Annotated example of a land carbon stock calculation using standard values
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1 Background

The purpose of this paper is to provide insight into how economic operators and other interested bodies can execute a carbon stock calculation resulting from a land use change. This example calculation shows how the methodology as laid down in the Renewable Energy Directive (RED) and also further addressed by the European Commission (EC) in the Decision on guidelines for the calculation of land carbon stocks, works in practice.

The annotated example described in this report represents a hypothetical carbon stock change and uses standard values from the Decision.

2 Structure of report

A brief explanation of the methodology for calculating the GHG emissions resulting from a land use change is described in the next section, where it is shown what consecutive calculation steps need to be taken. This does not reproduce what’s already written in the RED or from the Decision, but functions as a guidance to our annotated example. The annotated example is described in Section 4 and in Section 5 we present the annexes where all relevant input values are given.

3 General GHG methodology

Emissions resulting from land use change are included as $e_l$ in the GHG methodology outlined in the RED.

The GHG calculation formula is detailed below:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}$$

---


2 Annex V, Section C - Methodology
where

\[ E = \text{total emissions from the use of the fuel}; \]
\[ e_{ec} = \text{emissions from the extraction or cultivation of raw materials}; \]
\[ e_l = \text{annualised emissions from carbon stock changes caused by land-use change}; \]
\[ e_p = \text{emissions from processing}; \]
\[ e_{td} = \text{emissions from transport and distribution}; \]
\[ e_u = \text{emissions from the fuel in use}; \]
\[ e_{sca} = \text{emission saving from soil carbon accumulation via improved agricultural management}; \]
\[ e_{ccs} = \text{emission saving from carbon capture and geological storage}; \]
\[ e_{ccr} = \text{emission saving from carbon capture and replacement}; \] and
\[ e_{ee} = \text{emission saving from excess electricity from cogeneration}. \]

The RED further states that GHG emissions from carbon stock changes caused by land-use change are calculated as:

\[ e_l = (CS_R - CS_A) \times 3.664^3 \times 1/20 \times 1/P - e_B \]

where

\[ e_l = \text{annualised emissions from carbon stock changes caused by land-use change}; \]
\[ CS_R = \text{the carbon stock per unit area associated with the reference land use}; \]
\[ (\text{measured as mass of carbon per unit area, including both soil and vegetation}); \]
\[ CS_A = \text{the carbon stock per unit area associated with the actual land use (measured as mass of carbon per unit area, including both soil and vegetation)}; \]
\[ '20' \text{ refers to the annualising over a 20 year period}; \]
\[ P = \text{the productivity of the crop (measured as biofuel or bioliquid energy per unit area per year)}; \] and
\[ e_B = \text{bonus of 29 gCO}_2\text{eq/MJ biofuel or bioliquid if biomass is obtained from restored degraded land}. \]

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3 The quotient obtained by dividing the molecular weight of carbon dioxide (44.010 g/mol) by the molecular weight of carbon (12.011 g/mol) is equal to 3.664.
4 The reference land use shall be the land use in January 2008, or 20 years before the raw material was obtained, whichever was the later.
5 See notes regarding calculation rules for CSA on page 8 of this document.
6 Under the conditions provided for in point 8 of Annex V, section C.
Guidelines for the calculation of the land carbon stocks, both for the reference land use (CS\textsubscript{R}) and actual land use (CS\textsubscript{A}) are provided in the Decision, and are based on the IPCC Tier 1 methodology.

\[
CS_{R/A} = (SOC + C_{VEG}) \times A
\]

where

CS\textsubscript{R/A} = the carbon stock per unit area associated with the land use (measured as mass of carbon per unit area, including both soil and vegetation);
SOC = soil organic carbon (measured as mass of carbon per hectare);
C\textsubscript{VEG} = above and below ground vegetation carbon stock (measured as mass of carbon per hectare);
A = factor scaling to the area concerned (measured as hectares per unit area).

The Decision states that for consistent representation of land carbon stocks, the following rules for determining the carbon stock per unit area associated with CS\textsubscript{R} and CS\textsubscript{A} shall apply:

1. The area for which the land carbon stocks are calculated shall for the entire area have similar:
   (a) biophysical conditions in terms of climate and soil type;
   (b) management history in terms of tillage;
   (c) input history in terms of carbon input to soil.

2. The carbon stock of the actual land use CS\textsubscript{A}, shall be taken as:
   • in the case of loss of carbon stock: the estimated equilibrium carbon stock that the land will reach in its new use,
   • in the case of carbon stock accumulation: the estimated carbon stock after 20 years or when the crop reached maturity, whichever the earlier.

4 Annotated example

In this example, a land use change from grassland to cropland, used for the cultivation of sugar beet in the East of England, the principal sugar beet growing area in the UK, will be illustrated. It is assumed that the grassland in question is not
classified as a type of degraded land, and so the bonus of 29 gCO₂/MJ is not applicable in this example.

Global maps of climate regions and soil types are included in the Decision and have also been reproduced in this report for convenience (Figures 1 and 2).

![Figure 1: Climate regions](image)

Legend: 1 = Tropical, montane, 2 = Tropical, wet, 3 = Tropical, moist, 4 = Tropical, dry, 5 = Warm temperate, moist, 6 = Warm temperate, dry, 7 = Cool temperate, moist, 8 = Cool temperate, dry, 9 = Boreal, moist, 10 = Boreal, dry, 11 = Polar, moist, 12 = Polar, dry.

![Figure 2: Geographic distribution of soil types](image)

Legend: 1 = Organic; 2 = Sandy Soils; 3 = Wetland Soils; 4 = Volcanic Soils; 5 = Spodic Soils; 6 = High Activity Clay Soils; 7 = Low Activity Clay Soils; 8 = Other Areas.

When undertaking a carbon stock calculation for the purposes of the RED, economic operators are required to establish what the climate region and soil type of the land in
question is. Climate region data layers and soil type data layers are available through the EC's Transparency Platform\(^7\). These are based on GIS mapping.

Figures 3 and 4 below are derived outputs from the Transparency Platform and show the climate region and soil types for the southern part of the UK.

\[\text{Figure 3: Climate regions for southern part of the UK (considered area in the East of England indicated by circle on map).}\]

\[\text{Figure 4: Soil types for southern part of the UK (considered area in the East of England indicated by circle on map).}\]

Based on this data the following climate region and soil type were determined for this hypothetical example of sugar beet for an area in the East of England.

- Climate region: Cold Temperate, dry\(^8\);
- Soil type: High activity clay (and mineral soil).

### 4.1 Calculation of carbon stocks for grassland (CS\(_R\))

As a recap, \(CS_R\) is calculated as: \(CS_{R/A} = (SOC_R + C_{VEG}) \times A\)

#### 4.1.1 Calculation of \(SOC_R\)

There are two methods of determining \(SOC_R\):

- Use of actual measurements; or
- Application of a calculation rule and use of standard values taking into account the climate region, soil type, land cover, land management and inputs.

In this example, the application of a calculation rule and the use of standard values will be used. For mineral soils, \(SOC_R\) can be calculated using the following formula:

\[
SOC_R = SOC_{ST} \times F_{LU} \times F_{MG} \times F_I
\]

where

- \(SOC_R\) = soil organic carbon (measured as mass of carbon per hectare);
- \(SOC_{ST}\) = standard soil organic carbon in the 0-30 centimeter topsoil layer (measured as mass of carbon per hectare);
- \(F_{LU}\) = land use factor reflecting the difference in soil organic carbon associated with the type of land use compared to the standard soil organic carbon;
- \(F_{MG}\) = management factor reflecting the difference in soil organic carbon associated with the principle management practice compared to the standard soil organic carbon;
- \(F_I\) = input factor reflecting the difference in soil organic carbon associated with different levels of carbon input to soil compared to the standard soil organic carbon.

The Decision provides data that can be used for the purposes of calculating \(SOC\). Specifically, Section 6 (Table 1) for \(SOC_{ST}\) and Section 7 (Tables 2 to 8) for \(F_{LU}\), \(F_{MG}\) and \(F_I\). The relevant parts of these data tables that are applicable to this annotated example are included in the Annex for convenience.

\(^8\) Cold temperate, moist would have been an alternative climate region to use.
In this example, it is assumed that the land was 'Nominally managed' (represents non-degraded and sustainably managed grassland, but without significant management improvements) and subject to 'Medium input' (applies where no additional management inputs have been used).

Using Tables 1, 5 and 6 in the Decision (see also Tables 2, 3 and 4 in the Annex of this report):

\[ \text{SOC}_{\text{ST}} = 50 \text{ tC/ha} \]
\[ F_{\text{LU}} = 1 \text{ (Grassland)} \]
\[ F_{\text{MG}} = 1 \text{ (Nominally managed)} \]
\[ F_{\text{I}} = 1 \text{ (Medium input)} \]

Using \( SOC_R = \text{SOC}_{\text{ST}} \times F_{\text{LU}} \times F_{\text{MG}} \times F_{\text{I}} \)

\[ SOC_R = (50 \times 1 \times 1 \times 1) \text{ tC/ha} \]
\[ = 50 \text{ tC/ha} \]

**4.1.2 Calculation of C\text{VEG}**

There are two methods of determining \( C_{\text{VEG}} \):
- Application of a calculation rule and actual measurements\(^9\); or
- Use of standard values taking into account the climate region and soil type.

In this example, the latter option will be used.

The Decision guidelines provide an overview of the \( C_{\text{VEG}} \) values for all land types and climate regions\(^{10}\).

For grasslands, in the Cool Temperate, Dry climate region, \( C_{\text{VEG}} \) is **3.3 tC/ha**.

**4.1.3 Calculation of CS\text{R}**

Using \( CS_R = (SOC + C_{\text{VEG}}) \times A \)

\[ CS_R = (50 + 3.3) \times 1^{11} \]
\[ = 53.3 \text{ tC/ha} \]

\(^9\) Refer to Section 5 of the Decision.

\(^{10}\) Refer to Section 8 for the vegetation values for cropland, grassland and forestland (see tables 13-18).

Vegetation values for grassland are detailed in Table 13.

\(^{11}\) \( A \), the scaling factor, is assumed to be 1 in this annotated example.
4.2 Calculation of carbon stocks for cropland (CSₐ)

A similar approach to that describe above in section 4.1 should be followed for the calculation of CSₐ.

4.2.1 Calculation of SOCₐ

In this example, it is assumed that the land is subject to ‘Reduced Tillage’ (Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion) and normally leaves surface with > 30 % coverage by residues at planting.) and ‘Medium input’ (representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g. manure) is added. Also requires mineral fertilisation or nitrogen-fixing crop in rotation.)

Using Tables 1, 2 and 3 in the Decision (see also Tables 2, 5 and 6 in the Annex of this report):

SOCโต๊ะ=50 tC/ha(161,514),(233,526)

Fₙₕ = 0.8 (Cultivated)

Fₘₕ = 1.02 (Reduced tillage)

Fᵢ = 1 (Medium input)

Using SOCₐ = SOCₜₜ x Fₙₕ x Fₘₕ x Fᵢ

SOCₐ = (50 x 0.8 x 1.02 x 1) tC/ha

= 40.8 tC/ha

4.2.2 Calculation of Cₜₐₗ₃

As indicated in 4.1.1, the Decision guidelines provide an overview of the Cₜₐₗ₃ values for all land types and climate regions.¹²

For cropland cultivating sugar beet, in the Cool Temperate, Dry climate region, Cₜₐₗ₃ is 0 tC/ha.

4.2.3 Calculation of CSₐ

Using CSₐ = (SOC + Cₜₐₗ₃) x A

CSₐ = (40.8 + 0) x 1

= 40.8 tC/ha

¹² Refer to Section 8 for the vegetation values for cropland, grassland and forestland (see tables 9-12).
Vegetation values for cropland are detailed in Table 9. Note that all crops have a vegetation value of 0, with the exception of sugarcane and perennial crops (including short rotation coppice and oil palm).
4.3 Calculation of emissions from carbon stock change from grassland to cropland

To recap, the carbon stock emissions associated with a land use change are calculated using the following formula:
\[ e_l = (CS_R - CS_A) \times 3.664 \times 1/20 \times 1/P - e_B \]

In this example, \(CS_R - CS_A\) have been calculated, while \(e_B\) is assumed to be 0. Therefore, only \(P\) remains to be calculated.

4.3.1 Calculation of \(P\)

A number of parameters are required to calculate \(P\), the productivity of the crop (measured as biofuel energy yield per hectare per year). These are detailed in Table 1, along with representative values\(^{13}\).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar beet yield</td>
<td>68.86</td>
<td>Ton moist sugar beet/ha</td>
</tr>
<tr>
<td>Moisture content</td>
<td>75</td>
<td>%</td>
</tr>
<tr>
<td>LHV</td>
<td>16.3</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Crop losses</td>
<td>0</td>
<td>%</td>
</tr>
<tr>
<td>Energy of ethanol produced per energy input of sugar beet</td>
<td>0.544</td>
<td>MJ ethanol / MJ sugarbeet</td>
</tr>
</tbody>
</table>

\[ P = 68.86 \times 1 \times 1000 \times (100 - 75)\% \times 16.3 \times (100 - 0)\% \times 0.544 \]
\[ = 152 \, 649 \, \text{MJ}_{\text{ethanol}}/\text{ha} \, \text{a} \]

4.3.2 Calculation of \(e_l\)

It is now possible to calculate the carbon stock emissions associated with the land use change from grassland to cropland, cultivating sugar beet.
\[ = (53.3 - 40.8) \times 1 \times 1000 \times 3.664 \times 1/20 \times 1/152 \, 649 \]
\[ = 15.0 \, \text{gCO}_2/\text{MJ ethanol} \]

\(^{13}\) The values are taken from the 'Ethanol from Sugar Beet' default chain in the BioGrace tool: Refer to: http://www.biograce.net/content/ghgcalculationtools/excelghgcalculations
A further calculation needs to be performed to allocate the GHG emissions between the biofuel and co-product (i.e. sugar beet pulp), resulting from the production of sugar beet ethanol. In this example, 71.3% of the GHG emissions are allocated to the biofuel and the remainder to the co-product.

\[ (15.0 \times 0.713) \text{ gCO}_2/\text{MJ ethanol} \]
\[ = 10.7 \text{ gCO}_2/\text{MJ ethanol} \]

4.4 Checking that the 35% GHG threshold is still met with the inclusion of carbon stock emissions resulting from land use change

The GHG emissions from land use change calculated in 4.3.2 need to be added to the other actual or default GHG emissions for the production of ethanol from sugar beet to determine whether the GHG savings threshold of 35% has been met.

In case disaggregated default values are used (12 gCO$_2$/MJ for 'cultivation', 26 gCO$_2$/MJ for 'processing', 2 gCO$_2$/MJ for 'transport and distribution' and other factors are zero), this leads to:

\[ 40 \times (12 + 26 + 2) + 10.7 \text{ gCO}_2/\text{MJ ethanol} \]
\[ = 50.7 \text{ gCO}_2/\text{MJ ethanol} \]

Compared with the fossil fuel reference of 83.8 gCO$_2$/MJ this is equivalent to 39% GHG savings

So, in this example, the biofuel still meets the GHG savings threshold (of 35%) with the inclusion of the carbon stock emissions resulting from land use change.
5 Annexes

Table 2: SOC_{ST} standard soil organic carbon in the 0-30 centimetre topsoil layer (Section 6, Table 1 in the Decision).

<table>
<thead>
<tr>
<th>Climate region</th>
<th>Soil type</th>
<th>High activity clay soils</th>
<th>Low activity clay soils</th>
<th>Sandy soils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold temperate, dry</td>
<td></td>
<td>50</td>
<td>33</td>
<td>34</td>
</tr>
</tbody>
</table>

Table 3: Factors for grassland – Temperate/Boreal, dry (Section 7.3, Table 5 in the Decision).

<table>
<thead>
<tr>
<th>Climate region</th>
<th>Land Use</th>
<th>Management (F_{MG})</th>
<th>Input</th>
<th>F_{LU}</th>
<th>F_{MG}</th>
<th>F_{I}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperate/Boreal, dry</td>
<td>Grassland</td>
<td>Improved</td>
<td>Medium</td>
<td>1</td>
<td>1.14</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td></td>
<td>1</td>
<td>1.14</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nominally managed</td>
<td>Medium</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderately degraded</td>
<td>Medium</td>
<td>1</td>
<td>0.95</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Severely degraded</td>
<td>Medium</td>
<td>1</td>
<td>0.7</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4: Guidance on management and input for grassland (Section 7.3, Table 6 in the Decision).

<table>
<thead>
<tr>
<th>Management/Input</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved</td>
<td>Represents grassland which is sustainably managed with moderate grazing pressure and that receive at least one improvement (e.g. fertilisation, species improvement, irrigation).</td>
</tr>
<tr>
<td>Nominally managed</td>
<td>Represents non-degraded and sustainably managed grassland, but without significant management improvements.</td>
</tr>
<tr>
<td>Moderately degraded</td>
<td>Represents overgrazed or moderately degraded grassland, with</td>
</tr>
</tbody>
</table>
somewhat reduced productivity (relative to the native or nominally managed grassland) and receiving no management inputs.

Severely degraded  Implies major long-term loss of productivity and vegetation cover, due to severe mechanical damage to the vegetation and/or severe soil erosion.

Medium  Applies where no additional management inputs have been used.

High  Applies to improved grassland where one or more additional management inputs/improvements have been used (beyond that is required to be classified as improved grassland).

**Table 5: Factors for cropland – Temperate/Boreal, dry (Section 7.1, Table 2 in the Decision).**

<table>
<thead>
<tr>
<th>Climate region</th>
<th>Land Use</th>
<th>Management ($F_{MG}$)</th>
<th>Input</th>
<th>$F_{LU}$</th>
<th>$F_{MG}$</th>
<th>$F_{I}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperate/Boreal, dry</td>
<td>Cultivated</td>
<td>Full-tillage</td>
<td>Low</td>
<td>0.8</td>
<td>1</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Medium</td>
<td>0.8</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High with manure</td>
<td>0.8</td>
<td>1</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High without manure</td>
<td>0.8</td>
<td>1</td>
<td>1.04</td>
</tr>
<tr>
<td>Reduced tillage</td>
<td>Low</td>
<td></td>
<td>Medium</td>
<td>0.8</td>
<td>1.02</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High with manure</td>
<td>0.8</td>
<td>1.02</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High without manure</td>
<td>0.8</td>
<td>1.02</td>
<td>1.04</td>
</tr>
<tr>
<td>No till</td>
<td>Low</td>
<td></td>
<td>Medium</td>
<td>0.8</td>
<td>1.1</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High with manure</td>
<td>0.8</td>
<td>1.1</td>
<td>1.37</td>
</tr>
</tbody>
</table>
Table 6: Guidance on management and input for cropland and perennial crops (Section 7.1, Table 3 in the Decision).

<table>
<thead>
<tr>
<th>Management/Input</th>
<th>Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-tillage</td>
<td>Substantial soil disturbance with full inversion and/or frequent (within year) tillage operations. At planting time, little (e.g. &lt; 30 %) of the surface is covered by residues.</td>
</tr>
<tr>
<td>Reduced tillage</td>
<td>Primary and/or secondary tillage but with reduced soil disturbance (usually shallow and without full soil inversion) and normally leaves surface with &gt; 30 % coverage by residues at planting.</td>
</tr>
<tr>
<td>No till</td>
<td>Direct seeding without primary tillage, with only minimal soil disturbance in the seeding zone. Herbicides are typically used for weed control.</td>
</tr>
<tr>
<td>Low</td>
<td>Low residue return occurs when there is due to removal of residues (via collection or burning), frequent bare-fallowing, production of crops yielding low residues (e.g. vegetables, tobacco, cotton), no mineral fertilisation or nitrogen-fixing crops.</td>
</tr>
<tr>
<td>Medium</td>
<td>Representative for annual cropping with cereals where all crop residues are returned to the field. If residues are removed then supplemental organic matter (e.g. manure) is added. Also requires mineral fertilisation or nitrogen-fixing crop in rotation.</td>
</tr>
<tr>
<td>High with manure</td>
<td>Represents significantly higher carbon input over medium carbon input cropping systems due to an additional practice of regular addition of animal manure.</td>
</tr>
<tr>
<td>High without manure</td>
<td>Represents significantly greater crop residue inputs over medium carbon input cropping systems due to additional practices, such as production of high residue yielding crops, use of green manures, cover crops, improved vegetated fallows, irrigation, frequent use of perennial grasses in annual crop rotations, but without manure applied (see row above).</td>
</tr>
</tbody>
</table>
Table 7: Vegetation values for cropland and grassland (Section 8.1, Table 9 and Section 8.3, Table 13 in the Decision).

<table>
<thead>
<tr>
<th>Land category</th>
<th>Climate region</th>
<th>$C_{\text{VEG}}$ (tonnes carbon per hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland</td>
<td>All</td>
<td>0 (For sugar beet and other annual crops\textsuperscript{14})</td>
</tr>
<tr>
<td>Grassland</td>
<td>Cool temperate - dry</td>
<td>3.3</td>
</tr>
</tbody>
</table>

\textsuperscript{14} Note that $C_{\text{VEG}}$ is greater than 0 for: 1. Sugar cane, 2. Perennial crops, namely multi-annual crops, whose stem is usually not annually harvested such as short rotation coppice and oil palm and 3. Specific perennial crops including Coconut, Jatropha, Jojoba and Oil palm.