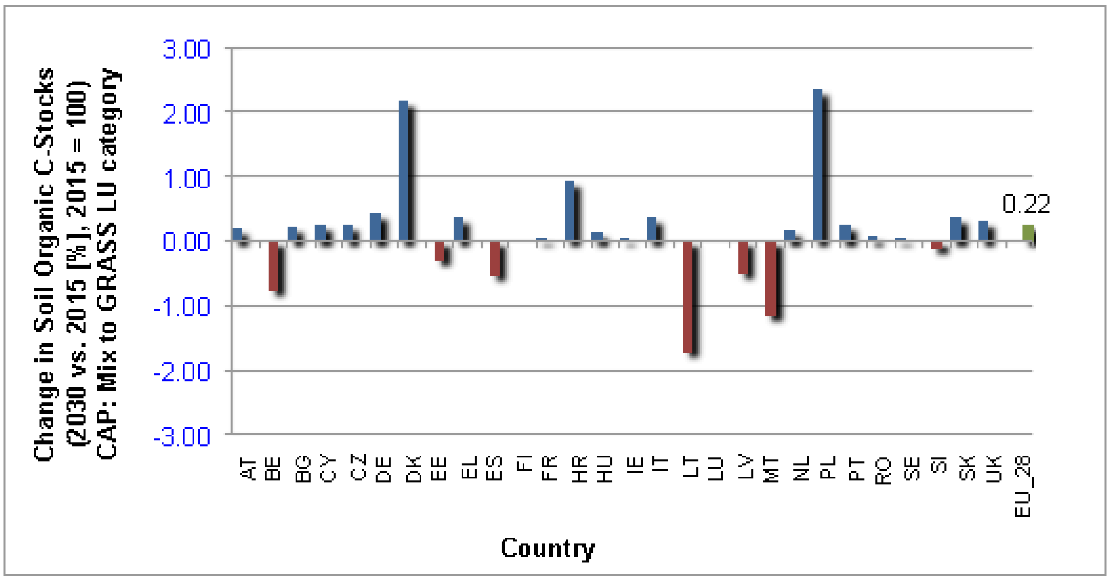

Figure 4: Relative changes in soil organic C-stocks in mineral soils from 2015 to 2030 (2015 = 100%) for TRS-CAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to GRASS Land use category, EU Member States and EU28

The graph indicates that the increase in SOC-stocks, and the corresponding removals of atmospheric CO_2, are most pronounced in Poland (2.3%), followed by Denmark (2.2%). There are also countries that indicate a negative trend, such as Belgium (-0.8%), Lithuania (-1.7%) and Malta (-1.2%).

The estimated absolute changes in SOC-stocks [Mt C] from 2015 to 2030 by country are presented in Figure 5.

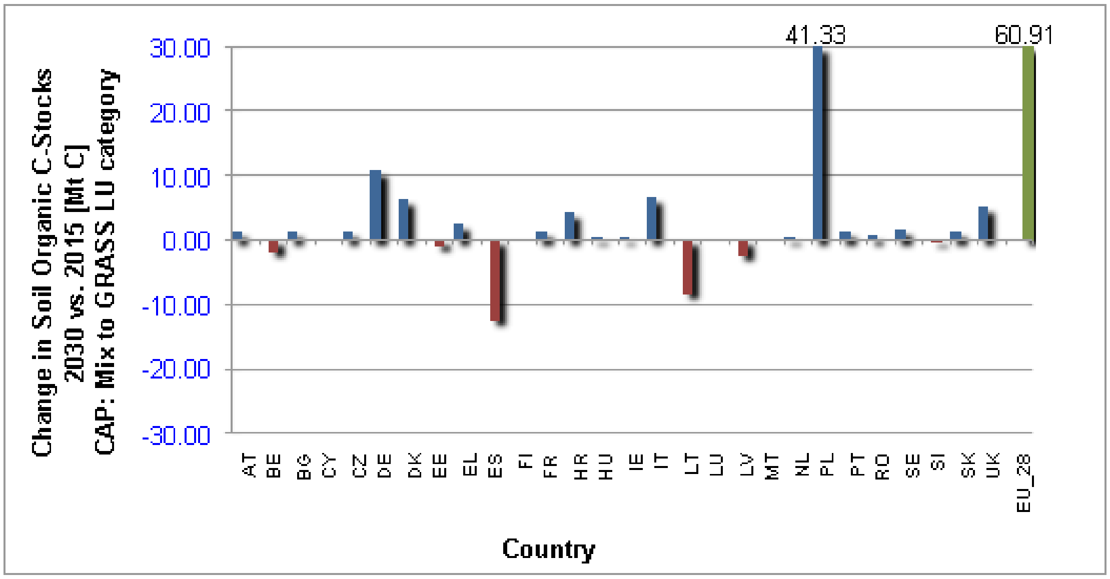

Figure 5: Changes in soil organic C-stocks in mineral soils from 2015 to 2030 [Mt C] for TRS-CAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to GRASS land use category, EU Member States and EU28

For the TRS-CAP scenario the change in SOC-stocks for EU28 is estimated with an increase of 60.9 Mt C (removal of 223.4 Mt CO_2) in from 2015 to 2030. These removals are largely due to changes in land use in Poland, which accounts for 70% of the overall removals. By contrast, land use changes in Spain are estimated to result in a reduction in SOC-stocks of 12.3 Mt C (emission of 45.1 Mt CO_2) over the same period.

The relative changes in SOC-stocks estimated from the TRS-CAP scenario by NUTS Level 2 regions are presented in Figure 6.

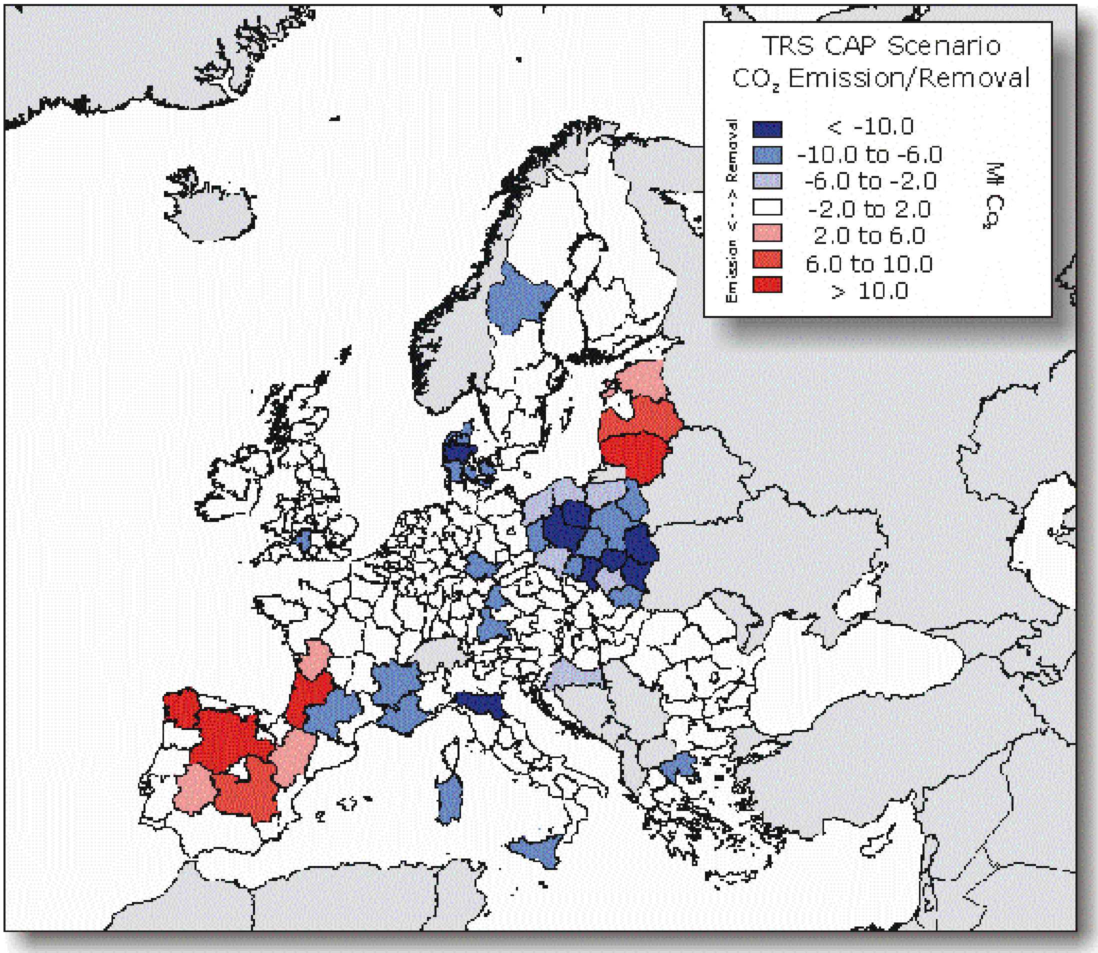

Figure 6: CO_2 emissions and removals from changes in soil organic C-stocks in mineral soils from 2015 to 2030 (2015 = 100%) for TRS-CAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to GRASS category, NUTS Level 2

The map of regional changes presents in blue areas where CO_2 removals (negative value) from increases in SOC-stocks occur and in red emissions (positive values) from decreasing SOC-stocks. For most NUTS Level 2 areas the level of emissions or removals remains stable over the TRS period. The countries with distinct increased in SOC-stocks, i.e. Denmark and Poland, the national trend is present also at NUTS level 2. For France, regions with marked increases in SOC-stocks as well as some with clear decreases are found. It is the only country that shows such divergent trends for the national area.

The changes in CO_2 emissions and removals when assigning all areas of the class “*Mixed Crop / Livestock*” to the CULT land use category are presented in Figure 7.

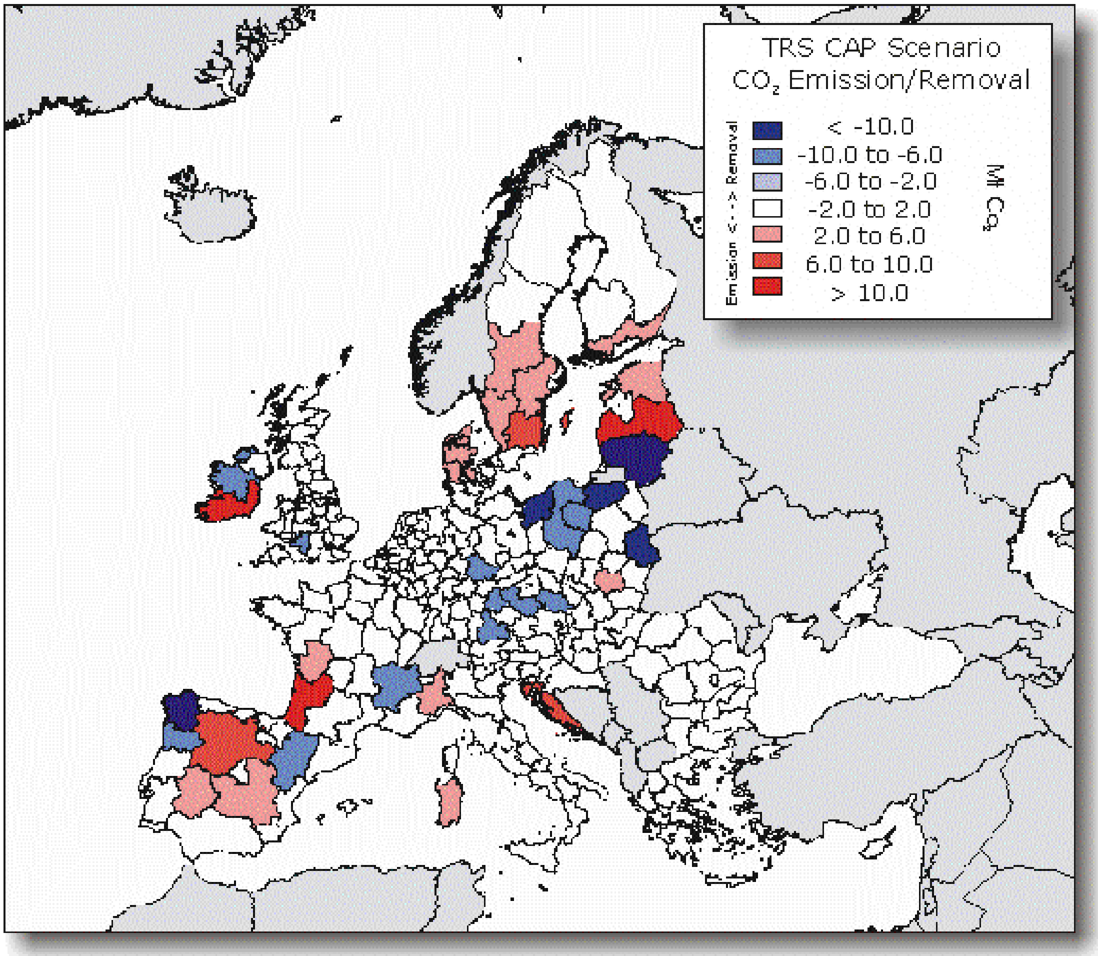

Figure 7: CO_2 emissions and removals from changes in soil organic C-stocks in mineral soils from 2015 to 2030 (2015 = 100%) for TRS-CAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to CULT category, NUTS Level 2

The EU28 total of CO_2 emissions and removals from changes in SOC-stocks on mineral soils obtained from the treatment of the mixed TRS class to the GRASS land use category is -16.3 Mt CO_2 (removal), which is 26.7% of the removal under the GRASS assignment. Compared to the former, there is more variation in national and sub-national trends. Some countries show an inversion of the trend, such as Denmark and Lithuania or parts of Sweden. Ireland indicates a different trend between NUTS Level 2 regions, which was not obvious in the results obtained from the GRASS assignment.

3.2.2 TRS-CAP Scenario Emissions from Managed Organic Soils

The annual emissions from managed organic soils are only evaluated when processing the scenario data under the configuration of processing the historic data. This treatment is preferable over the use of the direct assessment, because of the consistency of the spatial layer of organic soils.

The estimated CO_2 emissions from managed organic soils in EU28 from 1990 to 2030, together with the CO_2 emissions and removals from mineral soils, are presented in Figure 8.

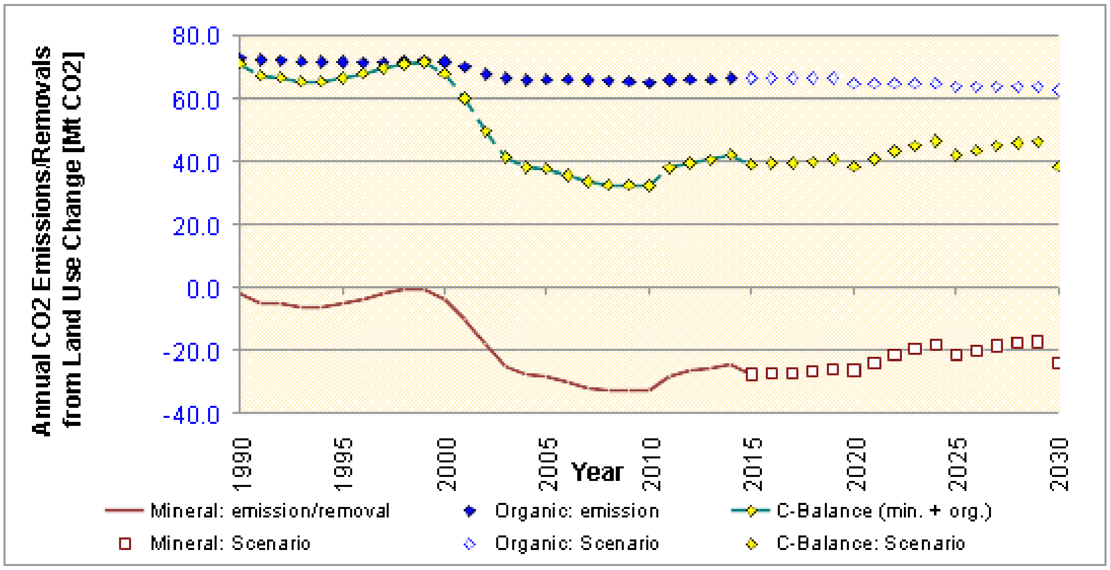

Figure 8: Annual CO_2 emissions and removals from Land Use and Land Use Change from the soil for historic and scenario periods, EU28

For mineral soils CO_2 is removed, through an increase in SOC-stocks, with an estimated average of 26.9 Mt CO_2 for 2015-2020 and an average of 19.6 Mt CO_2 from 2025 to 2030. Annual emissions from managed organic soils for EU28 are estimated to decrease from 66.4 Mt CO_2 yr^{-1} (18.1 Mt C yr^{-1}) (average for 2015-2020) to 62.5 Mt CO_2 yr^{-1} (17.1 Mt C yr^{-1}) (average 2025-2030).

For the combined emissions and removals from managed soils the annual rate of change tends to become positive after 2010 and continues this trend until 2030. As a consequence, the overall emissions from land use and land use change from the soil have general tendency to increase, because the annual rate of SOC-stock removals decreases.

The annual emissions from managed organic soils by EU Member State are given in Figure 9.

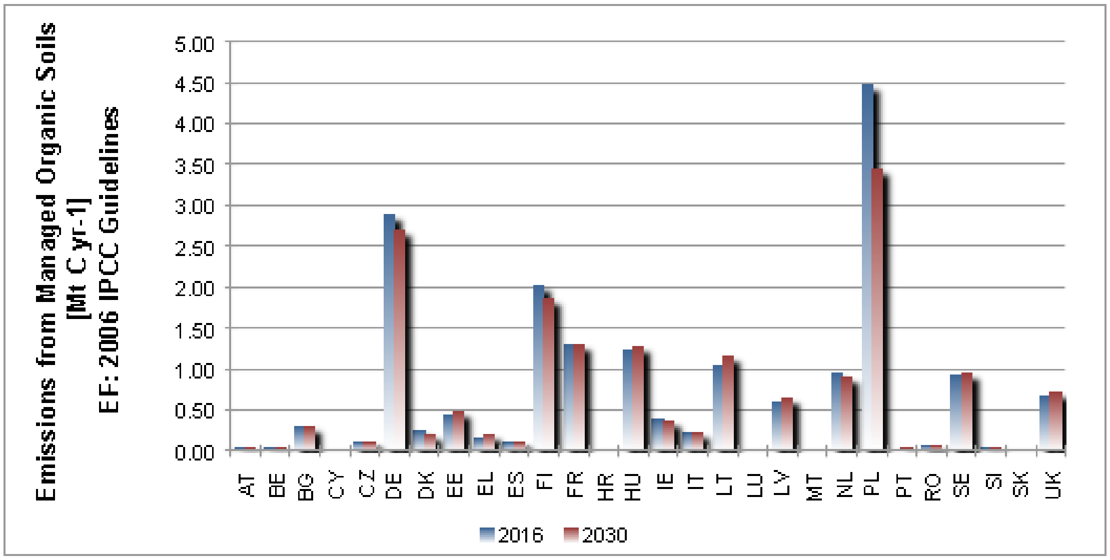

Figure 9: CO_2 emissions from managed organic soils in 2030 compared to 2016 by country for TRS-CAP scenario, including residual effects from historic period, mixed cropland / livestock assigned to GRASS category, EU Member States

The highest emissions are estimated for Poland. The level of annual emissions from managed organic soils decreases from 4.46 Mt C yr^{-1} (16.3 Mt CO_2 yr^{-1}) in 2015 to 3.44 Mt C yr^{-1} (12.6 Mt CO_2 yr^{-1}) in 2030. The second largest amount of emissions from managed organic soils are estimated for Germany. The level of emissions decreases from 2.9 Mt C yr^{-1} (10.6 Mt CO_2 yr^{-1}) in 2015 to 2.7 Mt C yr^{-1} (Mt CO_2 yr^{-1}) in 2030. In 2030 the emissions from managed organic soils in Poland amount to 20.2% (2015: 24.6%) of the EU28 emissions from managed organic soils, while the share of Germany would be 15.8% (2015: 15.9%).

3.3 TRS-NoCAP Scenario Emission and Removals from Mineral Soils

In addition to the TRS CAP scenario the land use and land use changes were also modelled by LUISA for a scenario without the CAP (TRS-NoCAP). As for the TRS-CAP scenario the effect of the scenario on changes in SOC-stocks and subsequent CO_2 emissions and removals were processed without taking residual changes from the historic period into account.

The relative changes in SOC-stocks for the TRS-CAP and the TRS-NoCAP scenarios when all areas of the TRS class "*Mixed Crop / Livestock*" are either assigned to the GRASS or CULT land use category are presented in Figure 10.

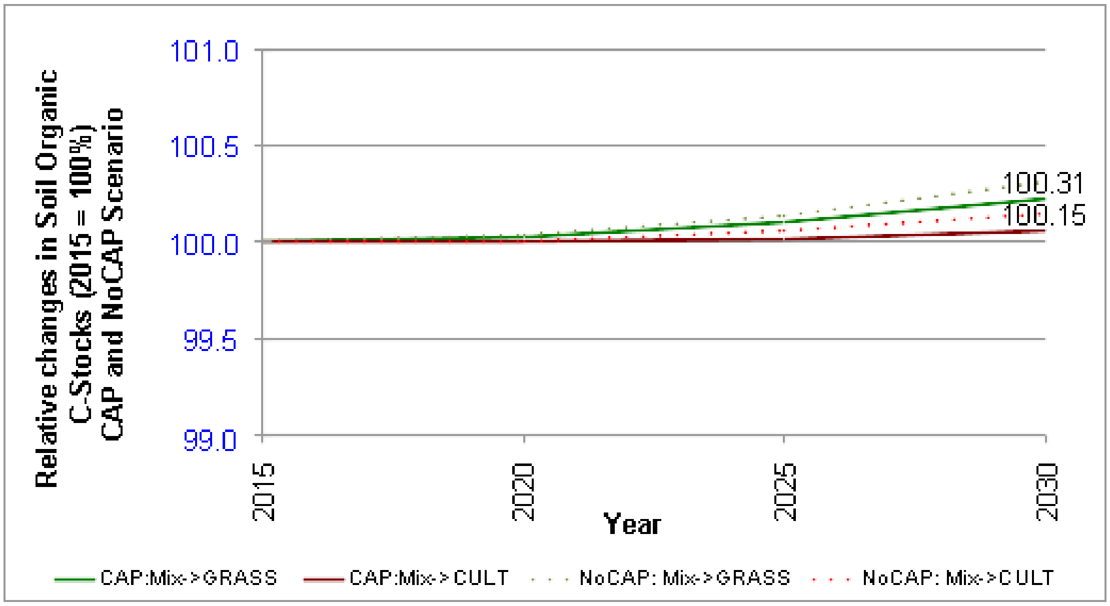

Figure 10: Relative changes in soil organic C-stocks in mineral soils from 2015 to 2030 (2015 = 100%) for TRS-CAP and TRS-NoCAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to GRASS or CULT land use category, EU28

The graph shows slightly higher C-stocks for the TRS-NoCAP scenario than the TRS-CAP scenario (0.1% in 2030), regardless of the assignment of the mixed class. This difference is attributed to the higher losses of cultivated land in the TRS-NoCAP scenario compared to the TRS-CAP scenario for 2030. The difference is 0.7% of the total land area, while the higher area of abandoned arable land, which would increase SOC-stocks, amount to 0.06% of the total land area.

The relative changes in SO C-stocks when assigning all areas of the TRS class "*Mixed Crop / Livestock*" to the GRASS land use category are presented in Figure 11.

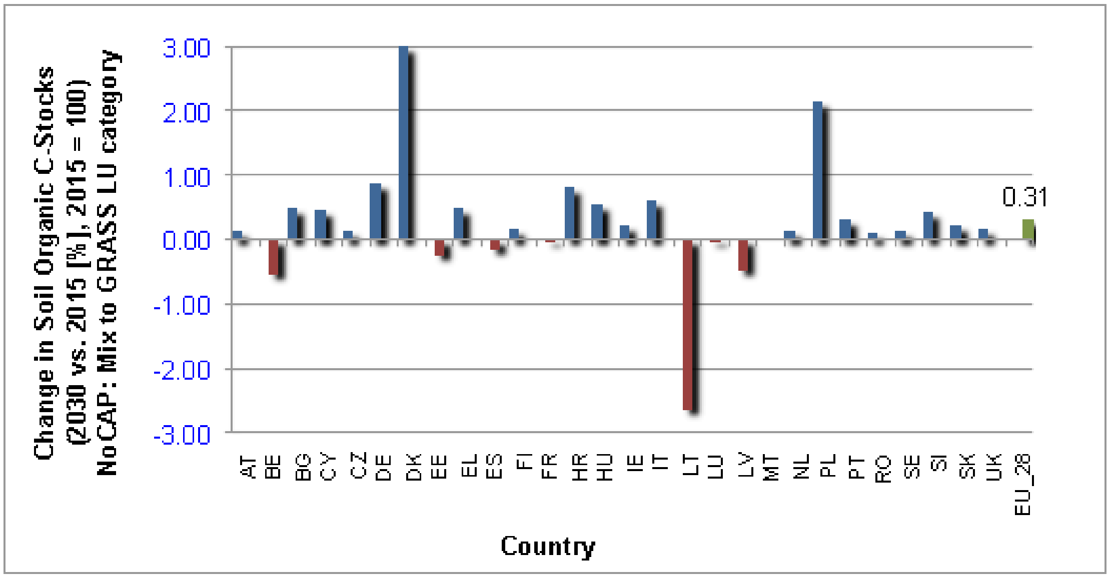

Figure 11: Relative changes in soil organic C-stocks in mineral soils from 2015 to 2030 (2015 = 100%) for TRS-NoCAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to GRASS Land use category, EU Member States and EU28

The relative change in SOC-stocks in mineral soils for EU28 is estimated to increase by 0.31% (0.22% for TRS-CAP scenario) in 2030 over 2015 SOC-stocks. There are no particular variations between the scenarios in national changes in SOC-stocks, except for Lithuania, where the change of -2.6% is estimated (-1.7% for TRS-CAP).

The estimated changes in SOC-stocks in Mt C for EU Member States under the TRS-NoCAP scenario is presented Figure 12.

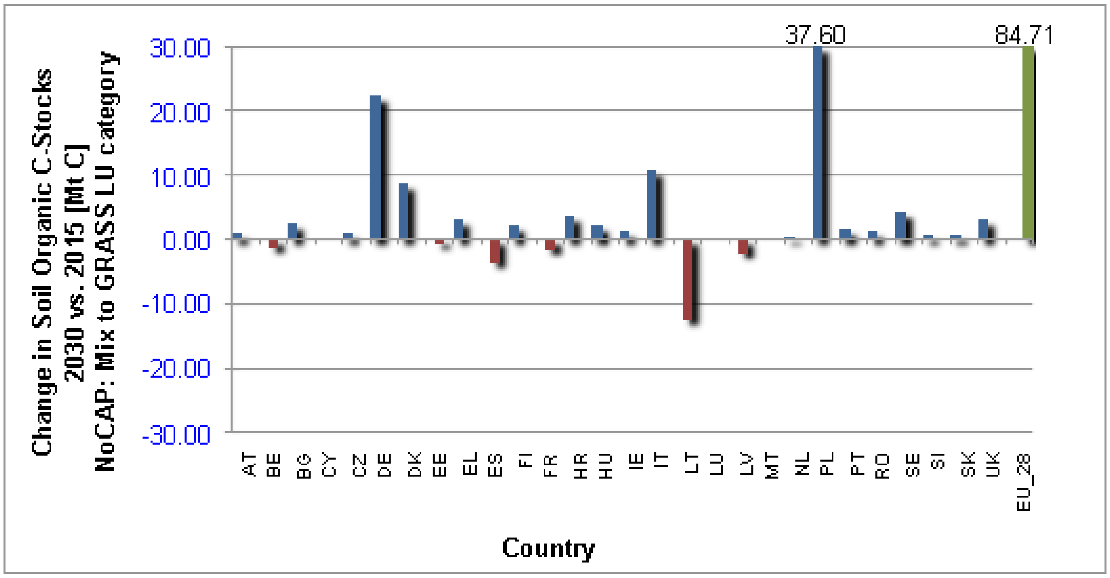

Figure 12:Changes in soil organic C-stocks in mineral soils from 2015 to 2030 [Mt C] for TRS-NoCAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to GRASS land use category, EU Member States and EU28

According to the scenario data SOC-stocks are estimated to increase by 84.7 Mt C in 2030 over those of 2015. Most of the increase is attributed to changes in land use in Poland (44.4%), followed by Germany (26.1%). For Lithuania SOC-stocks are estimated to decrease by 12.6 Mt C, which is exceptional for EU28.

To compare the TRS-NoCAP scenario to the TRS-CAP scenario the spatial pattern of the difference in relative changes in SOC-stocks for NUTS Level 2 regions were used. For the option of assigning all areas of the mixed class to the GRASS land use category the results are presented in Figure 13.

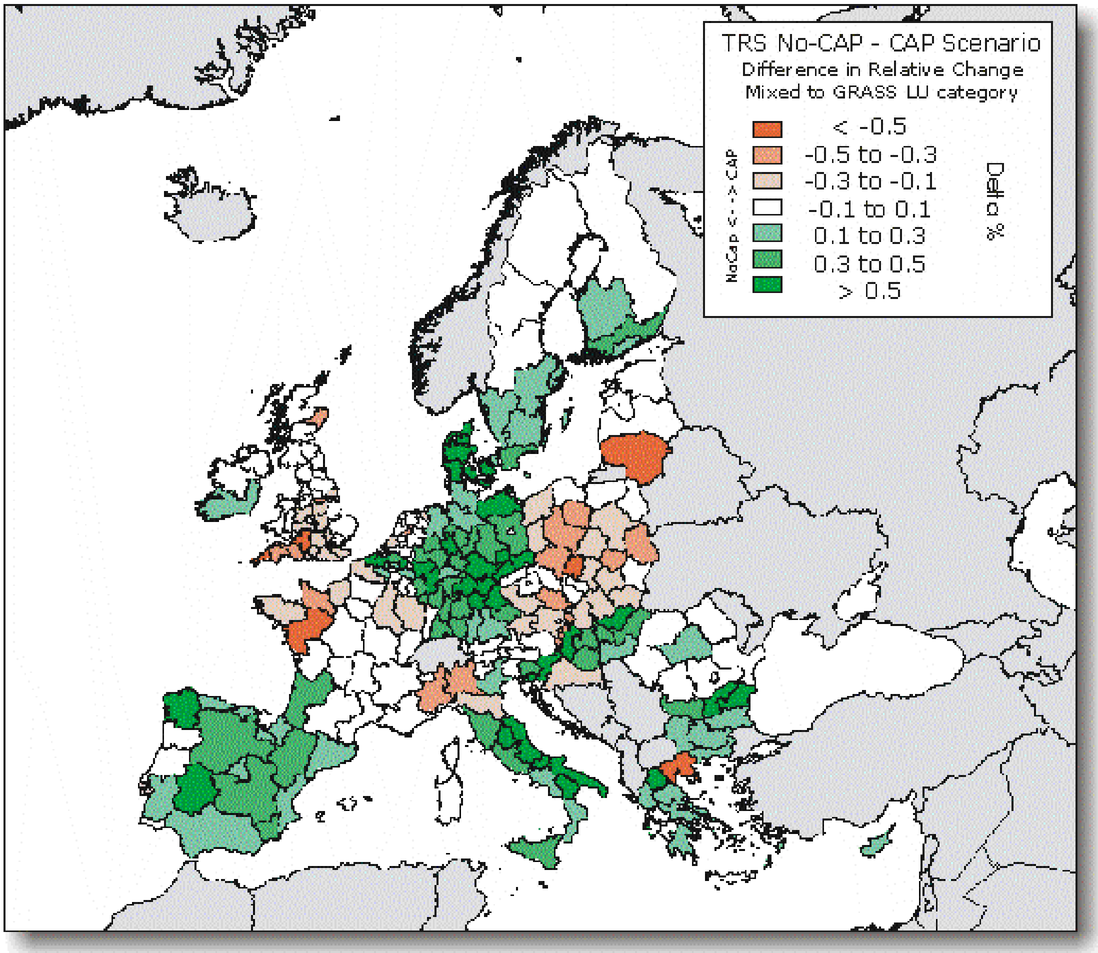

Figure 13: Difference in relative changes in soil organic C-stocks in mineral soils from 2015 to 2030 (2015 = 100%) for TRS-NoCAP and TRS-CAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to GRASS Land use category, NUTS Level 2

The TRS-NoCAP scenario has a (relatively) higher increase in SOC-stocks in areas shown in green, while the TRS-CAP scenario has land use changes that lead to higher SOC-stocks in areas shown in red. The map shows some distinctly different trends in the relative changes in SOC-stocks between countries. The TRS-NoCAP land use changes lead to higher SOC-stocks in countries such as Belgium, Denmark, Finland, Germany, Hungary, Romania, Spain or Sweden. The TRS-CAP land use changes lead to higher SOC-stocks in the Czech Republic, Lithuania, Poland, Slovakia or the United Kingdom. The differences are more pronounced between countries than within regions. Different trends in regions are noted for France, Greece and Italy.

The spatial distribution of the difference in relative change of SOC-stocks between the TRS-NoCAP and the TRS-CAP scenario when assigning the mixed class to the CULT land use category is presented in Figure 14.

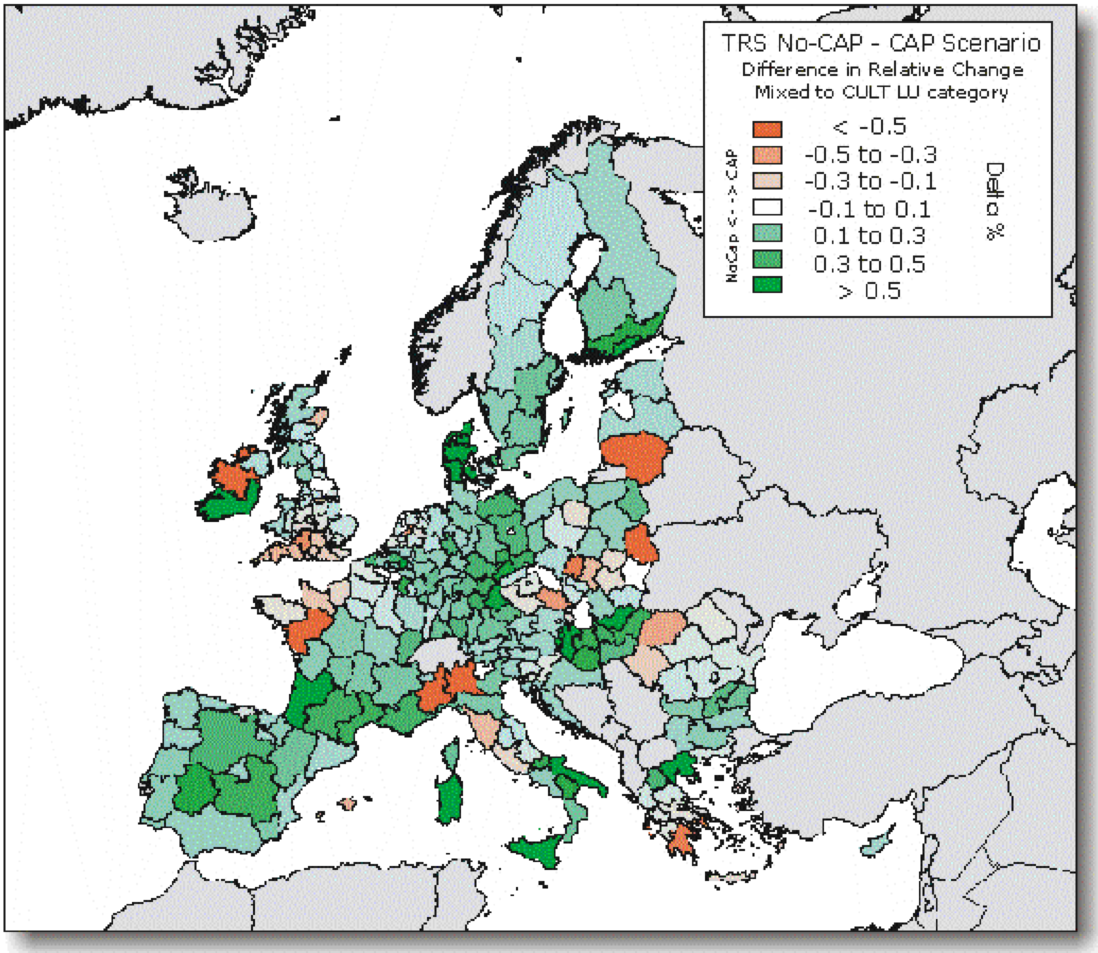

Figure 14:Difference in relative changes in soil organic C-stocks in mineral soils from 2015 to 2030 (2015 = 100%) for TRS-NoCAP and TRS-CAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to CULT Land use category, NUTS Level 2

The general distributing of the difference in relative changes between the TRS-NoCAP and the TRS-CAP scenario for the assignment of the mixed class to the CULT land use category is comparable to the assignment to the GRASS land use category. However, the NUTS Level 2 regions where the TRS-NoCAP land use changes result in higher SOC-stocks than the TRS-CAP scenario are more numerous for this treatment option. There are no countries where the TRS-CAP scenario generally leads to higher SOC-stocks and higher SOC-stocks in the TRS-CAP data are restricted to some NUTS Level 2 regions.

3.4 Flow of Soil Organic C-Stocks from Land Use Categories

The flow of SOC-stocks from the main land use categories in 2015 to those of 2030 were assessed for TRS data without taking historic changes into account. This approach reveals changes in SOC-stocks from changes in land use by a scenario with immediate effect, but does not have a baseline year according to the *IPCC 2006 Guidelines*. The assessment of the flow of SOC-stocks by land use category is not affected by disregarding the residual changes in SOC-stock from historic conditions, since they show a common and continuous trend.

For assessing the flow of SOC-stock changes the situation in Poland and Spain was used with an assignment of the mixed TRS class to the GRASS land use category. For the treatment the countries show comparatively little internal variations from the national trend, but the national trends point in opposite directions (see Figure 13).

The flow of SOC-stocks for Poland for the main land use categories on managed mineral soils and from 2015 to 2030 are given in Table 2.

Table 2: Flow of soil organic C-stocks from 2015 to 2030 for main Land Use Categories, for TRS-CAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to GRASS Land use category, Poland

Poland			**2015**		
2030	**Artificial**	**Cultivated**	**Grassland**	**Perennial**	**Mixed Crop / Livestock**
LU Category	**%**	**%**	**%**	**%**	**%**
Artificial	99.0	0.6	1.2		0.2
Cultivated		67.5			
Grassland		1.3	80.5		
Perennial		0.7	0.5	97.4	
Mixed Crop / Livestock		18.9	11.9		99.8
Abandoned	0.1	6.6	5.0	2.5	
Flow	0.1	32.5	19.5	2.6	0.2

The table shows the flow from 2015 to 2030 as a distribution of SOC-stocks in 2030 compared to 2015 in the columns by land use category. Also included are the TRS classes “Mixed Crop / Livestock” and a summary class of “Abandoned” land.

Because the direct processing of TRS scenario data only covers land use, but not management or input factors, the SOC-stocks of any land remaining in the same land use category will not change. A value of 67.5% of SOC-stock flow for cultivated land indicates that of the SOC-stock of cultivated land in 2015 67.5% remained on cultivated land in 2030. The final row of the table indicates the flow of SOC-stocks from a land use category to other categories. For Poland, 32.5% of SOC-stocks of cultivated land in 2015 moved to SOC-stocks of other categories, mainly to “Mixed Crop / Livestock”. For the grassland category 11.9% of the 2015 SOC-stocks moved to this class in 2030. The SOC-stocks of the class “Mixed Crop / Livestock” remain almost without flow (0.2%).

The flow of SOC-stocks for Spain for the main land use categories on managed mineral soils and from 2015 to 2030 are given in Table 3.

Table 3: Flow of soil organic C-stocks from 2015 to 2030 for main Land Use Categories, for TRS-CAP scenario, no residual effects from historic period, mixed cropland / livestock assigned to GRASS Land use category, Spain

Spain	**2015**				
2030	**Artificial**	**Cultivated**	**Grassland**	**Perennial**	**Mixed Crop / Livestock**
LU Category	**%**	**%**	**%**	**%**	**%**
Artificial	97.7	0.3	0.2	0.2	0.5
Cultivated		98.6	1.6	0.8	18.0
Grassland			93.0		4.6
Perennial		0.4	0.2	94.8	5.2
Mixed Crop / Livestock					22.6
Abandoned	2.3	0.4	4.5	4.0	36.1
Flow	2.3	1.4	7.0	5.2	77.4

For Spain the main LU categories retain their SOC-socks at levels above 90%. Most changes occur in the class “Mixed Crop / Livestock”, which only retains 22.6% of the 2015 SOC-stocks in 2030. Notable is that over 1/3rd of the 2015 SOC-stocks flow to abandoned areas.

The flows of SOC-stocks of the main LU categories differ considerably between Poland and Spain under the TRS-CAP scenario. While in Poland the regular LU categories of cultivated land and grassland undergo changes, these categories largely retain their SOC-stocks in Spain. The inverse dynamic is found for the class “Mixed Crop / Livestock”. This situation provides an explanation of the difference in the development of SOC-stocks in Poland when assigning all areas of the mixed class to cultivated land instead of grassland, while conditions in Spain show little change between the assignment options.

4 Discussion and Summary

4.1 Discussion

The evaluation of the effect of changes in land use, management practice or input level on SOC-stocks often concentrates on variations at a site. The differences in practice are then expressed as X kg C ha^{-1} yr^{-1}. This approach is suitable to evaluate the in situ effect of a particular management practice on local SOC-stocks, but not when studying the effects of land use change. Instead, to evaluate the effect of land use change on SOC-stocks from a scenario all land areas should be considered to allow for changes between land use categories. An evaluation restricted to SOC-stocks on land remaining in the same category would be incompatible with the objective of the study.

SOC-stocks depend primarily on land use and SOC-stock changes on land use changes (Dignac, et al., 2017). Conversion of one land use category to another may result in changes in SOC-stocks of up to about 50%, in particular changes to and from cropland (Gou & Gifford, 2002). Modifications of management practices and input levels on cropland, such as tillage practice, residue management or application of organic amendments, are important for land remaining cropland, but have considerably less effect on SOC-stocks than land use (Sandén, et al., 2017).

The estimated emissions and removals of CO_2 from mineral soils are from land use change alone and do not contain changes in management or input. Management practices and input levels are taken into account in the SOC-stock tool and affect the scenario period when retaining historic changes. However, the scenario data do not contain information on changes of those factors. Therefore, these conditions are present when processing the scenario data with historic trends, but invariable in the scenario data. No new residual effects on SOC-stocks are introduced and those retained become increasingly irrelevant.

Although the study closely follows the IPCC Tier 1 method and emission factors as given in the *IPCC 2006 Guidelines*, the estimates of changes in SOC-stocks are difficult to compare to estimates of emissions/removals from the LULUCF sector. For example, the estimates of 66 Mt CO_2 ha^{-1} yr^{-1} (2015) for annual emissions from managed organic soils are about four times higher than the estimates given for the LULUCF sector for Wetlands for 2013 (15 Mt CO_2, (Directorate-General for Climate Action (European Commission) , 2016)). This difference is not necessarily an indication of an inconsistency, since emissions from managed organic soils for CM and GM are reported there and not under Wetlands. For the historic period the estimates are close to those from (Schils, et al., 2008), who gave 90.95 Mt CO_2 ha^{-1} yr^{-1} for EU28, but using higher emission factors for cropland and grassland than either *IPCC 2006 Guidelines* or the *IPCC 2013 Wetland Supplement* (IPCC, 2014).

Overall, the estimates of 15 Mt CO_2 yr^{-1} (TRS-CAP) to 20 Mt CO_2 yr^{-1} (TRS-NoCAP) for 2030 are within the range of the removal potential of 9 to 38 Mt CO_2 yr^{-1} for cropland until 2050 given by (Frank, et al., 2015). The sequestration of the soil amounts to approx. 15% of the sequestration of the terrestrial biosphere of EU27 that is estimated from four SRES scenarios (Schulp, et al., 2008). The authors also highlight the need for a spatial analysis of the effect of land use changes on carbon fluxes, difficulties of comparing results between studies and high uncertainties of the estimates.

4.2 Summary

The output from LUISA for the TRS scenario from 2015 to 2030 could be processed for changes in SOC-stocks following land use changes, using a spatial implementation of the IPCC Tier 1 method. The exchange of data is straightforward and performed by an automated process.

As regards processing the scenario data two options were evaluated:

a) continuous procession of the scenario data from the historic period with 2015 as the start of the scenario period;

b) direct processing of the scenario data without taking residual changes in SOC-stocks from the historic period into account.

The former option is fully compatible with the specifications of the *IPCC 2006 Guidelines* for using a baseline year where all SOC-stock changes caused by previous changes in land use, management practice or input level are accounted for. For a scenario start year of 2015 such residual changes in SOC-stock may affect data of SOC-stock changes for the whole scenario period.

To evaluate only the effect of changes in land use on SOC-stocks and CO_2 emissions from managed soils the data were also processed without taking any residual historic changes into account. This option is not completely in line with *IPCC 2006 Guidelines*, but may more distinctly present the scenario conditions.

For both treatments the TRS scenario data continue the historic trend of an increase in SOC-stocks in mineral soils with annual rates that are comparable to those of the historic period. After 2020 differences in the annual rate of CO_2 sequestration in mineral soils appear, depending on the treatment of the class “Mixed Crop / Livestock”. When assigning all areas of the class to grassland the annual increases in SOC-stocks continues, at a steady rate of 6.1 Mt c yr^{-1}. Assigning all areas of the mixed class to cultivated land results in a reduced rate of annual SOC accumulation after 2025 of 2.2 Mt C yr^{-1}.

The changes in SOC-stock differ between countries, with some countries having an opposite trend to EU28. Regardless of the treatment option applied the most prominent changes in SOC-stocks would be expected for Poland. The changes in land use over the scenario period would amount to 40% to 70% of all SOC-stock changes of EU28. Under the TRS-CAP scenario most losses in SOC-stocks would be expected for Spain (12.3 Mt C).

For the TRS-NoCAP scenario the changes in SOC-stocks are generally higher than those of the TRS-CAP scenario. This could be attributed to the higher loss of cultivated land under the TRS-NoCAP scenario, while the higher losses in the areas of managed grassland would not affect SOC-stocks to the same degree.

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List of Acronyms

Acronym	Label
AFOLU	Agriculture, Forestry and Other Land Use
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact analysis
CLC	CORINE Land Cover
CORINE	Coordinate Information on the Environment
CM	Cropland Management
EEA	European Environment Agency
EF	Emission factor (organic soils)
EU	European Union
EU28	European Union of 28 Member States
GHG	Greenhouse gas
GIS	Geographic Information System
GM	Grazing Land Management
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use, land use change and forestry
LUISA	Land-Use based Integrated Sustainability Assessment modelling platform
LU	Land use
MCE	Multi-criteria evaluation
MLP	Multi-Layer Perceptron
NUTS	Nomenclature des Unités territoriales statistiques
sDSS	Spatial Decision Support System
SOC	Soil organic carbon
SOC_{REF}	Default reference value for the soil organic carbon stock
SRES	IPCC Special Report on Emissions Scenarios
TRS	Terrestrial Reference Scenario
UNFCCC	United Nations Framework Convention on Climate Change

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